

THE IMPACT OF A 10-WEEK PHYSICAL ACTIVITY INTERVENTION PROGRAMME ON SELECTIVE METABOLIC SYNDROME MARKERS IN BLACK ADOLESCENTS

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ABSTRACT

The purpose of this study was to determine the effects of a 10-week physical activity (PA) intervention on selective metabolic syndrome markers in black adolescents. All available adolescents (194 subjects), boys and girls, in the grade 9 class (15-19 years) attending a secondary school were recruited for the experimental group. A control group consisting of 57 adolescents from grade 9 of another secondary school in the same area was also recruited. The experimental group participated in a 10-week PA intervention. Body mass index (BMI), fasting insulin, fasting glucose, homeostasis model assessment of insulin resistance (HOMA-IR), systolic blood pressure (SBP), diastolic blood pressure (DBP), Windkessel arterial compliance (C_w), total peripheral resistance (TPR) and waist circumference were measured. After the 10-week PA intervention, adolescents from the control group had a significantly lower DBP compared to the intervention group ($p=0.00005$) and adolescents from the intervention group had a significantly lower SBP compared to the control group ($p=0.000061$). There was also a tendency towards a higher C_w and lower HOMA-IR in the intervention group compared to the control group. The findings of this study suggest that black adolescents had significantly lower SBP and a trend of lower HOMA-IR after a 10-week PA intervention.

Key words: Physical activity; Metabolic syndrome; Adolescents.

INTRODUCTION

Adolescents are no longer as physically active as a few decades ago (Deckelbaum & Williams, 2001; Dwyer *et al.*, 2009). Low levels of physical activity (PA) are widely assumed to be involved in the etiology of obesity and underlie public health messages globally (Must & Tybor, 2005). In South Africa the occurrence of obesity is two to three times higher in the black population than in the white population (Punyadeera *et al.*, 2000). This significantly higher rate of obesity in the black population is of serious concern, because the metabolic syndrome (MS) is high among obese children and adolescents (Weiss *et al.*, 2004). The MS is defined by the clustering of metabolic abnormalities, primarily overweight and more specifically central obesity, insulin resistance, dyslipidaemia and hypertension (Klein-Platat *et al.*, 2005; Jennings *et al.*, 2009). The MS affects a great number of adolescents (Jessup & Harrell, 2005; Day *et al.*, 2009) and is related to cardiovascular risk (Klein-Platat *et al.*, 2005; Day *et al.*, 2009; Leite *et al.*, 2009). However, studies designed to

explore the influence of a PA intervention on the components of the MS in black South African adolescents are lacking. This is a significant shortcoming in the study of the MS in South Africa, especially as previous studies in the US have found that black children, as compared to their white counterparts, have a higher prevalence of obesity (Schuster *et al.*, 1998; Deckelbaum & Williams; 2001), are more insulin resistant (Schuster *et al.*, 1998) and have higher blood pressure, independent of adiposity (Cruz *et al.*, 2002).

Adolescents require monitoring, as risk-related behaviour patterns for coronary heart disease have their origin in childhood and adolescence (Day *et al.*, 2009). Adolescents need to partake in PA on a regular basis to reduce their risk of developing Type 2 diabetes and cardiovascular diseases like hypertension (Ritenbaugh *et al.*, 2003). 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). Regular PA also increases insulin sensitivity (Schmitz *et al.*, 2002), 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). PA also has a significant negative relationship with blood lipids and blood pressure (McMurray *et al.*, 2002; Ritenbaugh *et al.*, 2003; Nassis *et al.*, 2005; Nemet *et al.*, 2005).

Studies of PA interventions on American adolescents have indicated a positive effect on MS markers (McMurray *et al.*, 2002; Ritenbaugh *et al.*, 2003; Nassis *et al.*, 2005; Nemet *et al.*, 2005), but no such study has been conducted on black adolescents in a South African setting. This exploratory study will seek to address this gap by analysing the effects of a 10-week PA intervention on selective markers of the MS in black boys and girls aged 15 to 19 years.

METHODS

Sample and Study design

The Physical Activity in the Young (PLAY) study was a pre-test, intervention, post-test study design that included an experimental group and a control group. The experimental group was subjected to a PA intervention programme while the control group received health information only on a single health promotion day at the school. The setting and design of the study were described by Mamabolo *et al.* (2007) and Swanepoel *et al.* (2007). All available adolescents, boys and girls, in the grade 9 class (15-19 years) attending a secondary school in the low socio-economic status (SES) area of Ikageng township (North-West Province, South Africa) were recruited for the experimental group. A total of 194 adolescents were in the experimental group (96 boys and 98 girls). Another 57 adolescents (16 boys and 41 girls) from grade 9 of a secondary school in the same low SES area were recruited for the control group. These schools were selected from a total of five high schools in the low socio-economic township, because they were attended only by adolescents from the surrounding neighbourhoods. The adolescents' status were similar with regard to growth phase, SES, diet and PA profiles.

Ethical considerations

The PLAY study was approved by the Ethics Committee of the North-West University, Potchefstroom Campus (no. 04M01) as well as the school principals. Consent was obtained from the adolescents' parents and from the adolescents for participation in the study and the collection of blood samples.

Measurements

The adolescents were transported to the university in groups of 20-30 per day for baseline- and end measurements before and after the PA intervention programme. Data were collected over a period of one week at baseline and after the intervention, respectively. The measuring sequence was as follows: Fasting blood samples were taken upon arrival in the morning. The participants were then taken to the remaining workstations, namely air displacement plethysmography (BOD-POD), blood pressure and anthropometry workstations. The participants were provided light refreshments before being guided to the demographic, PA and Tanner-stage questionnaire workstations.

Body composition

Body composition was compiled by determining the body mass index (BMI), waist-hip ratio (WHR) and percentage body fat. BMI was determined from the height (cm) by a vertical stadiometer using the stretch-method (Marfell-Jones *et al.*, 2006) 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. The circumferences were measured with a flexible steel tape (Lufkin, Cooper Tools, Apex, NC) to the nearest 0.1 cm. The measures of the abdomen (across the smallest or leanest area of the abdomen) and the hips (across the broadest part over the buttocks) were recorded. Body fat percentage was measured by means of air displacement plethysmography (BOD-POD, Life Measurement Inc, Concord, CA) according to standard guidelines (Fields *et al.*, 2000). Body mass was measured by means of a calibrated digital scale. When the body density is known, relative ratios of fat-containing and fat-free mass can be calculated. This technique is based on Boyle's law of pressure-volume ratios (Fields *et al.*, 2000).

Biochemical analysis

The participants fasted overnight (12 hours). A 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 ELISA method by means of the Immulite 2000 Analyzer. Insulin resistance was calculated according to the formula used by Matthews *et al.* (1985). For blood glucose concentrations blood was sampled in tubes with sodium fluoride and calcium oxalate. A total of 4.5 ml blood was mixed with the calcium oxalate and sodium fluoride (glucolite inhibitor) by turning the tube around carefully (not shaking). It was then placed on ice and centrifuged within 15 minutes. Plasma was immediately deposited into plastic micro tubes for analysis of glucose and frozen on dry ice. Plasma glucose was measured by means of Vitros DT60 II Chemistry Analyser

(Ortho-Clinical Diagnostics, Rochester, NY, USA) with VITROS reagents (catalogue number 1532316) and control (catalogue numbers 8420317, 1448042).

Blood pressure

A continuous blood pressure measurement was recorded for a period of at least five minutes by means of the Finometer apparatus (FMS, The Netherlands). The Finometer computed all cardiovascular variables online, the Beatscope 1.1 software programme integrated the subject's gender, age, height and weight and this information was further integrated to obtain systolic blood pressure (SBP) (mmHg), diastolic blood pressure (DBP) (mm Hg), total peripheral resistance (TPR) (mmHg/ml) and Windkessel arterial compliance (C_w) (ml/mmHg). The mean values of all the cardiovascular function variables were estimated in the last two minutes of the five minutes measuring time. The vascular unloading technique of Penáz together with the Physioal criteria of Wesseling provided reliable, non-invasive and continuous estimations of the cardiovascular function variables (Schutte *et al.*, 2004).

Tanner

The Tanner-stage questionnaires were used to determine the level of physical maturity in boys and girls and were administered by trained individuals in private rooms. 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). 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 respondents, who then indicated their own development level (Tanner & Whitehouse, 1982).

The Previous Day Physical Activity Recall (PDPAR)

Trained field workers were employed to collect information from respondents regarding their level of PA on one given weekday and one given weekend day. This method of classifying PA, called the PDPAR, developed by Trost *et al.* (1999), uses a 24 hour recall list to classify respondents PA levels as low (1), moderate (2) or high (3). According to this method respondents were asked to list their PA of a 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 (Ainsworth *et al.*, 1993; Weston *et al.*, 1997). 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 more than 6 METs, moderately active if two or more 30-minute periods had been coded as 3 to 6 METS, and inactive if a respondent failed to meet the criteria for high or medium PA (Pate *et al.*, 1997). This questionnaire has been validated and used in the assessment of PA of children and adolescents from various ethnic groups (Weston *et al.*, 1997).

Physical activity intervention and compliance

The intervention programme was performed three days a week for ten weeks and presented by 12 post-graduate Human Movement Science students. No activity periods were scheduled during school hours, therefore the programme had to be done directly after school hours. Although the adolescents were encouraged to participate in the programme their participation was voluntary. The 10-week period was selected to conform to a school term, the assumption being that adolescents will be more willing to partake in the intervention at school on school days than at school during a holiday. Each intervention session lasted one hour, consisting of aerobic activity (aerobic exercises, dancing, kata boxing) for 20 minutes, sport-specific activity (mini-soccer, ball skills) lasting 20 minutes, and strength and flexibility exercises (push-ups, lunges, stretching exercises) for 20 minutes. Compliance with exercise intensity was performed by determining the heart rates of the adolescents manually at random by the post-graduate Human Movement Science students. Heart rates between 136 and 155 (beats per minute) were the required intensity for this population as determined according to their age (Lamb, 1984). The intensity of this intervention was also monitored through accelerometers (Actical, Minimeter, Bend, Oregon), where learners were selected according to group lists to wear them at every session. The mean duration of the activity sessions was 69 minutes. Girls spent a mean of 28 minutes in vigorous activity and boys spent a mean of 29.5 minutes in vigorous activity. The frequency of participation was monitored through the use of an attendance register.

Statistical analysis

The Statistica Computer Processor Programme for Statsoft, Inc. STATISTICA (data analysis software system, version 7, 2004) was used for processing the documented data. The SAS programme was used individually for each adolescent to calculate height-for-age z-scores, according to the Centres for Disease Control (CDC) database (CDC, 2000). Descriptive statistics and the Mann-Whitney U-test were used to compare groups. Analysis of covariance (ANCOVA) was used to compare the data of the groups after the intervention (Thomas & Nelson, 2001).

RESULTS

Baseline characteristics of the adolescents

Baseline characteristics of participants by gender and group are presented in table 1. It should be noted that although the control and the intervention groups included participants from the same grade (Grade 9), the boys in the intervention group were significantly older than the boys from the control group. The majority of all the subjects in both the intervention and control groups reported to be in Tanner-stage 4 of physical development. The baseline data indicate that the boys of the intervention group had a higher mean muscle mass, than the boys of the control group. In subsequent statistical analyses age, body fat percentage and muscle mass, as well as the baseline variable corresponding to the dependent variable were included as covariates. The habitual PA levels in the intervention- and control groups are presented in Figure 1. The girls' PA levels were on average low when compared to the boys.

TABLE 1: BASELINE CHARACTERISTICS (MEAN ± SD, OR MEDIAN [INTERQUARTILE RANGE]) OF THE BOYS AND GIRLS OF THE INTERVENTION AND CONTROL GROUPS

Characteristic	Intervention group (n=194)		Control group (n=57)	
	Mean ± SD		Mean ± SD	
	Boys (n=96)	Girls (n=98)	Boys (n=16)	Girls (n=41)
Age (years)	15.8 ± 1.2 ^a	15.5 ± 1.1 ^a	14.7 ± 0.8 ^a	14.8 ± 1.0 ^a
Tanner stage: 1	0	0	0	1 (2.4%)
Tanner stage: 2	10 (10.4%)	7 (7.1%)	0	3 (7.1%)
Tanner stage: 3	17 (17.7%)	36 (36.7%)	7 (43.8%)	19 (45.2%)
Tanner stage: 4	53 (55.2%)	45 (45.9%)	9 (56.2%)	15 (35.7%)
Tanner stage: 5	16 (16.7%)	10 (10.1%)	0	4 (9.4%)
Body fat percentage (%)	18.1 ± 6.0 ^b	29.1 ± 6.2	21.4 ± 9.2 ^b	29.4 ± 7.5
Muscle mass (kg)	40.5 ± 8.2 ^c	34.4 ± 4.4	34.0 ± 5.7 ^c	33.8 ± 6.8
BMI (kg/m ²)	18.9 ± 2.6	20.3 ± 3.0	18.0 ± 1.5	20.7 ± 3.2
Height-for-age z-score	-1.26 ± 0.9	-1.12 ± 0.9	-1.29 ± 1.1	-0.89 ± 1.1
Waist circumference (cm)	66.3 ± 5.5	64.3 ± 5.5	64.0 ± 3.3	64.3 ± 6.0
Fasting plasma glucose (mmol/dL)	5.3 ± 0.6	5.0 ± 0.4	5.0 ± 0.4	4.8 ± 0.4
Systolic blood pressure (mm Hg)	105.8 ± 12.0	105.8 ± 10.8	102.8 ± 7.0	110.8 ± 13.3
Diastolic blood pressure (mm Hg)	72.7 ± 7.5	70.8 ± 6.7	68.7 ± 6.6	68.9 ± 9.3
Total Peripheral Resistance (TPR)	1.52 ± 0.37	1.72 ± 0.3	1.57 ± 0.23	1.39 ± 0.25
Windkessel arterial compliance (C _w)	1.70 ± 0.34	1.39 ± 0.2	1.55 ± 0.16	1.30 ± 0.09
Fasting plasma insulin (μU/ml) (median, 25%, 75%)	6.4 [4.8,10.2]	8.8 [6.3,12.6]	5.1 [4.7,6.6]	8.0 [6.1,12.6]
¹ Homeostasis Model Assessment insulin resistance (HOMA-IR)	1.56 [1.1,2.8]	1.94 [1.3,2.9]	1.64 [1.0,1.4]	1.75 [1.2,2.8]

¹ HOMA-IR = [(fasting insulin (μU/ml)) x (fasting venous glucose (mmol/L))/22.5]

^{a-c} Similar letters indicate significant differences between variables for intervention and control groups, p < 0.05; t-test and Mann-Whitney U-test

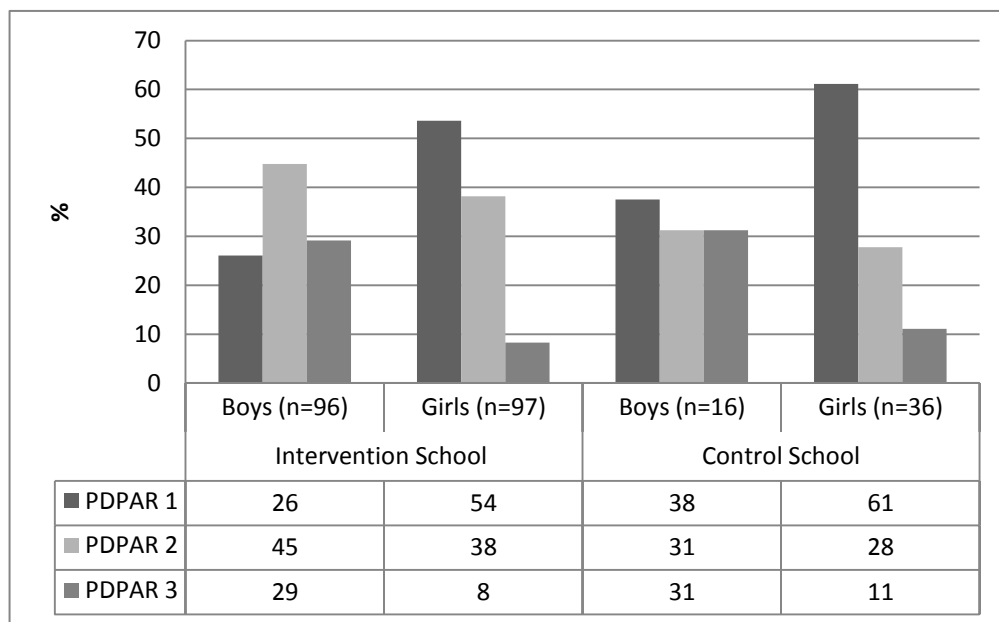


FIGURE 1: HABITUAL PHYSICAL ACTIVITY LEVELS IN THE INTERVENTION AND CONTROL GROUP AT BASELINE AS MEASURED WITH PREVIOUS DAY PHYSICAL ACTIVITY RECALL

Adolescents identified with markers of the metabolic syndrome

Six (two girls, four boys) out of the 156 subjects who consented to blood samples had a fasting blood glucose > 6.1mmol/L. Not one of the six above-mentioned subjects had high blood pressure, although only one had a waist circumference > 95th percentile of the British reference (McCarthy *et al.*, 2001). Both girls had a body fat percentage > 25% and both were inactive (PDPAR = 1). The four boys had a body fat percentage > 20% and were moderately active (PDPAR = 2). All six adolescents had a HOMA-IR reading above 2.8 (75th percentile in the present study).

Ten (six girls, four boys) out of the 214 adolescents measured had a waist circumference above the 95th percentile of the British reference (McCarthy *et al.*, 2001). Only one of the 10 subjects had high blood pressure and one had high fasting plasma glucose. All 10 had a body fat percentage > 25% for girls and > 20% for boys. Six were inactive and four moderately active. Six out of these 10 adolescents consented to blood samples and four had a HOMA-IR reading > 2.8.

Twenty-two (nine girls, 13 boys) out of the 216 measured, had blood pressure > 90th percentile (Jessup & Harrell, 2005). None of the 22 subjects had high fasting glucose, but one had a waist circumference > 95th percentile. Eleven subjects out of the 22 were inactive and

11 moderately active. Eleven had a body fat percentage > 25% (for girls) and > 20% (for boys). Fifteen out of 22 consented to blood samples and three had a HOMA-IR reading > 2.8.

Triacylglycerol and HDL-cholesterol were not determined in this study, therefore only blood pressure larger than the 90th percentile based on US age and sex reference curves (National High Blood Pressure Education Program, 2005), glucose concentrations >6.1 mmol/L and waist circumference > 95th percentile based on British reference curves (McCarthy *et al.*, 2001) were used as markers of the MS. The British reference was used because there is currently no reference curve or cut-off point for waist circumference of South African adolescents. In this study there was no participant that met all three the criteria for the MS, as defined in this study. Only two subjects met two of the three MS criteria (McCarthy *et al.*, 2001).

Compliance with the physical activity intervention

Only 31.4% of the adolescents attended 40% or more of the physical activity sessions. The most important reasons for not attending were household chores and living far from school. Attendance ranged between 0-100 % with only five adolescents attending no sessions and the rest of the group attending some sessions. The low compliance adolescents were not excluded from this study.

Figure 2 presents the percentage change from baseline to end for different variables of the intervention- and control groups after the PA intervention as a percentage change of median variables. In the intervention group there was an increase in the percentage change in C_w (3%), fasting plasma insulin (3%) and SBP (2%). There was also a decrease in the subjects' glucose (-4%), HOMA (-10%) and TPR (-12%). No difference in the subjects' DBP was found. The control group show increases in the percentage change in C_w (2%), fasting plasma glucose (1%), HOMA (6%), SBP (20%), and TPR (10%). There was also a decrease in their fasting plasma insulin (-1%) and DBP (-14%).

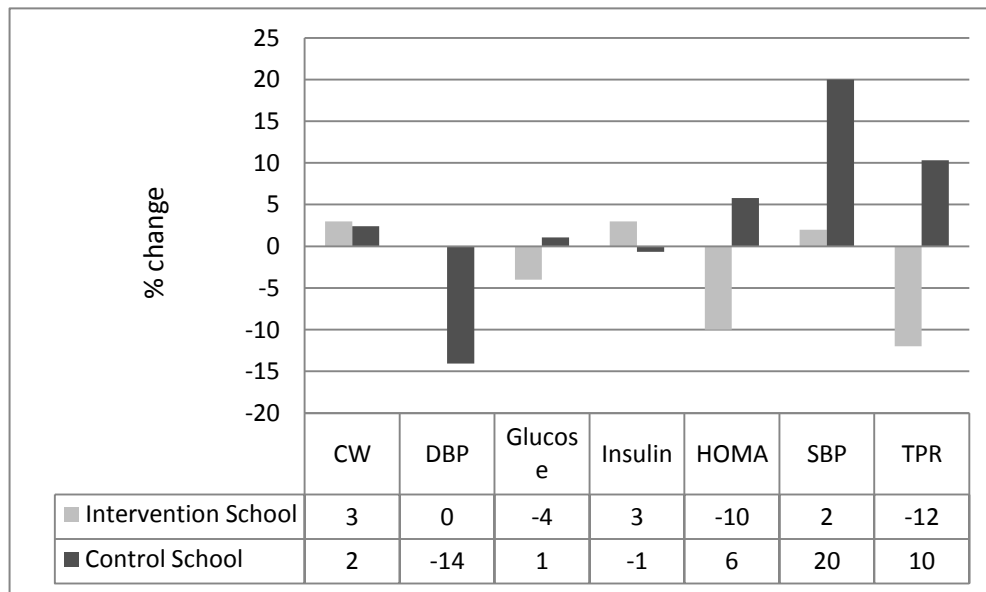


FIGURE 2: UNADJUSTED PERCENTAGE CHANGE FROM BASELINE TO END FOR DIFFERENT VARIABLES IN THE INTERVENTION- AND CONTROL GROUPS AFTER THE PA INTERVENTION (% CHANGE OF MEDIAN VARIABLES)

Changes in metabolic markers after the physical activity intervention

Table 2 gives the least squares means, 95% confidence intervals and level of significance for the difference in metabolic markers between the intervention group and the control group (ANCOVA with adjustment for age, gender, Tanner-stage, habitual PA, body fat percentage, muscle mass and baseline values of the relevant variable). Significant differences were found between diastolic- and systolic blood pressure, respectively of the two groups. Adolescents from the control group had a lower DBP compared to the intervention group and adolescents from the intervention group had a lower SBP compared to adolescents from the control group.

TABLE 2: LEAST SQUARES MEANS, 95% CONFIDENCE INTERVALS AND LEVEL OF SIGNIFICANCE FOR THE DIFFERENCE IN METABOLIC MARKERS BETWEEN THE INTERVENTION GROUP AND THE CONTROL GROUP

Variable	Level of significance	n	Intervention Group	n	Control Group
Model 1*					
Fasting plasma glucose (mmol/dL)	NS	50	4.84 [4.7, 4.9]	11	5.0 [4.7, 5.3]
Homeostasis Model Assessment	NS	48	0.61 [0.43, 0.78]	11	0.74 [0.35, 1.13]
insulin resistance (HOMA-IR)					
Systolic blood pressure (mm Hg)	p=0.00061	59	100 [97, 102]	20	110 [105, 114]
Diastolic blood pressure (mm Hg)	p=0.00005	59	63 [61, 66]	20	52 [48, 57]
Total Peripheral Resistance (TPR)	NS	53	1.54 [1.45, 1.63]	11	1.54 [1.33, 1.75]
Windkessel arterial compliance (C _w)	NS	53	1.51 [1.47, 1.55]	11	1.50 [1.41, 1.59]
Model 2**					
Fasting plasma glucose (mmol/dL)	NS	50	4.81 [4.7, 4.9]	11	5.1 [4.7, 5.5]
Homeostasis Model Assessment	NS	48	0.55 [0.35, 0.75]	11	0.99 [0.41, 1.58]
insulin resistance (HOMA-IR)					
Systolic blood pressure (mm Hg)	p=0.00061	59	100 [96, 103]	20	110 [101, 118]
Diastolic blood pressure (mm Hg)	p=0.00005	59	63 [60, 66]	20	53 [46, 60]
Total Peripheral Resistance (TPR)	NS	53	1.57 [1.47, 1.67]	11	1.39 [1.08, 1.71]
Windkessel arterial compliance (C _w)	NS	53	1.51 [1.46, 1.55])	11	1.49 [1.35, 1.63]

* Ancova with adjustment for gender, tanner-stage, habitual PA, body fat percentage, muscle mass and baseline values of the relevant variable

** Model 1 + percentage attendance in the PA intervention

As noted in Table 2, after an additional adjustment for percentage attendance in the PA intervention (model 2), there were still significant differences between DBP- and SBP of adolescents from the two groups. There was also a trend of a difference between HOMA-IR of the two groups.

DISCUSSION

The purpose of this study was to determine the effects of a 10-week PA intervention on selective markers of the MS in black adolescents. One of the main reasons for conducting a PA intervention was that atherosclerosis has been found in children and young adults and is associated with CVD risk factors such as obesity, abnormal plasma lipoprotein levels, elevated blood pressure, insulin resistance (Day *et al.*, 2009) and diabetes mellitus type 2 due to a lack of PA (Ritenbaugh *et al.*, 2003). The reason for this inactivity can in turn be attributed to a range of factors: urbanisation, lack of interest in PA, technology, unsafe neighbourhoods and schools that cannot afford hosting physical activities (Bar-or *et al.*, 1998; WHO, 1998).

There was a significant difference in PA participation between black and white adolescents in the USA (Kimm *et al.*, 2002), and it became more apparent with an increase in age (Jago *et al.*, 2008). In South Africa, significantly more males (57.1% [95%CI 54.6–59.6]) participated in vigorous- and moderate physical activities than females (34.7% [95% CI 31.7–37.6]), and a decrease in participation was apparent with an increase in age. Significantly more black females than black males were inactive, or showed low PA participation levels (MRC, 2002). The same tendency is seen in this study (figure 1) as the girls from both the intervention and control group's habitual PA levels were on average low when compared to the boys (PDPAR 1: Girls intervention = 54%, Girls control = 61%). On average, the boys were classified as being more moderately- and vigorously active, compared to the girls (figure 1). In this study only 31.4% of the adolescents attended 40% or more of the PA sessions. Despite their low level of PA, none of the study participants presented with all three of the MS markers.

Insulin resistance and consequently fasting plasma insulin of the adolescents from the intervention group did not show a significant improvement after the 10-week PA intervention. As presented in figure 2, the intervention group had a small increase in the percentage change in fasting insulin (3%) but a decrease in HOMA-IR (-10%). Changes in fasting plasma insulin were, however small in both groups. Insulin resistance increases during puberty, as insulin sensitivity is reduced in both non-diabetic and diabetic children, and therefore the body produces more insulin (Jessup & Harrell, 2005). This increased insulin secretion may be caused by an increased amount of circulating growth hormones and changes in body composition (Jessup & Harrell, 2005). African Americans' fasting insulin and acute insulin responses are significantly higher than in white children (Deckelbaum & Williams, 2001; Gower *et al.*, 2001; Cruz *et al.*, 2002), and it can be explained by black adolescents' altered rates of hepatic insulin extraction when compared to white adolescents, which contribute significantly to their peripheral hyperinsulinemia (Schuster *et al.*, 1998).

After the 10-week PA intervention, adolescents from the control group had a significantly lower DBP compared to the intervention group ($p=0.00005$) and adolescents from the intervention group had a significantly lower SBP compared to the control group

($p=0.000061$). The higher DBP encountered in the intervention group is attributed to the higher vascular resistance (TPR) found in the adolescents from the intervention group. Even after an additional adjustment for percentage attendance in the PA intervention, there were still significant differences between DBP- and SBP when the adolescents from the two groups were compared. As presented in figure 2, the intervention group had a small increase in SBP (2%), but no change in DBP. The control group showed an increase in SBP (20%) and a decrease in DBP (-14%). These results can be due to the increase in muscle mass in the intervention group which in turn may possibly elevate resting blood pressure (AAOP 1997). While some studies indicated that decreased blood pressure levels are associated with increased levels of PA (Ewart *et al.*, 1998; McMurray *et al.*, 2002), a study by De Visser *et al.* (1994) indicated a non-significant relationship between blood pressure and PA in adolescents. In a study by Fu and Hao (2002) on Hong Kong adolescents, SBP and DBP were related to sexual maturation, and increased with age. Insulin sensitivity did not improve significantly in this study.

Insulin resistance and hyperinsulinemia alter blood pressure through several mechanisms, including the insulin-mediated effects on the sympathetic nervous system and renal sodium reabsorption (Cruz *et al.*, 2002). In a study by Cruz *et al.* (2002), it was found that insulin resistance was a more important determinant of SBP in children than body fat. Furthermore it was found that black ethnicity and decreased insulin sensitivity were independently related to elevated blood pressure even at an early age.

After the PA intervention, the intervention group had an increase in the percentage change in C_w (3%) and a decrease in TPR (-12%) (figure 2). In a study by Otsuki *et al.* (2007) it was suggested that endurance training in school-age youths decreases arterial stiffness or increase C_w and continued endurance training would maintain this decrease. Because arterial pressure is determined by cardiac output and TPR, reductions in arterial pressure after endurance exercise training must be mediated by decreases in one or both of these variables. Reductions in resting cardiac output do not typically occur after chronic exercise; thus, decreased TPR appears to be the primary mechanism by which resting BP is reduced after exercise training.

LIMITATIONS

This study has several limitations. This study is firstly limited by the relatively small number of participants who consented to blood sampling pre- and post test. This small sample size makes it difficult to detect statistically significant changes with a great deal of accuracy. It is important to note that participants enrolled in this study voluntarily, which could also lead to potential bias. The second limitation was the duration of the study. School terms are, however, relatively short and it is almost impossible to maintain school-based interventions over school holidays. The third limitation was that triacylglycerol and HDL-cholesterol were not measured due to budget constraints. However, this study has provided valuable information for future studies on South African adolescents.

CONCLUSION

The findings of this study suggest that a 10-week PA intervention showed a significant decrease in SBP ($p=0.000061$), trends of decreased HOMA-IR and increased C_w in black adolescents. The implications of the results are that adolescents should be encouraged to increase their PA levels, which may result in significant improvements in selective markers of the MS. The present study is, however, limited by the small subject sample size and the small number of adolescents who gave consent for blood sampling after the intervention.

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