The effect of a physical activity intervention on selective markers of the metabolic syndrome in adolescents with low socio-economic status

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Innovation through diversity

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Preface

It is a privilege to thank the following people for their help and support in completing this study:

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Declaration

The co-authors of the articles of this dissertation, Dr. Hanlie Moss (promoter), Prof. Salome Kruger (co-promoter) and Prof. Johannes van Rooyen, hereby give permission to the candidate, Mrs. Annemarié Zeelie to include the 4 articles as part of a PhD thesis. The contribution (advisory and supportive) of these co-authors was kept within reasonable limits, thereby enabling the candidate to submit this thesis for examination purposes. This thesis, therefore serves as fulfilment of the requirements for the PhD degree in Human Movement Science within the School of Biokinetics, Recreation and Sport Science in the Faculty of Health Sciences at the North-West University, Potchefstroom Campus.

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Summary

Background

Physical inactivity causes obesity, a condition which is related to insulin resistance, hypertension, diabetes mellitus, dyslipidemia and the metabolic syndrome (MS). MS is the collective description of lifestyle diseases associated with significant morbidity and premature mortality. MS has recently been observed in youth, and if left untreated could lead to cardiovascular diseases. Regular physical activity (PA) and exercise training appear to modify the independent risk factors for MS and cardiovascular diseases, and has a positive effect on waist circumference, blood pressure, body fat percentage, insulin sensitivity and arterial compliance.

Aims

The aim of this study was to determine the relationship between body composition and selective markers of the MS, and the extent to which a PA intervention programme will influence selective markers of the MS, body composition and markers of vascular function in black adolescents.

Methods

Grade 9 classes from two high schools, in a low socio-economic status area near Potchefstroom, participated as the experimental and control group respectively. The experimental group consisted of 194 participants and the control group of 57 participants. The experimental group participated in a 10-week PA intervention. Body mass index, stature, body mass, waist-hip ratio, waist circumference, hip circumference, body fat percentage, fasting serum insulin, fasting plasma glucose, plasma leptin, homeostasis model assessment of insulin resistance (HOMA-IR), systolic blood pressure (SBP), diastolic blood pressure (DBP), Windkessel arterial compliance (C_w), total peripheral resistance, Tanner-stage and habitual physical activity were measured.

The data were analysed by means of descriptive statistics, Mann-Whitney U-tests, analysis of covariance (ANCOVA), Pearson's correlation analyses and multiple regression models. HOMA-IR and leptin were log transformed before analyses because of the skewed distribution. The Statistica for Windows and SAS computer programmes were used to analyse the data according to the above-mentioned aims of the study.

Results and conclusions

Firstly, a significant positive association was found between body fat percentage and both SBP (p=0.02) and HOMA-IR (p=0.02) respectively. Girls with a high body fat percentage had higher SBP (p=0.004), DBP (p=0.03), plasma insulin (p=0.004) and HOMA-IR (p=0.004) than girls with normal body fat percentage. Secondly, a 10-week PA intervention led to a significant decrease in SBP (p=0.000061), a trend of decreasing HOMA-IR, and a trend of increasing C_w in black adolescents. Lastly, no significant differences were found in body composition and vascular function variables for the normal- and over-fat group in this study after the 10-week PA intervention.

In conclusion, the results of this study showed firstly, that there was a positive association between body fat percentage and SBP and HOMA-IR respectively; and secondly, that PA had a positive effect on some MS markers, namely: SBP and HOMA-IR. Further research regarding PA intervention's influence on the MS in black adolescents should be conducted, as there is clearly a shortage of literature that focuses on this research theme within this South African ethnic group.

Key words: Obesity, metabolic syndrome, physical activity, adolescents

Opsomming

Agtergrond

Fisieke onaktiwiteit veroorsaak obesiteit, 'n toestand wat verwant is aan insulienweerstandigheid, hipertensie, diabetes mellitus, dislipidemie en die metaboliese-sindroom (MS). Die MS is die saamgevatte beskrywing van leefstylsiektes geassosieer met betekenisvolle morbiditeit en premature mortaliteit. MS is onlangs waargeneem by die jeug, en indien dit nie behandel sou word nie, kan dit tot kardiovaskulêre siektes lei. Gereelde fisieke aktiwiteit (PA) en oefening dien voorts om die onafhanklike risikofaktore van kardiovaskulêre siektes te wysig, en het 'n positiewe effek op die middelomtrek, bloeddruk, persentasie liggaamsvet, insulien-sensitiwiteit en arteriële meegewendheid.

Doelstellings

Die doelwitte vir hierdie studie was om die verhouding tussen liggaamsamestelling en selektiewe merkers van die MS, asook die invloed van 'n PA-intervensieprogram op die selektiewe merkers van die MS, liggaamsamestelling en merkers van vaskulêre funksie in swart adolessente te bepaal.

Metodes

Graad 9-klasse van twee hoërskole in 'n gebied met 'n lae sosio-ekonomiese status naby Potchefstroom het deelgeneem aan die studie, respektiewelik as die eksperimentele en kontrolegroep. Die eksperimentele groep het uit 194 deelnemers bestaan, en die kontrole groep uit 57 deelnemers. Die eksperimentele groep het deelgeneem aan 'n 10-week PA intervensie. Die liggaamsmassa-indeks, liggaamslengte, liggaamsmassa, middel-heup ratio, middelomtrek, heupomtrek, persentasie liggaamsvet, vastende seruminsulien, vastende plasma-glukose, plasma-leptien, insulienweerstandigheid (HOMA-IR), sistoliese bloeddruk (SBP), diastoliese bloeddruk (DBP), Windkessel arteriële meegewendheid (C_w), totale perifere weerstandigheid, demografiese inligting, Tanner-vlak en gebruiklike fisieke aktiwiteit (PDPAR) is gemeet.

Beskrywende statistiek, Mann-Whitney U-toetse, analises van kovariansie (ANCOVA), Pearson se korrelasie-analises en veelvuldige regressie-modelle is gebruik om die data te ontleed. HOMA-IR en leptien is voor die analises log-getransformeer as gevolg van die skewe dataverspreiding. Die Statistica vir Windows en SAS-rekenaarprogramme is gebruik om die data volgens die bogenoemde doelstellings te analiseer.

Resultate en gevolgtrekkings

Eerstens is 'n betekenisvolle positiewe verwantskap tussen persentasie liggaamsvet met respektiewelik SBP (p=0.02) en HOMA-IR (p=0.02) gevind. Meisies met 'n hoër persentasie liggaamsvet het hoër SBP (p=0.004), DBP (p=0.03), plasma-insulien (0.004) en HOMA-IR (p=0.004) as die meisies met 'n normale persentasie liggaamsvet gehad. Tweedens het 'n 10-week PA intervensie tot 'n betekenisvolle afname in SBP (p=0.000061), 'n neiging tot die afname in HOMA-IR en 'n neiging tot 'n verhoging in C_w by swart adolessente gelei. Laastens is geen betekenisvolle verskille in liggaamsamestelling en die veranderlikes van vaskulêre funksie in die normaal- en oorvet groep waargeneem na 'n 10-week PA-intervensieprogram nie.

Ten slotte, die resultate van die studie het eerstens getoon daar 'n positiewe verwantskap tussen persentasie liggaamsvet met respektiewelik SBP en HOMA-IR bestaan. Tweedens dat PA 'n positiewe effek op sekere MS-merkers het, naamlik SBP en HOMA-IR. Verdere navorsing oor die invloed van 'n PA-intervensie op die MS by swart kinders moet gedoen word omdat daar duidelik 'n tekort van soortgelyke studies op dié Suid Afrikaanse etniese groep in the literatuur bestaan.

Sleutelterme: Obesiteit, metaboliese-sindroom, fisieke aktiwiteit, adolessente

Table of Contents

CHAPTER 6: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

APPENDICES:

List of Figures

List of Tables

Chapter 4

Chapter 5

List of Abbreviations

A

ACSM	American College of Sports Medicine

B

BF	Body fat
BMI	Body Mass Index
BP	Blood pressure

C

CDC	Centre for disease control
cm	Centimetre
C_w	Windkessel Arterial Compliance

D

d/w	days per week
DBP	Diastolic blood pressure

E

et al.	And others

F

F	Fisher's F-distribution
Fe	Females

H

HDL-C	High-density lipoprotein cholesterol
HOMA-IR	Homeostasis model assessment of insulin resistance
HR	Heart rate

I

ISAK	International Society for the Advancement of Kinanthropometry

K

kg	Kilogram
kg/m^2	Kilogram per meter squared

L

LDL-C	Low-density lipoprotein cholesterol

M

M	Males
m^2	Meter squared
MET	Metabolic Equivalent
min	Minutes
ml	Millilitre
mmHg	Millimetres of mercury
mmHg/ml	Millimetres of mercury per millilitre
mmol/dL	Millimol per decilitre
mmol/L	Millimol per litre
MRC	Medical Research Council
MS	Metabolic syndrome

N

n	Number of participants
NRF	National Research Foundation
NS	Non significant

P

p	p-value (significant differences, $p<0.05$)
PA	Physical activity
PDPAR	Previous day physical activity recall
PLAY	Physical Activity in the Young

S

SBP	Systolic blood pressure
SD	Standard deviation

T

TC	Total cholesterol

U

USA	United States of America

V

$\dot{V}O_2max$	Maximal oxygen uptake

W

WC	Waist circumference
WHO	World Health Organization
WHR	Waist-hip-ratio

Y

y	Year/ years

All abbreviations are indicated and explained where they first appear in the text, after which only the abbreviations are used.

List of Symbols

%	Percentage
[ ]	Concentration
μU	Micro unit(s)

CHAPTER 1

Introduction

1.1 INTRODUCTION

Obesity has become a global epidemic, and it is not only seen in adults but also in children and adolescents (Bullo *et al.*, 2003:525; Dedoussis *et al.*, 2004:1037). Obesity is related to insulin resistance, hypertension, diabetes mellitus, dyslipidaemia and coronary heart disease (Karasalihoglu *et al.*, 2003:452, Romon *et al.*, 2004:1227; Weiss *et al.*, 2004:2362). Obesity has also been found to be a key factor in the development of the metabolic syndrome (MS) (Klein-Platat *et al.*, 2005:1182). MS is the collective description of lifestyle diseases associated with significant morbidity and premature mortality (Ascott-Evans, 2002:187). The black adult population of South-Africa is disproportionately affected, with obesity rates being two to three times higher in the black population compared to the white population (Mollentze *et al.*, 1995:93). Therefore, black South African adolescents appear to be a group that is particularly vulnerable to obesity and thus MS.

The escalated incidence of obesity among adolescents proves to be a result of a combination of various lifestyle factors, most notable an increase in sedentary lifestyles (Epstein *et al.*, 2005:200), and high-energy diets which are rich in saturated fats. Paradoxically, the quantity of food provision in communities has increased, but the nutrient quality has lowered (Ritenbaugh *et al.*, 2003:317). It would therefore be necessary to take in more food in order to reach adequate nutrient levels. These changes with regard to food intake and lack of physical activity (PA), when combined, would result in obesity (Ritenbaugh *et al.*, 2003:317). Furthermore, an increase in age has been shown to be related to a decrease in PA participation (MRC, 2002:63), which further underlines the importance of instilling the value of PA in children and adolescents.

1.2 PROBLEM STATEMENT

Long considered a condition affecting only the developed world, obesity has now joined the ranks of underweight, malnutrition, and infectious diseases as a major health problem of the developing world (Haslam & James, 2005:1197). Globally, childhood obesity has reached epidemic proportions with 155 million school-aged children being either obese or overweight (Noakes, 2004). In South Africa, more than 17% of adolescents are overweight and more than 4% are obese, according to the Youth Risk Behaviour Survey of 2002 (MRC, 2002:58). This is of serious concern as it has been found that obesity is a key factor in the development of diabetes and hypertension (Haslam & James, 2005:1197). About 18 million people die every year from cardiovascular diseases worldwide, for which diabetes and hypertension are major predisposing factors (Haslam & James, 2005:1197).

Even though clinical symptoms of cardiovascular risk factors appear only later in life, it is documented that risk-related behaviour patterns for coronary heart disease have their origins in childhood and adolescence (Froberg & Anderson, 2005:S34). One of the reasons for the increase in obesity is the fact that adolescents are no longer as physically active as they used to be a few decades ago (Epstein *et al.,* 2005:200). The Youth Risk Behaviour Survey of 2002 noted that a contributing factor to adolescent inactivity is the fact that 29% of South African adolescents have no physical education classes at school (MRC, 2002:66). Adolescents need to partake in PA regularly to reduce their risk of developing Type 2 diabetes and cardiovascular diseases such as hypertension (Ritenbaugh *et al.*, 2003:317). The benefits of regular PA are substantial as it plays a crucial role in the regulation and maintenance of an adolescent's body weight by decreasing the percentage body fat (ACSM, 2006:245). Regular PA also increases insulin sensitivity (Schmitz *et al.,* 2002:1310), slows down the normal loss of elasticity and compliance in the human cardiovascular system and can reverse some of the age-related declines in arterial stiffness (Tanaka *et al.,* 2000:1273). PA also has a significant negative relationship with blood lipids and blood pressure (McMurray *et al.*, 2002:125; Ritenbaugh *et al.*, 2003:309; Nassis *et al.,* 2005:1472; Nemet *et al.,* 2005:E443).

Studies designed to explore the influence of PA on the components of the MS in black South African adolescents are lacking. The vast majority of studies in African children focus on undernutrition (Bhutta, 2009:94) with precious few considering the alarming prevalence of increasing obesity. Therefore, the purpose of this study is to determine the relationship between body composition and markers of the metabolic syndrome as well as the effect of a 10-week physical activity intervention on the markers of the metabolic syndrome, body composition and vascular function.

The contribution of this research will be the exploration of the influence of a PA intervention on selective markers of the MS in black adolescents. The results will explore the relationship between body composition and fitness and markers of the metabolic syndrome and vascular function. These findings will contribute to the body of knowledge that is needed to influence policymakers in addressing physical activity levels in adolescents.

1.3 OBJECTIVES

The specific objectives of this study are to investigate:

- The relationship between body composition and selective markers of the MS in black adolescents.
- The influence of a 10-week PA intervention programme on selective markers of the MS in black adolescents.
- The influence of a 10-week PA intervention programme on body composition and vascular function in black adolescents.

1.4 HYPOTHESES

This study is based on the following hypotheses:

- There is a positive relationship between body composition components and selective markers of the MS in black adolescents.
- A 10-week PA intervention programme will significantly improve selective markers of the MS in black adolescents.
- A 10-week PA intervention programme will significantly improve body composition and vascular function in black adolescents.

1.5 STRUCTURE OF THE THESIS

This thesis is submitted in article format, as approved by the senate of the North-West University (Potchefstroom Campus). The articles have been submitted for publication in peer-reviewed journals. Chapters 1 and 6 are presented and referenced according to the guidelines of the North-West University (Harvard format). Chapters 2, 3, 4 and 5 are presented according to the author's instructions for each journal. The guidelines to the authors are placed in the list of appendices.

This thesis is presented in five main parts, namely an introduction (Chapter 1), a narrative review article (Chapter 2), three research articles (Chapter 3, 4, 5) and finally a summary with conclusions and recommendations (Chapter 6). The introduction presents the problem statement, objectives and hypotheses of the study. The narrative review article considers the influence of PA on components of the MS and vascular function in children and adolescents. The research article 1 (Chapter 3), investigates the association between body composition and selective MS markers in black adolescents. The research article 2 (Chapter 4) investigates the impact of a 10-week PA intervention programme on selective MS markers in black adolescents. The research article 3 (Chapter 5) investigates the impact of a 10-week PA intervention programme on body composition and markers of vascular function in normal- and over-fat black adolescents. The results of the studies in Chapter 2, 3, 4 and 5 are presented and interpreted in each chapter respectively and then summarised in Chapter 6, together with the conclusions and recommendations. Chapter 6 is followed by a list of appendices.

Chapter 1: Introduction

Chapter 2: Article 1: The influence of PA on components of the MS and vascular function in adolescents (A narrative review) (*African Journal for Physical, Health Education, Recreation and Dance*)

Chapter 3: Article 2: The relationship between body composition and selective MS markers in black adolescents in South Africa: PLAY study (*International Journal of Applied and Basic Nutritional Sciences*)

Chapter 4: Article 3: The impact of a 10-week PA intervention programme on selective MS markers in black adolescents: PLAY study (*The South African Journal for Research in Sport, Physical Education and Recreation*)

Chapter 5: Article 4: The impact of a 10-week PA intervention programme on body composition and markers of vascular function in over-fat black adolescents:

PLAY study (*African Journal for Physical, Health Education, Recreation and Dance*)

Chapter 6: Summary, conclusions and recommendations

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CHAPTER 2

The influence of physical activity on components of the metabolic syndrome and vascular function in adolescents: a narrative review

Authors: Zeelie, A., Moss, S.J. & Kruger, H.S.

Submitted to the African Journal for Physical, Health Education, Recreation and Dance

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ABSTRACT

Adolescents are no longer as physically active as a few decades ago. Inactivity causes obesity which is related to insulin resistance, hypertension, diabetes mellitus, dyslipidaemia, poor vascular health and the metabolic syndrome (MS). The MS has recently been observed in youth, and if left untreated it can lead to cardiovascular diseases. The aim of this research was to determine the influence of physical activity (PA) on the MS components and vascular function in children and adolescents by means of a narrative review of available studies (26 studies) focusing on habitual PA and physical interventions related to the MS and vascular function. The literature review was extensive, employing NEXUS, Science Direct, PubMed and Medline. The available evidence from studies suggested that increased PA and decreased sedentary behaviour may protect against the development of arterial stiffening, high blood pressure, -triglyceride levels, -glucose levels, -waist circumference and low high-density lipoprotein cholesterol values, all of which are associated with components of the MS.

Key words: Physical activity; metabolic syndrome; adolescents

INTRODUCTION

Adolescents are no longer as physically active as a few decades ago, with their lifestyle having become more sedentary (Deckelbaum & Williams, 2001). In South Africa, as in many other parts of the world, decreasing physical activity (PA) levels are contributing to the escalating trend in obesity (Kruger, Puoane, Senekal & Van Der Merwe, 2005), which in turn is a major risk factor for the development of many chronic diseases. Obesity plays a central role in the metabolic syndrome (MS), which includes hyperinsulinemia, hypertension, hyperlipidemia, Type 2 diabetes mellitus and atherosclerotic cardiovascular disease (Kelishadi, 2007). Conversely, research has shown that regular PA assists in lowering the chances of developing Type 2 diabetes and preventing cardiovascular diseases, hypertension and obesity (Ritenbaugh, Teufel-Shone, Aickin, Joe, Poirier, Dillingham, Johnson, Henning, Cole & Cockerham, 2003).

The purpose of this literature review was to determine the influence of PA on components of the MS and vascular function in children and adolescents by means of a narrative review of available studies (26 studies), focusing on habitual PA and PA interventions.

MATERIALS AND METHODS

Literature review

In order to ensure a comprehensive literature review, a computer-assisted search was conducted to identify all relevant studies published between 1990 and January 2009. The following databases were utilised: NEXUS, Science Direct, PubMed and Medline. Keyword filters related to PA (exercise, fitness, training), MS (insulin resistance syndrome, syndrome X), obesity (abdominal obesity, overweight), MS components (blood pressure, high-density lipoprotein cholesterol (HDL-C), triglyceride, abdominal obesity, fasting glucose, glucose intolerance, blood lipids, fasting insulin and waist circumference) and markers of vascular function (systolic blood pressure, diastolic blood pressure, arterial compliance and total peripheral resistance) were used to search. Additional information was obtained through literature-to-literature referencing, and each identified study was thoroughly investigated to ascertain any relevance to the topic. Randomised control trials and cross-sectional studies that considered the markers of MS and arterial compliance were included in this review.

RESULTS

The literature review focused on the topics of PA and associated MS markers and vascular function. Special attention was paid to studies pertaining to children and adolescents. A total of 26 randomised controlled trials as well as cross-sectional studies were used. Adolescents and children were classified as suffering from the MS if they met three or more of the criteria outlined by the National Cholesterol Education Programme Adult Treatment Panel III, which employs adapted cut-offs. Table 1 sets out these criteria.

Table 1: Assessing the metabolic syndrome: the national cholesterol education programme adult treatment panel III criteria, with adapted cut-offs for children

Criteria for the metabolic syndrome	Adapted cut-offs
Serum Triacylglycerol concentration	>90th percentile
Serum HDL-C concentration	<5th percentile
Systolic or diastolic blood pressure	>90th percentile
Fasting plasma glucose	>6.1 mmol/L
Waist circumference	> 95th percentile

[ ] = concentration; HDL = high-density lipoprotein cholesterol

(Jessup & Harrell, 2005:26)

Summaries of published studies about the influence of habitual PA and PA intervention studies on the markers of the MS and vascular function in children, adolescents and young adults are presented in Table 2 and Table 3 respectively. Information on the exercise intensity of physical activity interventions was not included in Table 3, due to the fact that the overwhelming majority of the studies did not report it.

Table 2: A summary of cross-sectional studies on the influence of habitual physical activity on the markers of the metabolic syndrome and vascular function in children, adolescents and young adults

Study	Number of Participants	Age (year)	Fitness or PA Assessment Method	Main finding
Kwee & Wilmore, 1990	399 M	8 - 15	$\dot{V}O_2$ max was determined by means of a treadmill test	Significant differences were found between fitness and body fat, plasma triglycerides, systolic and diastolic blood pressure respectively, with the higher fitness groups exhibiting significantly lower values
Armstrong, Williams, Balding, Gentle & Kirby, 1991	363 (164 Fe, 199 M)	11 - 16	$\dot{V}O_2$ max was determined by means of a treadmill test. Habitual PA was determined during three week days using self-contained computerised telemetry system	Skin fold thickness bad a significant negative relationship with peak $\dot{V}O_2$ max. No significant relationship between PA, BP and TC
Bazzono, Cunningham, Varrassi, & Falconio, 1992	164 (84 Fe, 80 M)	10 - 17	Fitness was tested with the 1-mile (1.6 km) run, pull-ups and sit-ups	The sum of skin folds had a significant negative relationship with DBP in boys and with SBP in girls. Sit-ups were significantly associated with SBP for boys. No significant relationship between 1.6 km run performance and resting BP
Suter & Hawes, 1993	97 (58 Fe, 39 M)	10 - 15	Fitness was evaluated by a sub maximal exercise test, and habitual PA was assessed using a questionnaire	Significant negative relationship between PA and blood lipid profile
De Visser, Van Hooft, Van Doornen, Hofman, Orlebeke & Grobbee, 1994	154 Fe & M	7 - 32	Fitness was evaluated by a maximal exercise test, and habitual PA was assessed using a questionnaire	No significant relationship between PA and BP
Dwyer & Gibbons, 1994	2400 (1200 Fe, 1200 M)	11 - 15	Endurance fitness was measured as physical work capacity on a Monark bicycle ergometer	Significant negative relationship between aerobic fitness and SBP. This relationship was only partly accounted for by the compounding effect of lower body fatness in fitter children.

Table 2: A summary of cross-sectional studies on the influence of habitual physical activity on the markers of the metabolic syndrome and vascular function in children, adolescents and young adults (continued)

Study	Number of Participants	Age (year)	Fitness or PA Assessment Method	Main finding
Raitakari, Porkka, Taimela, Telama, Räsänen & Viikari, 1994	2358 (1244 Fe, 1114 M)	11 - 24	PA was assessed with a standardised questionnaire and a sum index was derived from the product of intensity, frequency, and duration of leisure time PA	Serum insulin and serum triglyceride concentrations were significantly lower in active young men, who also reported a lower TC:HDL-C than their sedentary counterparts. Among young women, significant differences were observed in adiposity and in serum triglyceride concentration
Hager, Tucker, & Seljaas, 1995	262 (100 Fe, 162 M)	9.79 ± 0.48	The 1-mile run was used to estimate fitness	Significant relationship between 1.6km run/walk performance and body fatness. Fit children had significantly lower TC, LDL-C and triglyceride levels and significantly higher HDL-C levels than unfit children, except after adjustment for body fat and/or abdominal fat
Raitakari, Taimela, Porkka, Telama, Välimäki, Åkerblom & Viikari, 1997	2358 (1244 Fe, 1114 M)	11 - 24	Original survey in 1980, with follow-ups in 1983 and 1986. PA was assessed with a standardised questionnaire, and a sum index was derived from the product of intensity, frequency and duration of leisure time PA	Significant positive relationship between PA and HDL-C in males. Significant negative relationship between PA and triglyceride in males and females
Twisk, Kemper, Van Mechelen, & Post, 1997	181 (98 Fe, 83 M)	13 - 27	$\dot{V}O_2$ max was determined by means of a treadmill test, and habitual PA was assessed using a questionnaire	No significant relationship between PA and TC
Reed, Warburton, Lewanczuk, Haykowsky, Scott, Whitney, McGavock & McKay, 2005	99 Fe & M	9 - 11	PA was assessed with a 7-day questionnaire	There was a significant association between high aerobic fitness levels and lower arterial stiffness

Table 2: A summary of cross-sectional studies on the influence of habitual physical activity on the markers of the metabolic syndrome and vascular function in children, adolescents and young adults (continued)

Study	**Number of Participants**	**Age (year)**	**Fitness or PA Assessment Method**	**Main finding**
Brunet, Chaput, & Tremblay, 2007	1140 (549 Fe & 591 M)	7, 8 & 10	Physical fitness was measured by speed shuttle run	BMI and WC had a significant negative relationship with physical fitness. These associations were more pronounced in older children
Krekoukia, Nassis, Psarra, Skenderi, Chrousos & Sidossis, 2007	27 obese and 27 lean Fe & M	9 - 11.5	Habitual PA was measured by a 4-day triaxial accelerometer, cardiorespiratory fitness was measured by a sub maximal bicycle ergometer test	Total and central adiposity had a significant positive relationship, and PA had a significant negative relationship with insulin resistance in children
Thomas, Greene, Ard, Oster, Darnell & Gower, 2009	32 Fe & M	12 - 18	PA was assessed over 8 days using accelerometer (counts per min)	PA had a significant positive relationship with both glucose tolerance and resting energy expenditure

BMI = body mass index; BP = blood pressure; DBP = diastolic blood pressure; d/w = days per week; Fe = females; HDL-C = high-density lipoprotein cholesterol; LDL-C = low density lipoprotein cholesterol; M = males; min = minutes; PA = physical activity; SBP = systolic blood pressure; TC = total cholesterol; $\dot{V}O_2$ Max = maximal oxygen uptake; WC = waist circumference; % = percent/ percentage

Table 3: A summary of published studies on the influence of physical activity interventions on the markers of the metabolic syndrome and vascular function in children and adolescents

Study	**Number of Participants**	**Age (years)**	**Study Design**	**PA intervention**	**Main finding**
Al-Hazzaa, Sulaiman, Al-Matar & Al-Mobaireek, 1994	91 M	7 - 12	Randomised trial	7 weeks, daily PA was assessed using heart rate telemetry. The heart rate monitor was attached to each boy for a period of 8 hours at the end of a school day	Significant negative relationship between PA and body fat percentage, SBP and DBP respectively, but no significant relationship between PA and blood lipids
Webber, Osganian, Feldman, Wu, McKenzie, Nichaman, Lytle, Edmundson, Cutler, Nader & Luepker, 1996	4019 Fe & M	8 - 9	Randomised trial	2½ year diet and PA intervention. Increasing moderate to vigorous activity in physical education class to 40% of class period	No significant changes in blood lipid status
Rimmer & Looney, 1997	25 Fe & M	14 - 17	Quasi-experimental design	15 weeks; 4d/w; 40 min; aerobic activities	Significant reduction in TC but not in HDL-C or TC: HDL-C
Ewart, Young, & Hagberg, 1998	99 Fe	9th grade	Randomised trial	18 weeks; 50 min; aerobic exercises	Experimental group had significantly greater decrease in SBP compared with control group
Owens, Gutin, Allison, Riggs, Ferguson & Thompson, 1999	74 Fe & M	7 - 11	Randomised trial	4 months; 5d/w; 40 min; aerobic exercises	Significant decrease in visceral adipose tissue
McMurray, Harrell, Bangdiwala, Bradley, Deng & Levine, 2002	1140 (630 Fe, 510 M)	11 - 14	Randomised trial	8 weeks; 3d/w; 30 min; aerobic exercises	SBP and DBP increased significantly more in the control group, independent of body weight loss. The BMI did not change significantly in the experimental group
Watts, Beye, Siafarikas, Davis, Jones, O'Driscoll & Green, 2004.	19 Fe & M	14 ± 2	Randomised trial	8 weeks; 3d/w; 60 min; circuit weight training	Aerobic activity restored endothelial reactivity to levels seen in lean participants

Table 3: A summary of published studies on the influence of physical activity interventions on the markers of the metabolic syndrome and vascular function in children and adolescents (continued)

Study	Number of Participants	Age (years)	Study Design	PA intervention	Main finding
Carrel, Clark, Peterson, Nemeth, Sullivan & Allen, 2005	50 Fe & M	12.5 ± 0.5	Randomised trial	9 months; 5 days every 2 weeks; 45 min	Significant decrease in body fat and fasting insulin and an increase in cardiovascular fitness
Nassis, Papantakou, Skenderi, Triandafillopoulou, Kavouras, Yannakoulia, Chrousos & Sidossis, 2005	19 Fe	13.1 ± 1.8	Observational study	12 weeks; 3d/w; 40 min; aerobic training	Significant increase in insulin sensitivity in overweight and obese girls without change in body weight and percentage body fat
Nemet, Barkan, Epstein, Friedland, Kowen & Eliakim, 2005	46 Fe & M	6 - 16	Randomised trial	3 month; 2d/w, 60min; aerobic exercises	Significant decrease in body weight, BMI, body fat percentage, TC, LDL-C and an increase in fitness
Reed, Warburton, Macdonald, Naylor & McKay, 2008	268 Fe & M	9 - 11	Randomised trial	12 months; 2d/w; 40 min; physical education classes and 5d/w; 15 min activities (e.g. skipping, dancing)	Experimental group had a significant increase in fitness and a smaller increase in blood pressure compared to the control group
Wong, Chia, Tsou, Wansaicheong, Tan, Wang, Tan, Kim, Boh & Lim, 2008	24 M	13 - 14	Randomised trial	12 weeks; 2d/w; 45-60 min; circuit-based resistance training and aerobic exercises	Exercise training significantly increase lean muscle mass and fitness and significantly decrease BMI, resting HR, SBP and triglycerides in obese boys

BP = blood pressure; BMI = body mass index; DBP = diastolic blood pressure; d/w = days per week; Fe = females; HDL-C = high-density lipoprotein cholesterol; HR = heart rate; LDL-C = low density lipoprotein cholesterol; M = males; min = minutes; PA = physical activity; SBP = systolic blood pressure; TC = total cholesterol; % = percent/ percentage

The results of the studies summarised in Tables 2 and 3 indicate some beneficial association, as well as non-significant relationships, between PA and components of the MS and vascular function. The available evidence from the studies suggests that increased PA and higher fitness levels are mostly protective against high blood pressure, increased arterial stiffness, -triglyceride levels, -glucose concentrations and -waist circumference and low HDL-C values, all of which are associated with cardiovascular heart disease and components of the MS.

DISCUSSION

The influence of habitual PA and PA interventions on the markers of the MS and vascular function in children, adolescents and young adults, as presented in Tables 2 and 3, are as follows:

Physical activity and markers of vascular function

PA intervention studies have suggested that PA or fitness decreases blood pressure in hypertensive adults (Dengel, Galecki, Hagberg & Pratley, 1998). Whether the same benefits can be seen in adolescents remain inconclusive (Thomas, Baker & Davies, 2003). While some studies indicate that decreased blood pressure levels are associated with increased levels of habitual PA (Kwee & Wilmore, 1990; Dwyer & Gibbons, 1994), other studies show no significant relationship between blood pressure and PA (Armstrong *et al.,* 1991; Bazzano *et al.,* 1992; de Visser *et al.,* 1994). It should be noted, however, that five of the PA intervention studies found a significant negative relationship between PA and blood pressure (Al-Hazzaa *et al.*, 1994; Ewart *et al.,* 1998; McMurray *et al.,* 2002; Reed *et al.,* 2008; Wong *et al.,* 2008). Furthermore, in one study blood pressure was significantly decreased after only a 7-week PA intervention (Al-Hazzaa *et al.*, 1994). The significant negative association between fitness and blood pressure was found to be either independent of body weight loss (Al-Hazzaa *et al.*, 1994; McMurray *et al.,* 2002), or only partly accounted for by lower body fatness (Dwyer & Gibbons., 1994). Similar to adults, obese children appear to be characterized by poor vascular health, which may contribute to this population's tendency towards high blood pressure (Watts *et al.*, 2004). In the study by Reed *et al.* (2005), aerobic fitness was associated with arterial compliance, supporting the concept that physical fitness may exert a protective effect on the cardiovascular system. In a study by Watts *et al.* (2004) exercise training normalized endothelial-dependent dilatation to levels seen in lean controls after an 8-week PA intervention programme. However, arterial reactivity returned to pretraining levels within eight weeks following cessation from exercise, suggesting that vascular improvements from exercise training are transient and sensitive to the negative effects of obesity if children return to sedentary habits.

Physical activity and blood lipids

As shown in Tables 2 and 3, there is some controversy regarding the association between PA and the blood lipid profile. While some studies indicate that healthy blood lipid profiles are associated with increased levels of PA (Raitakari *et al.*, 1994; Hager *et al.*, 1995; Raitakari *et al.*, 1997; Suter & Hawes, 2003; Nemet *et al.*, 2005; Wong *et al.*, 2008), other studies have shown that there is no significant relationship between blood lipids and PA (Armstrong *et al.*, 1991; Al-Hazzaa *et al.*, 1994; Webber *et al.*, 1996; Twisk *et al.*, 1997). In one study, a 2½ year diet and PA intervention resulted in no significant change in blood lipid status (Webber *et al.*, 1996). However, another study showed that total cholesterol and LDL-cholesterol decreased after a mere 3-month PA intervention that only consisted of 60 minutes of aerobic exercises 2 days per week (Nemet *et al.*, 2005). A possible explanation for this controversy can be that blood lipids are affected by hormonal levels which can vary through the pubertal stage in adolescents (Jessup & Harrell, 2005). Total cholesterol decreases in mid-puberty and increases to adult levels at the end of puberty (Jessup & Harrell, 2005).

Physical activity and body composition

There is a significant negative relationship between cardiovascular fitness in adolescents and each of the following indicators respectively: body weight, BMI, and body fat percentage (Hager *et al.*, 1995; Carrel *et al.*, 2005; Nemet *et al.*, 2005; Wong *et al.*, 2008). Abdominal obesity/ central obesity, which has been indicated as a key component of the MS, (Klein-Platat, Drai, Oujaa, Schlienger & Simon, 2005) is negatively associated with PA levels (Owens *et al.*, 1999; Brunet *et al.*, 2007; Krekoukia *et al.*, 2007). As shown in Table 3, body weight, BMI and body fat percentages were significantly reduced after a 3-month PA intervention that consisted of 60 minutes of aerobic exercises, 2 days per week (Nemet *et al.*, 2005). However, in another study, adolescents' BMI, body weight and body fat percentage did not change significantly in the experimental group after an 8- or a 12-week PA intervention (McMurray *et al.*, 2002; Nassis *et al.*, 2005). A possible explanation for these different results can be that the 8-week PA intervention (McMurray *et al.*, 2002) was too short a time period to observe a change in body composition and that the 12-week PA intervention (Nassis *et al.*, 2005) involved only 19 participants, forming a rather small group for determining a significant outcome.

Physical activity, fasting blood glucose and -insulin

A significant improvement of glucose metabolism and a significant decrease in fasting glucose and fasting insulin levels was found in adults who participated in PA interventions (Dengel *et al.*, 1998; Brekke, Lenner, Taskinen, Månson, Funahashi, Matsuzawa & Jansson, 2005; Thomas *et al.*, 2009). It must be remembered that insulin secretion and insulin resistance increase during puberty (Jessup & Harrell, 2005). Such increased insulin secretion may be caused by an increased amount of circulating growth hormones and changes in body composition (Jessup & Harrell, 2005). However, some PA intervention studies show a significant improvement in insulin sensitivity (Carrel *et al.*, 2005; Nassis *et al.*, 2005), e.g. one study consisting of a PA intervention that was only 12 weeks in duration and only consisted of aerobic exercises 3 days per week for 40 minutes per day (Nassis *et al.*, 2005). In the studies by Carrel *et al.* (2005) and Nassis *et al.* (2005), aerobic exercise training improved insulin sensitivity, independent of changes in body weight or body fat.

SUMMARY

As noted from the studies that constitute this literature review, PA has a positive effect on the components of the MS and vascular function. Blood pressure decreased after a 7-week PA intervention, arterial compliance increased after a 8-week PA intervention, insulin sensitivity increased and blood lipids, body weight and body fat decreased after a 12-week PA intervention. However, PA intervention studies similar to those described in Table 3 have not yet been performed with regard to black adolescents in African countries. Further research is necessary to determine whether PA would have similar effects on markers of the MS and vascular function in children, especially black children in developing countries. A regular PA routine is essential for long-term weight management and may have significant positive effects on cardiovascular risk factors.

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CHAPTER 3

The relationship between body composition and selective metabolic syndrome markers in black adolescents in South Africa: PLAY study

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ABSTRACT

Objective: The purpose of this study was to determine the relationship between body composition and selective markers of the metabolic syndrome in black adolescents. *Research Methods & Procedures:* The group consisted of 232 adolescent boys and girls aged 15-19 years attending two secondary schools in a low socio-economic status area of Potchefstroom, South Africa. Body mass (kg), stature (cm), waist- (WC) and hip circumferences were measured using standard methods. Body mass index (BMI) and waist:hip ratio (WHR) were calculated. Percentage body fat and lean body mass were measured by air displacement plethysmography. Fasting plasma insulin, fasting glucose, homeostasis model assessment of insulin resistance (HOMA-IR), systolic blood pressure (SBP) and diastolic blood pressure (DBP), were measured using standard methods. *Results:* Children with a high body fat percentage (boys > 20%, girls >25%) had significantly higher serum leptin concentration than children with normal body fat percentage (boys p=0.005, girls p<0.0001). Girls with a high body fat percentage also reported significantly higher SBP (p=0.004), DBP (p=0.03), plasma insulin (p=0.004) and HOMA-IR (p=0.004) than girls with normal body fat percentage. Body fat percentage had a significant positive association with HOMA-IR (p=0.02) and SBP (p=0.02), respectively. A significant positive correlation was also found between plasma leptin concentration and BMI (p<0.0001), WC (p<0.0001), body fat percentage (p<0.0001) and fat:height index (p<0.001). *Conclusion(s):* A significant positive association was found between body fat percentage and both SBP and HOMA-IR respectively. Girls with a high body fat percentage had significantly higher BP, plasma insulin and HOMA-IR than girls with normal body fat percentage, indicating risk of non-communicable diseases.

Key words: Body composition; systolic blood pressure; insulin resistance; metabolic syndrome; adolescents

INTRODUCTION

The prevalence of obesity amongst adults and children in both developed and developing countries has reached epidemic proportions [1-3]. Of greatest concern is the fact that the increase in overweight and obesity is related to insulin resistance (HOMA-IR), hypertension, diabetes mellitus, dyslipidaemia, coronary disease and increased serum leptin levels [4-7]. Increases in the severity of obesity have also been shown to be related to the prevalence of the metabolic syndrome (MS) among children and adolescents [4]. Therefore, early identification of adolescents at risk of developing obesity is essential for the prevention of premature mortality [8].

Children in Africa are generally regarded to be predominantly underweight and the focus of recent research has been on undernutrition [9]. South Africa, however, has a low prevalence of underweight children (which may be due in part to the country's positive economic growth) [10]. Indeed, the Youth Risk Behaviour Survey (n = 9 054), conducted in 2002, found that more than 17% of South African adolescents were overweight, and 4.2% obese [11]. This trend is set to continue: based on the results of a regional school-based health and fitness survey of almost 5 000 children aged 12-18 years. It is estimated that the future prevalence of obesity in 18 year old girls will be 37% for black girls, 10% for caucasian girls and 20% for girls of mixed ancestry [10]. The factors that are causing this trend include sedentary behaviour and passive overeating, as well as socio-cultural and economic influences and an obesogenic environment [3].

Even though this trend has been identified, studies designed to explore the relationship between body composition and selective metabolic markers in black African adolescents are lacking [12;13] as the focus in developing countries is still on treating undernutrition [14]. Limited information is also available regarding the metabolic consequences of black adolescents in particular being overweight [15]. This being the case, the purpose of this investigation is to determine the relationship between body composition and selective metabolic syndrome markers in black South African adolescents.

MATERIALS AND METHODS

Sample and study design

This cross-sectional study formed part of the Physical Activity in the Young Study (PLAY) and was conducted in a low socio-economic area in the North-West Province of South Africa. The setting and design of the study is described by Mamabolo *et al.* [12] and Swanepoel *et al.* [13]. All available adolescents, 251 boys and girls, in the grade 9 class (15-19 years) attending two secondary schools, were recruited and informed consent was obtained from 232 children, of whom 180 received parental consent to give blood samples. The adolescents came from two schools where the situations were similar with regard to growth phase, socio-economic status, diet and physical activity profiles [12]. The schools were selected according to the advice of the district nutrition advisor, who identified the schools that were most at risk of undernutrition. The main focus of the PLAY-study was to investigate children at risk of undernutrition, as earlier studies in the North-West Province of South Africa had found that undernourished children have a unique body composition, with a relatively low proportion of lean body mass and a relatively higher proportion of body fat [16].

Ethical considerations

The PLAY study was approved by the Ethics Committee of the North-West University, Potchefstroom Campus (no. 04M01) as well as by the principals of the participating schools. Informed consent was obtained from both the adolescents and their parents or guardians for participation in the study and the collection of blood samples.

Measurements

Participants were measured in a controlled environment in groups of between 40-50 participants per day over a period of one week. Upon arrival fasting blood samples were taken after which body fat percentage, lean body mass, blood pressure (BP) and anthropometric measurements were performed. The participants were then presented with light refreshments, after which the habitual physical activity (PDPAR), demographic information and Tanner stage questionnaires were completed.

Body composition

BMI was determined from the stature (cm) of participants by a vertical stadiometer using the stretch-method to the nearest 0.1 cm and body mass by means of a calibrated electronic scale (Precision, A&D Company, Saitama, Japan) to the nearest 0.1 kg [17]. The circumferences were measured with a flexible steel tape (Lufkin, Cooper Tools, Apex, NC) to the nearest 0.1 cm of the waist at the narrowest part between the lower rib and the iliac crest and the hips across the broadest part over the buttocks. The waist-hip ratio (WHR) was calculated by dividing the waist circumference (WC) by the hip measurement [17]. Fat mass, body fat percentage and lean body mass were measured by means of air displacement plethysmography (ADP, BOD-POD, Life measurement Inc, Concord, CA) according to standard guidelines [18]. Fat:height index was calculated as the ratio of fat mass (kg) divided by height in meters squared. Girls with a body fat percentage larger than 25% and boys with a body fat percentage larger than 20% were classified as having a high body fat percentage [19].

Biochemical analysis

An over-night (12 hours) fasting sample of 20 ml blood was taken from each participant for all biochemical analyses of the study. Blood samples for plasma were collected in ethylenediamine tetra-acetate-(EDTA)-coated venepuncture tubes. The plasma and serum were immediately separated and stored in Eppendorff tubes at –80°C until the analyses were performed. Fasting serum insulin was measured according to the microparticle enzyme immunoassay (MEIA) AxSYM-method, (Abbott, Wiesbaden, Germany). The inter-assay coefficient of variation (CV) for insulin was 5.7% and the intra-assay CV was 3.8%. Insulin sensitivity was measured by means of the Quantitative Insulin sensitivity Check Index (QUICKI) [20]. HOMA-IR was calculated according to the equation proposed by Matthews *et al.* [21]. For blood glucose concentrations, blood was sampled in sodium fluoride and calcium oxalate tubes. Plasma glucose was measured by means of Vitros DT60 II Chemistry Analyser (Ortho-Clinical Diagnostics, Rochester, NY, USA) with VITROS reagents and control. The inter-assay CV for plasma glucose was 2.1% and the intra-assay CV was 1.2%. Plasma leptin concentrations were determined by using an immunoradiometric assay (Active Human Leptin IRMA, DSL-23100, Diagnostic System Laboratories Inc., Webster, TX, USA). The inter-assay CV for plasma leptin was 5.1% and the intra-assay CV was 3.2%. All plasma or serum samples were run in the same assay for each test in an accredited laboratory (Ampath, Pretoria, South Africa).

Blood pressure

A continuous BP measurement was recorded for a period of at least 5 minutes by means of the Finometer apparatus (FMS, The Netherlands) to obtain both systolic blood pressure (SBP) (mmHg) and diastolic blood pressure (DBP) [22].

Tanner

The Tanner-stage questionnaires were used to determine the level of physical maturity in boys and girls. Trained adults of the same gender as the child administered the questionnaire in a private room. Classification for Tanner 1 was PH1 (no pubic hair) to PH5 (adult stage). Classification for Tanner 2 is MA1 (no breasts) to MA5 (adult stage) for girls. Genital development in boys is classified from level 1 (no enlargement) to level 5 (adult stage). A sketch with descriptions of the five stages of development in boys and girls was shown to the participants, who then indicated their own development level [23].

The Previous Day Physical Activity Recall (PDPAR)

Trained field workers were employed to collect information from respondents regarding their level of physical activity on one given weekday and one given weekend day. This method of classifying PA, called the PDPAR, developed by Trost *et al.* [24], uses a 24 hour recall list to classify respondents as vigorously, moderately active or inactive. According to this method respondents were asked to list their PA of the given day in 30 minute time frames, on an activity list. Using a difficulty factor, the type as well as intensity of activity was classified as high, medium or low. The metabolic equivalent (MET) values of PA were taken from *The Compendium of physical activities,* and the energy usage list was taken from the PDPAR [25]. The number of 30-minute periods with a MET value of 3 METs or more, as well as 30-minute periods with a MET value of 6 METs or more, was aggregated. Respondents were classified as vigorously active if two or more 30-minute periods had been coded as 6 METs or more, moderately active if two or more 30-minute periods had been coded as 3-5 METS and inactive if a respondent failed to meet the criteria for high or medium PA [26].

Statistical analysis

Statistical computer software (Statistica 2007, Stat Soft, Inc. for Windows, Tulsa, OK) was used for the analysis of the collected data [27]. Data are presented as means ± standard deviations. Children were divided into two groups based on body fat percentage.

Comparisons between the groups with different body fat percentage were made using Mann-Whitney U-tests. Associations between body composition and metabolic variables were assessed using Pearson's correlation analyses, with adjustment for gender and Tanner stage. The relationships between variables were then analysed using multiple regression models. Interactions between body fat percentage and the different metabolic marker variables (HOMA-IR, SBP, leptin) were tested, with covariates gender, Tanner stage and habitual physical activity (PDPAR score), as well as height in the model, and SBP as the dependent variable. Because no interaction was observed with sex, all the results are presented with both sexes pooled. HOMA-IR and leptin were log transformed before analyses because of the skewed distribution of the data.

RESULTS

Anthropometric and biochemical characteristics of the normal- and high body fat percentage participants are presented in Table 1. In contrast to these categories based on % BF, only 4.1% of the boys and 9.9% of the girls had a BMI above the cut-off points proposed by Cole *et al.* [28] for overweight and obesity. It is evident that the boys with a high body fat percentage had a significantly higher BMI, hip circumference and serum leptin concentrations than the boys with normal body fat percentage. Similarly, the girls with high body fat percentage had significantly higher BMI, WC, hip circumference and leptin, as well as higher SBP, DBP, fasting insulin concentrations, and HOMA-IR than the girls with a normal body fat percentage.