HUMAN BiOLOGY AND PUBLiC HEALTH
JOURNAL OF THE AUXOLOGICAL SOCIETY
ISSN 2748-9957 | Vol. 2 2025 | pp. 1–18

Physical activity, health-related physical fitness and markers of metabolic syndrome in adolescents: The PAHL-study

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Citation:

Sedumedi, C.M./Moss, S.J./van Niekerk, E. et al. (2025). Physical activity, health-related physical fitness and markers of metabolic syndrome in adolescents: The PAHL-study, Human Biology and Public Health 2. https://doi.org/10.52905/hbph2025.2.106.

Received: 2025-04-07
Accepted: 2025-07-18
Published: 2025-12-20

Conflict of Interest:

There are no conflicts of interest.

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Keywords

Adolescents, health-related physical fitness, metabolic syndrome, physical activity, waist circumference

Abstract

Background Globally, declining physical activity (PA) and health-related physical fitness (HRPF) levels among adolescents, if not intervened, may increase the risk of developing metabolic syndrome (Mets).

Objective We aimed to determine the relationship between PA, HRPF, and MetS markers in adolescents enrolled in the Physical Activity and Health Longitudinal (PAHL)-study.

Sample and Methods This cross-sectional study included 215 adolescents from the 2011 data point of the PAHL-study in Potchefstroom, North West Province, South Africa. We measured PA with the IPAQ-S, HRPF with the EUROFIT fitness tests, and blood lipid profiles. Participants were classified as having MetS markers according to the International Diabetes Federation and the National Cholesterol Education Program Adult Treatment Panel. Multiple regression analysis was performed to report the associations between PA, HRPF and MetS markers.

Results Multivariable regression analysis for the total group showed that waist circumference had significant ($p \leq 0.047$) negative associations with standing broad jump ($\beta = -0.29$), bent arm hang ($\beta = -0.45$), sit-ups ($\beta = -0.14$), and predicted VO_{2max} ($\beta = -0.36$). In girls only, triglycerides showed a significant negative association with predicted VO_{2max} ($\beta = -0.36$; $p \leq 0.044$).

Conclusion High abdominal fatness was evident in the South African adolescent and associated with poor HRPF. Based on these findings, HRPF interventions should be explored as a cost-effective strategy to mitigate MetS risk in adolescents.

Take-home message for students A high WC is primarily required to meet the criteria for classification of MetS, and play a role in the early development of MetS in adolescents. WC is negatively related to HRPF in South African adolescents, and appropriate interventions should be investigated to mitigate MetS development.

Abbreviations

BMI Body mass index
HDL-C High-density lipoprotein cholesterol
HRPF Health-related physical fitness
IDF International Diabetes Federation
IPAQ-S International Physical Activity Questionnaire
LMICs Low- and middle-income countries
METs Metabolic equivalents
MetS Metabolic syndrome
MVPA Moderate-to-vigorous physical activity
NCEP National Cholesterol Education Program
PA Physical activity
PAHL Physical Activity and Health Longitudinal
PF Physical fitness
VO_{2max} Maximal oxygen uptake
WC Waist circumference

Funding statement

This work was supported by the National Research Foundation (NRF) and South African Medical Research Council (SAMRC). None of the authors directly benefited from any funding.

Introduction

Background

Despite the widely reported benefits of physical activity (PA) and health-related physical fitness (HRPF) in children and adolescents, these levels are declining rapidly, leading to unfavourable health outcomes linked to premature death later in life (Fühner et al. 2021; Santos et al. 2023; Silva et al. 2020). Low levels of PA and high sedentary behaviour increase the risk of overweight and obesity in children and adolescents (Mahumud et al. 2021; Wilhite et al. 2023). Overweight and obesity are associated with an increased prevalence of metabolic syndrome (MetS) defined as a constellation of interconnected physiological, biochemical, clinical, and metabolic factors (Kaur 2014; Park et al. 2023). Metabolic syndrome risk factors include dyslipidaemia, elevated blood pressure and blood glucose levels, and a large waist circumference (WC) (Mohamed et al. 2023). Notably, these combined risk factors increase the likelihood of developing atherosclerotic cardiovascular disease and Type-2-Diabetes mellitus later in life (Alam et al. 2021; Burger et al. 2023; Silveira Rossi et al. 2022).

To prevent the development of MetS and achieve health benefits, it is recommended that children aged 5–17 years participate in an average of 60 minutes or more moderate-to-vigorous PA (MVPA) throughout the week (Bull et al. 2020). PA levels also impact health-related cardiorespiratory fitness as physical inactivity leads to a diminished load on the cardiorespiratory system and consequently reduces cardiorespiratory endurance (Fühner et al. 2021). Furthermore, HRPF has decreased globally for boys and girls over the years, with the biggest decline observed in boys (Fühner et al. 2021). HRPF includes upper and lower body muscle endurance and strength components, aspects that are needed to ensure long-term engagement with PA and the prevention of developing lifestyle diseases, such as obesity and Type-2-Diabetes mellitus. A high prevalence of overweight and obesity was reported in South African children and adolescents, of which girls report the highest prevalence (Kruger et al. 2023).

Strategies aimed at reducing overweight and obesity, such as increasing PA and HRPF levels, have been shown to lower the prevalence of MetS (Fühner et al. 2021; Angelico et al. 2023; Renninger et al. 2020). The global prevalence of physical inactivity in adolescents is 80%, with no hope of the numbers dropping to under 70% by the year 2030 (Guthold et al. 2020). This is coupled with a high prevalence of obesity, increasing the risk of developing one or more of the MetS risk markers at a younger age. Metabolic syndrome in low- and middle-income countries (LMICs) is an emerging public health concern in children and adolescents, with a prevalence of 3.98% according to the International Diabetes Federation (IDF) criteria and 6.71% according to the National Cholesterol Education Program (NCEP) Adult Treatment Panel (ATP III) criteria (Bitew et al. 2020). Although the body of literature suggests an inverse relationship between PA, physical fitness (PF), and MetS, the findings are inconclusive (de Lima et al. 2021; Vasquez et al. 2025). Data on observational and intervention studies largely stem from high-income countries, while studies in LMICs remain limited, highlighting the need for further research in these regions (van Sluijs et al. 2021; Muvhulawa et al. 2024). Based on the existing literature, the current study aimed to determine the relationship between PA, HRPF, and markers of MetS in adolescent boys and girls from a LMIC. The findings will assist in guiding future more extensive studies and intervention programs.

Methods

This study is part of an observational study from the Physical Activity and Health Longitudinal (PAHL) study that began in 2010 and continued until 2014. The overarching PAHL study aimed to longitudinally describe the changes in PA and the determinants of health risk factors in 14–18-year-old adolescents. The study details are reported elsewhere (Monyeki et al. 2012). Due to financial constraints, blood samples for lipid profiles were collected once in 2011 with no follow-ups. Additionally, cultural beliefs hindered some adolescent participants from giving blood samples, resulting in a smaller sample size than the one in the first paper of the PAHL study published by Monyeki et al. (Monyeki et al. 2012). The current study followed a cross-sectional design from the 2011 measurements to determine the relationship between PA, HRPF, and markers of MetS in adolescents from the Tlokwe Municipality, Potchefstroom, North West Province, South Africa. A total of 215 adolescents (of which n=86 were boys and n=129 were girls, of which n=150 were of Black and n=79 of White ethnicity), 14–18-years-old, provided assent after parental informed consent to take part in the current study.

Measurements

Body composition

Measurements of stature, body mass, and WC were performed by Level 2 criteria anthropometrists according to the standard procedures described by the International Society for the Advancement of Kinanthropometry (Marfell-Jones et al. 2006). Stature was measured to the nearest 0.1cm using a stadiometer with participants standing barefoot in the upright position with their head in the Frankfort plane. Body mass was measured to the nearest 0.1kg with an electronic scale (Seca, Italy), with participants wearing minimal clothing. Body mass index (BMI) was calculated by dividing body mass by stature in square metres (kg/m2). A 7mm flexible steel tape (Lufkin, Copper Tools, Apex, NC) was used to measure WC to the nearest 0.1cm at the midpoint between the lower rib margin and the iliac crest. Age and sex specific cut-off points of the IDF (≥ 90th percentile) and NCEP/ATP III (≥ 90th percentile) criteria were applied.

Blood pressure measurement

Systolic and diastolic blood pressure measurements were taken on the left arm using an Omron MIT Elite Plus (Omron Healthcare Co. Ltd., Japan) device. Participants were asked to lie down and rest for five minutes before blood pressure measurements were taken, and talking was not permitted during the resting period nor during the blood pressure measurements. The average measurements from two separate measurements, at least five minutes apart, were used in the analysis (O'Brien et al. 2005). A measurement of >130/85mmHg was classified as abnormal according to the IDF criteria, and systolic blood pressure ≥ 90th percentile was considered abnormal according to the NCEP/ATP III criteria.

Blood sampling and analysis

Participants were requested to fast overnight prior to blood collection. Blood samples were collected by a registered nurse in the morning with venous blood taken on the left arm from the cephalic vein into blood collecting tubes. The blood was centrifuged at 2,000 revolutions per minute for 10 minutes, serum (clotted blood) and plasma (non-clotted blood) were then aliquoted into small Eppendorf tubes and stored at -80oC until analysis by an accredited pathology laboratory was performed. Triglycerides, high-density lipoprotein cholesterol (HDL-C), and blood glucose levels were measured using a Siemens Dimension EXL 200 Chemistry analyser manufactured by Beckman Coulter (Brea, California, USA). The system uses the timed endpoint method, measuring the change in absorbance (560nm for HDL-C, 340nm for blood glucose and 520nm for triglycerides). The change in absorbance is directly proportional to the analyte in the sample. The concentrations of the analyte were expressed in mmol/L.

Diagnosis of metabolic syndrome according to various cut-off points

The IDF criteria and the NCEP/ATP III criteria indicated in Table 1 were used for MetS classification in the current study (Della Corte et al. 2015; Kryuchko et al. 2024).

Physical activity level measurement

PA levels were self-reported using the short form of the International Physical Activity Questionnaire (IPAQ-S) (Dellinger 2002; World Health Organisation 2009). The questionnaire is valid for use in this population (Craig et al. 2003). It consisted of seven questions which asked the participants about the frequency and time spent sitting, walking, and engaging in MVPA during the previous seven days. Only sessions which lasted ten minutes or longer were included in the calculation of total PA.

Total PA was calculated as Total METs (metabolic equivalents) min/week = (Walk METs*min*days) + (Moderate METs * min * days) + (Vigorous METs * min * days) for moderate-to-vigorous, walking, and sitting activities in the last seven days. Subsequently, MVPA daily was computed according to the following equation: MVPA daily = (Moderate METs.min / week + Vigorous METs.min / week)/7. Scores ≥ 60 min/day indicate that PA guidelines have been achieved, while below 60 min/day means that the PA recommendations have not been met.

Health-related physical fitness measures

Selected HRPF tests were performed in accordance with the European Test of Physical Fitness test protocol (Council of Europe 1987). Lower body explosive power was determined with the measuring a standing broad jump to the nearest 0.1cm. Bent arm hang was used to measure arm and shoulder muscle strength and endurance to the nearest 0.01sec, and the sit-ups test was used to measure abdominal muscle strength and endurance as the maximum number of sit-ups performed in 30sec. Participants were granted two opportunities, and the best results of the two attempts were recorded.

A beep test also referred to as the 20m shuttle run test, was used as a measure of cardiovascular fitness as it is a valid and reliable measure of cardiorespiratory fitness in adolescents (Tomkinson et al. 2019). Predicted VO_{2max} (maximal oxygen uptake), was calculated from a valid and reliable equation for children, proposed by Leger et al. (Léger et al. 1988) $VO_{2\,max}(\text{ml/kg/ min}) = 31.025 + 3.238 * S - 3.248 * A + 0.1536 * SA$; Where: S = Final speed (km/h); A = Age (years); $(S = 8 + 0.5) *$ last stage completed, which was previously applied in South African adolescents (Pienaar et al. 2015).

Statistical analysis

Data were analysed using IBM Statistical Package for Social Sciences version 29 (IBM Corporation, Armonk, New York). To check for the normality of variables, histograms were used and variables that were not normally distributed were log transformed. In descriptive statistics, normally distributed data were reported as means with standard deviations (SD); whereas age and non-normally distributed data were reported as median with 25th and 75th percentiles. Comparisons between the outcome variables for boys and girls were determined with independent t-Tests. The relationships between MetS markers with selected HRPF and PA were determined by means of Pearson correlations and multivariable analysis. In multivariable analysis, adjustments were made for age, sex, ethnicity, and stature in the total group, and for age, ethnicity, and height in sex-specific groups. The level of statistical significance was set at $p \leq 0.05$.

Table 1 IDF and NCEP/ATP III criteria for classification of metabolic syndrome (Della Corte et al. 2015; Kryuchko et al. 2024)

Variable	IDF	NCEP/ATP III
HDL-Cholesterol	< 1.03mmol/L	< 1.03mmol/L
Glucose	≤ 5.6mmol/L	> 6.1mmol/L
Triglycerides	≥ 1.7mmol/L	≥ 1.24mmol/L
Diastolic Blood Pressure	≥ 85mmHg	
Systolic Blood Pressure	≥ 130mmHg	≥ 90thpercentile
Waist Circumference	≥ 90thpercentile	≥ 90thpercentile for age and sex

Abbreviations: IDF, International Diabetes Federation; NCEP/ATP III, National Education Cholesterol Programme/Adult Trial Panel III; HDL, High-density lipoprotein cholesterol.

Results

The total group of participants comprised 215 adolescents with a median age of 14.92 (14.41; 15.32) years, of which 86 participants (40.0%) were boys and 150 participants (69.8%) were of Black ethnicity. Boys were significantly taller ($p < 0.001$), with higher systolic blood pressure ($p = 0.034$) and blood glucose ($p < 0.001$), and lower HDL-C levels ($p = 0.002$) when compared to girls. Significantly, more boys met the metabolic risk factor criteria of a high WC ($p = 0.008$) and high blood glucose levels ($p = 0.011$) according to the IDF criteria, and of high systolic blood pressure ($p = 0.005$) according to the NCEP/ATP III criteria. However, boys performed better in the standing broad jump, bent arm hang, sit-ups, and beep or indirect VO_{2max} test (all $p < 0.001$) when compared to girls (Table 2).

Pearson correlations of PA, HRPF and metabolic syndrome markers in the total group are presented in Table 3, and of boys and girls in Table 4. In the total group, WC correlated negatively with bent arm hang ($r = -0.22$; $p = 0.002$), systolic blood pressure positively with standing broad jump ($r = 0.19$; $p = 0.006$), and diastolic blood pressure negatively with total weekly PA METs ($r = -0.18$; $p = 0.027$). In the same group, blood glucose correlated positively with standing broad jump ($r = 0.22$; $p = 0.001$), bent arm hang ($r = 0.21$; $p = 0.003$), and sit-ups ($r = 0.31$; $p < 0.001$), whereas triglycerides correlated positively with sit-ups ($r = 0.14$; $p = 0.043$). In boys, WC correlated negatively with bent arm hang ($r = -0.28$; $p = 0.012$) and predicted VO_{2max} ($r = -0.38$; $p = 0.001$), while diastolic blood pressure correlated negatively with total weekly METs ($r = -0.31$; $p = 0.025$), and blood glucose correlated negatively with predicted $\dot{V}O2max$ ($r = -0.26$; $p = 0.031$). In girls, WC correlated negatively with standing broad jump ($r = -0.24$; $p = 0.007$), bent arm hang ($r = -0.40$; $p < 0.001$), and predicted VO_{2max} ($r = -0.23$; $p = 0.019$), while blood glucose ($r = 0.22$; $p = 0.012$) and triglycerides ($r = 0.19$; $p = 0.033$) correlated positively with sit-ups.

Multivariable regression analysis in Table 5 was adjusted for age, sex, ethnicity, and stature in the total group. WC associated negatively with standing broad jump ($\beta = -0.29$; $p < 0.001$), bent arm hang ($\beta = -0.45$; $p < 0.001$), sit-ups ($\beta = -0.14$; $p = 0.047$), and predicted VO_{2max} ($\beta = -0.36$; $p < 0.001$) in the total group. In the same group, blood glucose associated positively with sit-ups ($\beta = 0.17$; $p = 0.022$); although variance in blood glucose could not be explained by sit-ups (adj. $R^2 = 0.03$).

In boys, Table 6 show that WC negatively associated with standing broad jump ($\beta = -0.32$; $p = 0.001$), bent arm hang ($\beta = -0.47$; $p < 0.001$), and predicted $\dot{V}O2max$ ($\beta = -0.36$; $p < 0.001$). In girls, Table 7 indicate that WC negatively associated with standing broad jump ($\beta = -0.28$; $p < 0.001$), bent arm hang ($\beta = -0.45$; $p < 0.001$), sit-ups ($\beta = -0.25$; $p = 0.011$), and predicted VO_{2max} ($\beta = -0.42$; $p < 0.001$). Additionally, in girls, triglycerides associated negatively with predicted VO_{2max} ($\beta = -0.21$; $p = 0.044$).

Table 2 Descriptive statistics of the total group, 14–18-year-old boys and girls (Tlokwe Municipality, Potchefstroom, North West Province, South Africa)

	Total group (n=215) $\bar{x}\,(SD)\,/\tilde{x}\,(P25\%;\ P75\%)$	Boys (n=86) $\bar{x}\,(SD)\,/\tilde{x}\,(P25\%;\ P75\%)$	Girls (n=129) $\bar{x}\,(SD)\,/\tilde{x}\,(P25\%;\ P75\%)$	*p*-value
Age (years)	14.92 (14.41; 15.32)	14.92 (14.45; 15.32)	14.92 (14.37; 15.32)	0.55
Ethnicity, Black, n (%)	150 (69.8)	54 (62.8)	96 (74.4)	0.069
Height (cm)	161.59 (9.11)	166.28 (9.87)	158.47 (7.05)	**<0.001**
Weight (kg)	55,65 (13.06)	57.70 (14.19)	54.29 (12.11)	0.060
Body mass index (kg/m2)	21.18 (3.95)	20.67 (3.83)	21.52 (4.01)	0.12
WC (cm)	68.44 (8.43)	69.49 (8.59)	67.74 (8.27)	0.14
SBP (mmHg)	102.06 (9.69)	103.86 (10.99)	100.85 (8.55)	**0.034**
DBP (mmHg)	67.30 (7.60)	67.33 (8.30)	67.28 (7.14)	0.97
Glucose (mmol/L)	4.87 (0.47)	5.01 (0.49)	4.78 (0.43)	**<0.001**
Triglycerides (mmol/L)	0.7 (0.50; 1.11)	0.7 (0.50; 1.11)	0.7 (0.50; 1.11)	0.38
HDL-C (mmol/L)	1.29 (0.34)	1.21 (0.32)	1.35 (0.34)	**0.002**
Prevalence of metabolic syndrome risk factor according to the International Diabetes Federation				
MetS, n (%)	5 (2.3)	3 (3.5)	2 (1.6)	0.36
WC, n (%)	19 (8.8)	13 (15.1)	6 (4.7)	**0.008**
SBP, n (%)	2 (0.9)	2 (2.3)	0 (0.0)	0.082
DBP, n (%)	5 (2.3)	1 (1.2)	4 (3.1)	0.36
Glucose, n (%)	12 (5.6)	9 (10.5)	3 (2.3)	**0.011**
Triglycerides, n (%)	8 (3.7)	4 (4.7)	4 (3.1)	0.55
HDL-C, n (%)	71 (33.0)	25 (29.1)	46 (35.7)	0.31
Prevalence of metabolic syndrome risk factor according to National Cholesterol Education Program				
MetS, n (%)	12 (5.6)	2 (2.3)	10 (7.8)	0.090
WC, n (%)	20 (9.3)	7 (8.1)	13 (10.1)	0.63
SBP, n (%)	8 (3.7)	7 (8.1)	1 (0.8)	**0.005**
Glucose, n (%)	1 (0.5)	1 (1.2)	0 (0.0)	0.22
Triglycerides log, n (%)	27 (12.6)	13 (15.3)	14 (10.9)	0.34
HDL-C, n (%)	49 (22.8)	29.1 (29.1)	24 (18.6)	0.073
Health-related physical fitness and physical activity markers				
Standing broad jump (cm)	163.68 (28.87)	185.42 (26.20)	149.23 (20.26)	**<0.001**
Bent arm hang (sec)	6.10 (2.00; 14.64)	15.05 (8.52; 25.32)	2.78 (1.10; 6.31)	**<0.001**
Sit-ups (reps)	29.05 (10.77)	36.05 (6.59)	24.33 (10.48)	**<0.001**
Beep	5.83 (2.44)	7.85 (2.06)	4.47 (1.57)	**<0.001**
VO2max (mL/kg/min)	32.84 (8.41)	39.84 (7.15)	28.08 (5.30)	**<0.001**
Total METs (min/week)	97.01 (51.10; 875.99)	239.99 (51.10; 1157.98)	70.99 (49.93; 729.96)	0.15
Meet MVPA, n (%)	47 (21.9)	19 (25.3)	28 (24.8)	0.93
Participate in sport, n (%)	167 (77.7)	71 (82.6)	96 (74.4)	0.080

Values are expressed as arithmetic means and standard deviations (for normally distributed data) or medians with 25th and 75th percentiles (for non-normally distributed data and age), and proportions (for categorical data). Abbreviations: DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; METs, metabolic equivalents; MetS, metabolic syndrome; MVPA, moderate-to-vigorous physical activity; P25%, 25th percentile; P75%,75th percentile; SBP, systolic blood pressure; SD, standard deviation; VO_{2max}, volume of maximum oxygen consumption; WC, waist circumference; $\bar{x}$=Mean; and $\tilde{x}$=Median. Bold values denote significance as $p < 0.05$

Table 3 Correlation matrix between physical activity, health-related physical fitness and metabolic syndrome markers in adolescents (Tlokwe Municipality, Potchefstroom, North West Province, South Africa)

	WC (cm)	SBP (mmHg)	DBP (mmHg)	Glucose (mmol/L)	Trig (mmol/L)	HDL-C (mmol/L)
Standing broad jump (cm)	r=-0.10	**r=0.19**	r=0.09	**r=0.22**	r=0.003	r=-0.07
Bent arm hang (sec)	**r=-0.22**	r=0.09	r=-0.03	**r=0.21**	r=-0.03	r=0.01
Sit-ups (reps)	r=0.09	r=0.12	r=0.01	**r=0.31**	**r=0.14**	r=-0.13
Predicted VO2max (mL/kg/min)	r=-0.12	r=0.09	r=-0.03	r=0.14	r=0.05	r=-0.10
Total METs (min/week)	r=-0.05	r=-0.06	**r=-0.18**	r=-0.06	r=0.02	r=0.01

Abbreviations: DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; SBP, systolic blood pressure; METs, metabolic equivalents; Trig, triglycerides; VO_{2max}, volume of maximum oxygen consumption; and WC, waist circumference. Bold values denote significance as $p < 0.05$

Table 4 Correlation matrix between physical activity, health-related physical fitness and metabolic syndrome markers according to sex of adolescents from Tlokwe Municipality, Potchefstroom, North West Province, South Africa

	WC (cm)	SBP (mmHg)	DBP (mmHg)	Glucose (mmol/L)	Trig (mmol/L)	HDL-C (mmol/L)
Boys						
Standing broad jump (cm)	r=-0.18	r=0.19	r=0.08	r=0.004	r=-0.14	r=0.09
Bent arm hang (sec)	**r=-0.28**	r=0.12	r=0.10	r=-0.01	r=-0.06	r=0.11
Sit-ups (reps)	r=0.20	r=0.13	r=-0.04	r=0.20	r=-0.01	r=0.01
Predicted VO_{2max} (mL/kg/min)	**r=-0.38**	r=0.11	r=-0.10	**r=-0.26**	r=-0.11	r=0.08
Total METs (min/week)	r=-0.08	r=-0.19	**r=-0.31**	r=0.000	r=-0.06	r=-0.03
Girls						
Standing broad jump (cm)	**r=-0.24**	r=0.03	r=0.11	r=0.17	r=0.04	r=0.07
Bent arm hang (sec)	**r=-0.40**	r=-0.10	r=-0.11	r=0.16	r=-0.06	r=0.17
Sit-ups (reps)	r=-0.04	r=0.002	r=0.02	**r=0.22**	**r=0.19**	r=-0.03
Predicted VO_{2max} (mL/kg/min)	**r=-0.23**	r=-0.11	r=0.02	r=0.13	r=0.03	r=0.09
Total METs (min/week)	r=-0.06	r=-0.01	r=-0.10	r=-0.16	r=0.04	r=0.08

Abbreviations: DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; SBP, systolic blood pressure; METs, metabolic equivalents; Trig, triglycerides; VO_{2max}, volume of maximum oxygen consumption; and WC, waist circumference. Bold values denote significance as $p < 0.05$

Table 5 Multivariable analysis between physical activity, health-related physical fitness and metabolic syndrome markers in adolescents (Tlokwe Municipality, Potchefstroom, North West Province, South Africa)

	Adj. R^2	β (95% CI)	*p*-value
Waist circumference			
Standing broad jump (cm)	**0.25**	**-0.29 (-0.41; -0.17)**	**<0.001**
Bent arm hang (sec)	**0.37**	**-0.45 (-0.57; -0.34)**	**<0.001**
Sit-ups (reps)	**0.18**	**-0.14 (-0.27; -0.01)**	**0.047**
Predicted VO2max (mL/kg/min)	**0.29**	**-0.36 (-0.49; -0.23)**	**<0.001**
Total METs (min/week)	0.16	-0.06 (-0.21; 0.09)	0.42
Systolic blood pressure			
Standing broad jump (cm)	0.03	0.09 (-0.04; 0.23)	0.18
Bent arm hang (sec)	0.02	0.02 (-0.12; 0.16)	0.80
Sit-ups (reps)	0.04	0.14 (-0.01; 0.29)	0.062
Predicted VO2max (mL/kg/min)	0.02	0.02 (-0.14; 0.17)	0.82
Total METs (min/week)	0.02	-0.07 (-0.23; 0.09)	0.39
Diastolic blood pressure			
Standing broad jump (cm)	0.01	0.09 (-0.05; 0.23)	0.20
Bent arm hang (sec)	-0.01	-0.01 (-0.16; 0.13)	0.86
Sit-ups (reps)	**-0.01**	**0.03 (-0.12; 0.18)**	**0.66**
Predicted VO2max (mL/kg/min)	-0.01	-0.01 (-0.17; 0.14)	0.87
Total METs (min/week)	**0.02**	**-0.18 (-0.34; -0.12)**	**0.029**
Glucose			
Standing broad jump (cm)	0.02	0.09 (-0.05; 0.22)	0.22
Bent arm hang (sec)	0.01	0.06 (-0.09; 0.20)	0.44
Sit-ups (reps)	0.03	0.17 (0.03; 0.32)	0.022
Predicted VO2max (mL/kg/min)	0.01	-0.05 (-0.21; 0.10)	0.49
Total METs (min/week)	0.01	-0.10 (-0.27; 0.06)	0.21
Triglycerides			
Standing broad jump (cm)	0.09	-0.05 (-0.18; 0.09)	0.49
Bent arm hang (sec)	0.10	-0.13 (-0.26; 0.01)	0.070
Sit-ups (reps)	0.09	-0.02 (-0.16; 0.12)	0.78
Predicted VO2max (mL/kg/min)	0.09	-0.07 (-0.22; 0.08)	0.33
Total METs (min/week)	0.08	0.02 (-0.14; 0.18)	0.81
High-density lipoprotein cholesterol			
Standing broad jump (cm)	0.09	-0.05 (-0.18; 0.09)	0.49
Bent arm hang (sec)	**0.10**	-0.13 (-0.26; 0.01)	0.070
Sit-ups (reps)	0.09	-0.02 (-0.16; 0.12)	0.78
Predicted VO2max (mL/kg/min)	0.09	-0.07 (-0.22; 0.08)	0.33
Total METs (min/week)	0.08	0.02 (-0.14; 0.18)	0.81

Adjustments were made for age, sex, ethnicity, and height. Bold values denote significance ($p < 0.05$). Abbreviations: Adj. R^2, adjusted R-square; CI, confidence intervals; METs, metabolic equivalents; PA, physical activity; Std. β, standardised beta; and VO_{2max}, maximal oxygen consumption

Table 6 Multivariable analysis between physical activity, health-related physical fitness and metabolic syndrome markers in 14–18-year-old boys (Tlokwe Municipality, Potchefstroom, North West Province, South Africa)

	Adj. R^2	β (95% CI)	*p*-value
Waist circumference			
Standing broad jump (cm)	**0.33**	**-0.32 (-0.51; -0.13)**	**0.001**
Bent arm hang (sec)	**0.45**	**-0.47 (-0.65; -0.30)**	**<0.001**
Sit-ups (reps)	0.24	0.02 (-0.19; 0.22)	0.89
Predicted VO2max (mL/kg/min)	**0.36**	**-0.36 (-0.56; -0.16)**	**<0.001**
Total METs (min/week)	0.22	-0.09 (-0.35; 0.18)	0.52
Systolic blood pressure			
Standing broad jump (cm)	0.02	0.16 (-0.07; 0.39)	0.17
Bent arm hang (sec)	0.01	0.12 (-0.11; 0.36)	0.30
Sit-ups (reps)	0.02	0.15 (-0.08; 0.38)	0.20
Predicted VO2max (mL/kg/min)	-0.01	0.07 (-0.17; 0.32)	0.56
Total METs (min/week)	**-0.01**	**-0.19 (-0.49; 0.10)**	**0.20**
Diastolic blood pressure			
Standing broad jump (cm)	-0.01	0.03 (-0.20; 0.26)	0.78
Bent arm hang (sec)	-0.01	0.09 (-0.15; 0.33)	0.45
Sit-ups (reps)	-0.01	-0.06 (-0.29; 0.18)	0.63
Predicted VO2max (mL/kg/min)	-0.01	-0.13 (-0.38; 0.12)	0.30
Total METs (min/week)	0.05	-0.31 (-0.60; -0.02)	0.036
Glucose			
Standing broad jump (cm)	-0.02	-0.03 (-0.26; 0.21)	0.82
Bent arm hang (sec)	-0.02	-0.07 (-0.30; 0.17)	0.59
Sit-ups (reps)	0.01	0.17 (-0.07; 0.40)	0.16
Predicted VO2max (mL/kg/min)	**0.04**	**-0.26 (-0.50; -0.02)**	**0.034**
Total METs (min/week)	-0.06	-0.01 (-0.32; 0.29)	0.95
Triglycerides			
Standing broad jump (cm)	0.07	-0.22 (-0.44; 0.04)	0.054
Bent arm hang (sec)	0.04	-0.14 (-0.38; 0.09)	0.22
Sit-ups (reps)	0.04	-0.10 (-0.34; 0.13)	0.37
Predicted VO2max (mL/kg/min)	0.02	-0.08 (-0.32; 0.17)	0.53
Total METs (min/week)	-0.01	-0.12 (-0.31; 0.28)	0.92
High-density lipoprotein cholesterol			
Standing broad jump (cm)	-0.02	0.09 (-0.14; 0.32)	0.45
Bent arm hang (sec)	-0.01	0.14 (-0.10; 0.37)	0.25
Sit-ups (reps)	-0.03	0.02 (-0.21; 0.26)	0.84
Predicted VO2max (mL/kg/min)	-0.04	0.05 (-0.20; 0.30)	0.69
Total METs (min/week)	-0.01	-0.02 (-0.31; 0.28)	0.92

Adjustments were made for age, ethnicity, and height. Bold values denote significance ($p < 0.05$). Abbreviations: Adj. R^2, adjusted R-square; CI, confidence intervals; METs, metabolic equivalents; PA, physical activity; Std. β, standardised beta; and VO_{2max}, maximal oxygen consumption

Table 7 Multivariable analysis between physical activity, health-related physical fitness and metabolic syndrome markers in 14–18-year-old girls (Tlokwe Municipality, Potchefstroom, North West Province, South Africa)

	Adj. R^2	β (95% CI)	*p*-value
Waist circumference			
Standing broad jump (cm)	**0.18**	**-0.28 (-0.44; -0.12)**	**<0.001**
Bent arm hang (sec)	**0.30**	**-0.45 (-0.60; -0.29)**	**<0.001**
Sit-ups (reps)	**0.15**	**-0.25 (-0.43; -0.06)**	**0.011**
Predicted VO2max (mL/kg/min)	**0.23**	**-0.42 (-0.61; -0.22)**	**<0.001**
Total METs (min/week)	0.10	-0.06 (-0.25; 0.13)	0.54
Systolic blood pressure			
Standing broad jump (cm)	0.04	0.07 (-0.11; 0.24)	0.46
Bent arm hang (sec)	0.03	-0.06 (-0.24; 0.13)	0.53
Sit-ups (reps)	0.05	0.15 (-0.05; 0.35)	0.14
Predicted VO2max (mL/kg/min)	0.02	0.01 (-0.21; 0.24)	0.91
Total METs (min/week)	0.02	-0.01 (-0.21; 0.19)	0.90
Diastolic blood pressure			
Standing broad jump (cm)	0.11	0.22 (-0.07; 0.29)	0.22
Bent arm hang (sec)	-0.01	-0.09 (-0.28; 0.10)	0.35
Sit-ups (reps)	-0.01	0.10 (-0.11; 0.30)	0.36
Predicted VO2max (mL/kg/min)	-0.02	0.08 (-0.15; 0.31)	0.50
Total METs (min/week)	-0.01	-0.11 (-0.31; 0.10)	0.30
Glucose			
Standing broad jump (cm)	0.03	0.17 (-0.01; 0.34)	0.065
Bent arm hang (sec)	0.02	0.14 (-0.04; 0.33)	0.13
Sit-ups (reps)	0.03	0.18 (-0.02; 0.38)	0.074
Predicted VO2max (mL/kg/min)	0.01	0.10 (-0.13; 0.33)	0.38
Total METs (min/week)	0.02	-0.15 (-0.35; 0.05)	0.14
Triglycerides			
Standing broad jump (cm)	0.17	0.01 (-0.15; 0.17)	0.95
Bent arm hang (sec)	0.19	-0.15 (-0.32; 0.02)	0.078
Sit-ups (reps)	0.17	-0.02 (-0.20; 0.17)	0.84
Predicted VO2max (mL/kg/min)	**0.20**	**-0.21 (-0.41; -0.01)**	**0.044**
Total METs (min/week)	0.16	0.07 (-0.12; 0.25)	0.49
High-density lipoprotein cholesterol			
Standing broad jump (cm)	-0.01	0.07 (-0.11; 0.25)	0.43
Bent arm hang (sec)	**0.02**	**0.21 (0.02; 0.39)**	**0.030**
Sit-ups (reps)	-0.02	0.03 (-0.18; 0.23)	0.78
Predicted VO2max (mL/kg/min)	0.01	0.19 (-0.04; 0.41)	0.11
Total METs (min/week)	0.16	0.07 (-0.12; 0.25)	0.49

Adjustments were made for age, ethnicity, and height. Bold values denote significance ($p < 0.05$). Abbreviations: Adj. R^2, adjusted R-square; CI, confidence intervals; METs, metabolic equivalents; PA, physical activity; Std. β, standardised beta; and VO_{2max}, maximal oxygen consumption.

Discussion

This study's main aim was to investigate the relationship of PA, HRPF and MetS markers in a group of boys and girls, respectively from the North West Province of South Africa. The main findings of this study indicated that relatively high central obesity significantly and inversely associated with upper, lower body and abdominal muscle strength and cardiovascular fitness test items in the total group, as well as for boys and girls.

Various studies report the prevalence of MetS in different settings. There is, however, no consensus between these studies, partly because of a lack of universally acceptable criteria for the classification of MetS. Additional reasons could include urban vs rural environments, age, sex, and ethnicity (Kaur 2014). Our study reports the presence of MetS in this group of adolescents, although comparisons with other studies are met with challenges due to different criteria used across different studies. Nonetheless, the reported prevalence warrants prevention strategies. A nationally representative study on 10–19-year-old children in India reported a prevalence of 5.2% based on the NCEP–ATP III MetS criteria (Ramesh et al. 2022). Likewise, when we employed the NCEP-ATP III criterion, we found a prevalence of 5.6%. A study performed on Ethiopian adolescents aged 16.59±1.36 years revealed a MetS prevalence of 12.4% based on IDF criteria (Bekel and Thupayagale-Tshweneagae 2020). This is higher than the prevalence of 2.3% that we found by applying the IDF criteria to our sample. It should be noted that a high WC is primarily required to meet the criteria for classification of MetS, in addition to two other risk factors (Della Corte et al. 2015; Kryuchko et al. 2024). The difference between studies may therefore be a result of a higher percentage of adolescents with a high WC among Ethiopian adolescents (32.3%) when compared to our study (8.8%).

The present study did not report any significant sex differences in the prevalence of MetS. Other studies have reported similar results, where they could not see any disparities in the prevalence of MetS according to gender (Calcaterra et al. 2020; Choi et al. 2021). These findings are however in disagreement with a study by Ramesh et al. (Ramesh et al. 2022), who reported that boys had a significantly higher prevalence of MetS compared to girls. The differences may be due to their sample size being nationally representative of Indian children, while ours only targeted a small population in a specific region of South Africa. Additionally, MetS prevalences are higher in obese and overweight children compared with those with a normal weight (Bitew et al. 2020). There were no gender differences in terms of BMI values in our group of adolescents.

Low HDL-C was the most common marker of MetS in the current study, reported at 33% and 22.8% by IDF and NCEP ATP III criteria, respectively. This agrees with the finding from a study conducted on South African children aged 10–16 years by Matsha et al. (Matsha et al. 2009), who reported that HDL-C was the most common marker of MetS at 48.8%. Low HDL-C has been linked to an increased risk of heart diseases, whereas participation in regular PA of moderate-to-vigorous intensity has been shown to increase HDL-C concentrations (Al Zaki et al. 2023). Our findings are contradictory to other studies, as central obesity, which was reported in 34.2% of the participants, was the most common marker of MetS in adolescents aged 9–18-year-old from various regions in the world (Guthold et al. 2020). The reason might be the larger age range of participants and larger sample sizes, while our study had a narrower age range and smaller sample size. The age range of our study is within the puberty stage where hormonal changes may affect various physiological markers in the blood, such as cholesterol. Regional differences related to dietary intake may also contribute to the differences in findings compared to other regions in the world.

Over the years, children and adolescents have reported declining levels of PA (Guthold et al. 2020). The current study supports the lack of sufficient PA in adolescents with only 21.9% achieving the recommended average of 60 minutes or more of MVPA. PA did not associate with any of the MetS markers. This is inconsistent with findings from a study performed by Silva et al. (Silva et al. 2023) on Brazilian adolescents aged 10–19 years. They reported that spending more time in lower levels of PA was associated with increased risk of MetS, higher WC, and dyslipidaemia. In the same study, higher levels of PA associated with increased insulin sensitivity. The significant beneficial relationship between PA and MetS markers in their study may be explained by the larger sample size as compared to our study. There are several other reasons that could explain the lack of significant findings in our study; one of them could be due to the low levels of PA reported in this group. Another reason could be due to the method employed to determine PA levels in the study. Though self-reporting measures of PA show potential in characterising PA levels, limitations of subjective PA measures may lead to over- or underestimation of PA levels (Marasso et al. 2021). The MetS prevalence in the adolescents of this study may not solely be due to physical inactivity but also the increased circulating levels of insulin. Adolescence is associated with the state of acute insulin resistance as a result of conservation in β-cell function (Goran and Gower 2001). Increased prevalence of insulin resistance plays a major role in the development of MetS (Mohamed et al. 2023). The level of insulin resistance is however not reported in the present study. Diet, which is a key lifestyle factor for the development of MetS, may have played a role in these adolescents (Xu et al. 2018). This was however also not reported.

Physical fitness is an important indicator of health, whereas lower levels are associated with the development of MetS (Filho et al. 2022). Cardiorespiratory fitness, a health-related component of PF, has decreased over the years for boys and girls, with the biggest decline observed among boys (Führer et al. 2021). In the current study, boys report a 29.52% higher VO_{2max} when compared to girls. This is consistent with research findings reported by Gomwe et al. (Gomwe et al. 2024) on 9–14-year-old children in the Eastern Cape. The decline in cardiorespiratory fitness is attributed to several factors including social, behavioural, physical, psychosocial, and physiological factors (Führer et al. 2021). Higher levels of central obesity or BMI play a role in the decline in cardiorespiratory fitness (Führer et al. 2021). WC, which is a proxy measure of central obesity, is one of the markers of MetS (Mohamed et al. 2023). Multivariable regression analysis revealed that a high WC is associated with lower cardiorespiratory fitness when adjustments were made for age, sex, ethnicity, and height. Similar results were also reported in other studies. WC was negatively associated with cardiorespiratory fitness in 10–14-year-old children from Europe (Pojskic and Eslami 2018). In adolescents aged 14–19-year-old Brazilians, higher WC identified lower levels of cardiorespiratory fitness (de Andrade Gonçalves et al. 2022). Higher cardiorespiratory fitness is strongly related to lower MetS in adolescence, if this is carried to adulthood, it could possibly have a protective effect against MetS later in life (Mäestu et al. 2020).

Although there is research on the health benefits of muscle strength and endurance, its association with MetS in adolescent boys and girls, especially in LMICs is scanty and the findings are uncertain (de Lima et al. 2021). More research in this area is needed. Muscle strength and endurance are beneficial to decrease risk of adiposity and unfavourable cardiometabolic parameters (Filho et al. 2022; Lopes et al. 2017). Physical development and body composition play a role in muscle status in childhood (Kim et al. 2021). We report that boys significantly perform better in terms of standing broad jump, bent arm hang, and sit-ups compared to girls. Similar results were reported in children aged 6–14-year-old from Portugal, where boys had more muscle strength compared to girls (de Castro Pinto et al. 2020). Research data has shown that adolescents with low muscle strength are more likely to have MetS when compared to children with a high muscle mass (de Lima et al. 2021; Pilli et al. 2021). In our study, we report that WC is negatively associated with standing broad jump, bent arm hang, and sit-ups, Similarly, a study in 10–17-year-old Chilean adolescents revealed that those with higher WC had lower muscle strength (hand grip strength) (Palacio-Agüero et al. 2020). Muscle strength status was predictive of WC levels in an overweight and obese group of adolescents aged 12–18 from the United States of America (Pilli et al. 2021). Regular PA activates muscles, which drives the circulating glucose into the cells for energy production, therefore reducing circulating insulin concentrations and fat deposition (Chomiuk et al. 2024; Yuniana et al. 2023). Additionally, participation in regular PA has an anti-inflammatory effect that is associated with a decrease in visceral fat (Chomiuk et al. 2024). Although all MetS markers did not associate with PF indicators, strategies are needed to improve PF and tackle central obesity, thereby improve health outcomes in adolescence.

The results should be interpreted with the following limitation in mind: the participants were adolescent students from a localised community in the North West Province and do not represent all adolescents in South Africa. Additionally, due to the uneven distribution of data by ethnicity and sex despite the homogeneity of adolescents attending schools in the same environment, analysis based on ethnicity was not possible. Intervention studies are needed to obtain more information regarding cause and effect, while this study presented data of a cross-sectional nature. Finally, the study analysed PA data obtained by means of questionnaires, which could lead to either over- or under-estimation of PA. Future studies should incorporate PA data which has been objectively determined. The strength of the study should also be acknowledged, we employed two MetS classifications in adolescents of Black and White ethnicity, and our study may add to the body of literature regarding health research in LMICs.

Conclusion

WC as one of the MetS markers was shown to be significantly and negatively associated with HRPF measures after adjustment of potential cofounders in adolescents from Tlokwe Municipality of the North West Province, South Africa. The lack of a consensus criterion for the classification of MetS in adolescents provided conflicting findings, this can pose a challenge when intervention strategies are developed. Standardised cut-off points for South African adolescents should be derived for accurate identification of MetS.

Declarations

Ethics approval and consent to participate

The research ethics committee for humans of the North-West University (Ethics number: NWU-0058-01-A1) approved the study. Before participating in the study, adolescents provided assent after informed consent was received from the parents or legal guardians.

Availability of data and materials

The authors confirm that data and materials supporting the study findings are available and can be made available in accordance with the NWU data sharing policy upon reasonable request.

Funding

This work was supported by the National Research Foundation (NRF) and South African Medical Research Council (SAMRC).

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Authors' contributions

Sedumedi CM was involved in the conceptualisation and design of the paper. She was also involved in data collection and analysis. She further approved the final version of the paper. **Moss SJ** was involved in conceptualisation and design of the paper. She was also involved in data collection, reviewing of the manuscript and approval of the final draft. **van Niekerk E** was involved in the conceptualisation and design of the paper. She was also involved in the data analysis. She further approved the final version of the paper. **Monyeki AM** is the principal investigator of the PAHL study, he was involved in the study conceptualisation and design, funding application and data collection. He was involved in conceptualisation, drafting and reviewed the manuscript and approved the final draft of the paper.

Acknowledgements

The cooperation of the District Office of the Department of Education, school authorities, teachers, parents and children in the Tlokwe Municipality is greatly appreciated. We thank the fourth-year (2010–2014 honours) students in the School of Human Movement Sciences for their assistance in the collection of the data. The vital guidance of Professors Esté Vorster (NWU) and Han Kemper (Vrije University, Amsterdam, The Netherlands) at the inception of the Physical Activity and Health Longitudinal Study (PAHLS) is greatly appreciated. In addition, the contribution of all researchers in the PAHLS is highly appreciated.

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