Associations between objectively measured physical activity and metabolic syndrome in African-origin adults from five countries

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Associations between objectively measured physical activity and metabolic syndrome in African-origin adults from five countries

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29 Abstract

30 Metabolic syndrome affects approximately 25% of adults worldwide. Physical inactivity has been
31 identified as a key modifiable risk factor for metabolic syndrome, but studies are conflicting when using
32 different methods to measure physical activity (PA), including both objective measures versus self-report.
33 Furthermore, there is a lack of studies exploring these relationships in African-origin populations, who
34 present with a higher prevalence compared to other race/ethic groups. The aim of this study was to
35 explore the association between objectively-measured PA and metabolic syndrome in 5 African-origin
36 populations spanning the epidemiologic transition.

37 2506 adults from Ghana, South Africa, Jamaica, Seychelles and the United States were recruited
38 between 2010-2011 in the Modeling the Epidemiologic Transition Study (METS). Data collection,
39 included clinical and laboratory measures, anthropometrics, and 7-days of accelerometer-measured
40 moderate-to-vigorous PA (MVPA), observed in mean minutes per day. Study procedures were identical
41 in the 5 sites. Metabolic syndrome was defined as having any three of the following five risk factors: large
42 waist circumference, elevated triglycerides, low high-density lipoprotein cholesterol, high blood pressure
43 and elevated fasting glucose. The prevalence of metabolic syndrome and its constituent risk factors was
44 stratified by sex and site. Logistic regression analysis was used to explore the association between MVPA
45 and metabolic syndrome in the pooled cohort, adjusting for lifestyle factors (alcohol use, smoking status
46 and sleep duration), age, sex, BMI and body fat percentage.

47 Of 1167 male participants (median age 35, IQR: 30-40 years) and 1339 female participants (median age
48 35, IQR: 29-40), males had a lower BMI (23.6 kg/m^2, IQR: 20.9-27.5) compared to females (26 kg/m^2,
49 IQR: 22-31). Across all sites, the prevalence of metabolic syndrome was 17% (n=431), and higher among
50 females (n=287, 11%) compared to males (n=144, 6%). After adjusting for covariates, MVPA was not
51 associated with metabolic syndrome (aOR 1.00, 0.99-1.00), nor meeting the PA guidelines of ≥30
52 mins/day (aOR = 0.76, 0.57-1.01). Our results suggest that other environmental lifestyle factors may play
53 a more significant role in the development of metabolic syndrome in this population of African-origin
54 adults. Future research should focus on understanding the relationship between other environmental
55 lifestyle factors, including sleep, and dietary intake, and metabolic syndrome.

Introduction

Metabolic syndrome is a significant public health challenge affecting approximately 25% of adults worldwide, and is associated with an increased risk of all-cause mortality and cardiovascular events, such as heart attack and stroke [1]. As defined by the World Health Organization (WHO), metabolic syndrome is a pathologic condition identifiable by insulin resistance, abdominal obesity, hypertension and hyperlipidaemia [2]. Individuals with metabolic syndrome experience a two to three fold higher risk of developing type 2 diabetes (T2D) and a one and a half to two fold higher risk of developing cardiovascular disease (CVD) [3, 4]. It is also associated with non-alcoholic fatty liver disease, polycystic ovary syndrome, and certain types of cancer [5-7]. As a clustering of risk factors for these noncommunicable diseases (NCDs), which cause substantial morbidity, mortality, and healthcare costs [8], metabolic syndrome is a significant burden on healthcare systems worldwide. The mean annual healthcare cost per person with metabolic syndrome is approximately $2 000 USD higher than for those without the condition [9].

Given this substantial economic burden associated with metabolic syndrome and the increasing prevalence worldwide, prevention strategies that target lifestyle-related risk factors are essential. The majority of the risk factors for metabolic syndrome are related to lifestyle factors, including physical inactivity, unhealthy dietary habits, and smoking [10]. Physical inactivity has been found to be a key modifiable risk factor for metabolic syndrome and its related diseases [11]. On the other-hand participating in regular physical activity (PA) has been found to improve insulin sensitivity, glucose metabolism, blood pressure, and lipid profiles, all of which are critical components of metabolic syndrome [11]. Participating in regular PA has also been found to be an inexpensive modifiable behavioural intervention related to the reduced risk of CVD and T2D [12, 13]. To a limited extent, mechanisms involved in metabolic syndrome are favorably influenced by interventions relating to PA. It is important to understand that PA interventions which result in improved fitness, are not likely to control and stabilize insulin resistance, lipid disorders or obesity. Instead, improved fitness enhances the health outcome related to metabolic syndrome by reducing the severity of the contributing risk factors such as reduced weight, reduced blood pressure, improve lipid imbalances by increasing HDL and reducing triglycerides [14-16]. However, these findings focus on long-term intervention-based exercise programs and not PA in a daily living-environment [14-16]. For example, both Wewege, Thom [17] and Ostman, Smart [18] concluded that exercise training intervention programs, which range from four weeks to a year in duration, significantly improved characterizing factors of metabolic syndrome, specifically, waist circumference, fasting glucose HDL cholesterol triglycerides and blood pressure [17, 18]. The present study will address this gap by exploring the effect PA, specifically moderate-to-vigorous physical activity (MVPA), on metabolic syndrome with PA measures based on individuals' activity in a day-to-day living-environment.

Some studies have found self-reported MVPA as a potential behavioural characteristic associated with metabolic risk reduction among individuals who meet the recommended PA guidelines (≥150 min of moderate or ≥75 min of vigorous PA weekly) [19-22]. However, a large disparity exists between self-reported and objectively measured PA, where self-reported measures are often over-estimated and relatively inaccurate [23]. This is due to the tendency of social desirability and the difficulties in correctly interpreting PA terms such as "moderate-intensity" [24]. A methodological study conducted an extensive review of validity, reliability and responsiveness to change was done using self-reported PA measures against objective accelerometer-captured PA [25]. Accelerometers were found to have lower variability of PA measurements compared to self-reported PA. Test-retest reliability of self-reported PA measurements decreased as the duration of recollection increased, with objective measures were found to have moderate to strong test-retest reliability levels. The study noted that in living environments, longer

101 observational periods are required for relatively reliable self-report PA measures, whereas three days are
102 recommended for a reliable objective PA measure of total PA using accelerometers [25]. The present
103 study will be able to fill this research gap as the primary data source of PA in a living environment was
104 collected by use of accelerometers observed for more than three days [26]. Notably, the outcomes of this
105 study may have important public health implications, including contributing to interventions that can
106 improve the health outcomes of individuals with metabolic syndrome by including PA to treatment
107 regimens.

108 Almost 80% of premature NCDs are in low-to-middle income countries (LMICs) [27]. Notably, the World
109 Health Organization recognizes that individuals from LMICs have a higher risk for NCDs, driven by
110 various factors, including a significant contribution from metabolic risk factors for premature death [27].
111 The present study explores five diverse African-origin populations spanning the epidemiologic transition,
112 including three LMICs: Ghana, South Africa (SA) and Jamaica.

113 Key risk factors for metabolic syndrome, including CVD and T2D have shown a notable increase over
114 the subsequent decade, spanning from 2009 to 2019 [28]. According to the Global Burden of Disease,
115 the study's five African-origin populations have experienced a 12% (with a range of 11-15%) increase in
116 CVD and a substantial 25% (with a range of 24-36%) increase in T2D [28] (Fig 1, Supplementary files).
117 However, a significant gap exists in research, with the majority of studies exploring the associations
118 between MVPA and metabolic syndrome in populations of European descent. This study fills a critical
119 gap by focusing on five distinct adult African-origin populations: Ghana, SA, Jamaica, Seychelles and
120 United States (US). This descriptive aspect of the prevalence of metabolic syndrome provides insight into
121 the health state of these populations. This study provides crucial insights into the factors that contribute
122 to the development of metabolic syndrome among African-origin adults and the role of the PA in its
123 prevention and management, pertaining to a physiologically beneficial and cost-effective intervention as
124 PA is a modifiable behaviour characteristic. The study has the potential to inform future interventions
125 aimed at reducing the burden of this condition on both individuals and the health care system.

126 The aim of the current study, was therefore to explore the relationship between PA and metabolic
127 syndrome in a diverse African-origin population, through the following objectives: (i) to describe the
128 prevalence of metabolic syndrome in the five diverse African-origin adult population in Ghana, SA,
129 Jamaica, Seychelles and the US; (ii) to explore the association between MVPA and metabolic syndrome
130 in the same five populations adjusting for lifestyle factors including sleep, alcohol use, and smoking.

131 Methods

132 Study design

133 This study is a secondary data analysis of the Modeling the Epidemiologic Transition Study (METS), an
134 established prospective cohort study aimed at assessing the association between cardiometabolic
135 disease risk, body composition, and PA [26]. The baseline enrollment of the METS occurred between
136 January 2010 and September 2011.

137 Characteristics of study populations

138 The study participants were 2500 adults of African descent aged 25 – 45, with 500 individuals from each
139 of the following regions: rural Kumasi in Ghana, peri-urban Cape Town in SA, island nation Mahé in
140 Seychelles, urban Kingston in Jamaica and suburban Maywood in the US. Excluded from the study were
141 individuals presenting with infectious diseases including HIV, pregnant or lactating women, and
142 individuals presenting with any condition which prevents them from engaging in normal PA tasks, such

143 as extremity disabilities. One study site was located in each of the above-mentioned regions [26]. Sample
144 size calculations were done for the primary data source, and not redone for this secondary data analysis.
145 The required sample size to detect minimum differences between PA and body compositional measures
146 with a 90% statistical power was 460 participants per group [26].

147 Recruitment and enrollment

148 The METS data was obtained using population-based samples appropriate to each country. In Ghana, a
149 simple random sample was done using a population census of those within the appropriate age range.
150 Sex and age stratified random samples were taken from national censuses in both the SA and Seychelles
151 regions. In the Jamaica and US regions, door-to-door recruitment was done in randomly sampled districts
152 [26].

153 Research procedures and data collection methods

154 At data collection appointments, participants completed 17 standardized study procedures at each study
155 site, located within outpatient departments. All study staff were trained at Loyola University in Chicago.
156 The study procedures have previously been described in full [26].

157 Physical activity

158 For the assessment of PA, participants wore an Actical accelerometer (Phillips Respironics, Bend, OR,
159 US) around their waist all day for eight days; including during sleep and with the exception of during
160 water-related activities, such as showering or swimming. Raw activity data captured between 7am and
161 11am was processed using a method developed by the National Cancer Institute in 2014 [29]. The
162 process identified periods when the device was not being worn based on prolonged periods of zero
163 activity counts. A day of PA monitoring was considered valid if the device was worn for at least 10 hours.
164 Participant data were included if they had at least four valid days of monitoring. This resulted in a total of
165 six complete days, after accounting for the two partial days. This accelerometer was able to capture
166 intensity, duration and frequency of PA through the omnidirectional motion sensors. Activity is captured
167 as epoch minutes used as a subunit of time and provides a good level of reliability (0.8-0.92%) based on
168 preliminary tests [26]. The accelerometer yielded the following measures of PA in mean minutes of a
169 minimum of 1-minute bouts: MVPA, moderate activity, vigorous activity, sedentary activity, light sedentary
170 activity, and total intensity counts from all wear in mean minutes per day. The MVPA per day was further
171 categorized by whether individuals met the PA guidelines to provide insight on the effect of the
172 established guidelines recommendation and metabolic syndrome. Individuals were considered to have
173 met the PA guidelines if they had a mean of least 30 minutes of MVPA per day, in bouts lasting at least
174 one minute each [30].

175 Anthropometric and body composition measurements

176 At all sites for all participants, height was measured using a stadiometer, weight was captured using a
177 calibrated balance and waist circumference taken using a flexible tape measure around the maximum
178 buttock point. All participants also underwent a bioelectrical impedance analysis (BIA) to assess their
179 body composition by assessing the resistance encountered by body tissues when subjected to a low-
180 level alternating electric current. From this, estimates on total body water, fat-free mass and fat mass are
181 181 derived.

182 Blood pressure

183 Participant blood pressure was measured in triplicate at the antecubital fossa at heart level using the
184 Omron Automatic Digital Blood Pressure Monitor, as per previously defined training procedures [31-35].

185

186 Biochemical measures

187 Participants were required to fast for one evening prior to blood samples taken for the assessment of
188 plasma glucose, triglycerides and cholesterol levels. Within two hours of collection, blood plasma or
189 serum samples were separated and stored at -80°C in the laboratory at each site. Glucose oxidase
190 method was used to measure fasting plasma glucose levels at collection. Assays for the measurement
191 of triglycerides and cholesterol was conducted at the Zentrum für Lambormedizin, Leiter Klinische
192 Chemie und Hämatologie, St. Gallen, Switzerland [26].

193 Medical history, socio-demographics, and health questionnaires

194 All participants were required to complete a survey in which information on smoking status, alcohol use
195 and health history was collected [26]. Participants were classified as non-smokers (including ex-smokers
196 of more than one month or those who have never smoked before) and regular/occasional smokers
197 (currently smoking ≥1 cigarette per day or currently smoking ≥1 cigarette per week). Volume and
198 frequency of alcohol use was captured. Heavy alcohol use is categorized as eight or more drinks per
199 week for women and fifteen or more drinks per week for men, as defined by the CDC [36]. The continuous
200 number of hours of self-reported sleep per night were grouped into three categorized; short (< 7 hours),
201 normal (7 – 9 hours) and long (> 9 hours) [37]. A BMI of ≥30 was classified as obese, according to the
202 CDC [38].

203 Definition of metabolic syndrome

204 Metabolic syndrome is the accumulation of disorders or risk factors which together increase the risk of
205 developing CVD and T2D [39]. The criteria for clinical diagnosis for metabolic syndrome include a
206 diagnosis of any three of the following five risk factors. These include: (i) a large waist circumference
207 indicative of abdominal obesity with cutoff points of ≥ 94 centimeters (cm) for men and ≥ 80 cm for
208 women in populations of Sub-Saharan origins, and higher thresholds of ≥ 102 cm for men and ≥ 88 cm
209 for women in Jamaican and US-based populations [40]; (ii) elevated levels of triglycerides with a cutoff
210 point of ≥ 150 milligrams per deciliter (mg/dL) [40]; (iii) low levels of high-density lipoprotein cholesterol
211 (HDL-C) with a cutoff point of < 40 mg/dL [40]. Current drug treatment for reduced HDL-C is an alternative
212 measure [40]; (iv) high blood pressure with cutoff points of ≥ 130 Hg systolic and/or ≥ 85 Hg diastolic.
213 Current treatment for hypertension is an alternative measure [40]; (v) elevated fasting glucose levels with
214 a cutoff point of ≥ 100 mg/dL. Alternatively, drug treatment for high glucose is an indicator [40]. Common
215 drug treatment for elevated triglycerides and low levels of HDL-C are fibrates and nicotinic acid. The use
216 of either of these drugs by a patient can be classified as to have elevated triglycerides and reduced HDL-
217 C [40].

218 Data analysis

219 Data processing and analysis was conducted using the open-sourced software RStudio, version 4.3.1.
220 Descriptive characteristics were presented for each site stratified by males and females, including age,
221 BMI, lifestyle factors (smoking status, alcohol use and sleep), body composition (waist circumference,
222 fat-free mass, fat mass, body fat percentage), biochemical measures (HDL-C and triglycerides), and PA
223 measures (MVPA, PA guidelines met, moderate PA, vigorous PA, sedentary PA and light sedentary PA).

224 The prevalence of metabolic syndrome, as well as the prevalence of the constituent risk factors of
225 metabolic syndrome, were calculated and presented per site, stratified by males and females. A Fisher's
226 exact test was used to identify any significant difference between the prevalence of these risk factors and
227 metabolic syndrome between males and females at each site.

228 Multivariable logistic regression was used to assess the association between PA and metabolic
229 syndrome. PA was included as a continuous variable in Model 1 (MVPA, mean minutes per day), and as
230 a categorical variable in Model 2 (meeting PA guidelines of ≥ 30 minutes MVPA per day, or not).
231 Additional lifestyle factors considered in the model for adjustment include alcohol use, smoking status
232 and sleep, and the model was additionally adjusted for age, sex, body mass index (BMI), body fat
233 percentage and study site. Two different selection methods were used to identify which variables to adjust
234 for: i) an *a priori* determined model including available variables considered relevant, based on existing
235 evidence, and ii) logistic least absolute shrinkage and selection operator (LASSO) [41], to confirm the fit
236 of the *a priori* selected model.

237 A priori adjustment for pool site analysis

238 We used a directed acyclic graph (DAG) to describe the paths between metabolic syndrome and PA and
239 relevant confounding variables (Fig 2, Supplementary files). Age, sex, site, BMI, body fat percentage,
240 and additional lifestyle factors (smoking, alcohol use and sleep) were the variables included in the DAG,
241 to be adjusted for in the multivariable logistic regression models.

242 LASSO adjustment for pool site analysis

243 The regularization technique LASSO was applied over the logistic regression to account for the expected
244 multicollinearity of the independent variables. Regularization assists to prevent overfitting of the data by
245 adding a "penalty" component to the optimal model obtained from the trained data, with the goal of
246 reducing the variability in the predicted outcomes when tested on new data [42]. LASSO makes use of
247 the minimum cross-validated error (presents the most parsimonious model with the best predictive
248 performance) and the one standard error rule (the largest lambda within one standard error of the
249 minimum cross-validated error) [42]. Since this method does not take biological plausibility into account,
250 the resulting model from the LASSO adjustment was compared against the model with *a priori* selected
251 variables.

252 Using the minimum cross-validated error to achieve the most parsimonious model with best predictive
253 performance, the following variables were selected; site, age, sex, BMI, body fat percentage, smoking,
254 alcohol use and sleep. Whereas by using the one standard error rule, which provides a more conservative
255 choice of lambda to sacrifice a small amount of predictive performance to produce a simpler model, only
256 the following variables were selected; site, age, BMI and body fat percentage.

257 The variables selected by use of LASSO minimum cross-validated error are the same as the *a priori*
258 variables as presented in the DAG in Fig 2, thus, this LASSO adjustment supports the selection of the
259 initially selected *a priori* variables. Furthermore, based on the biological complexity of metabolic
260 syndrome, the minimum-cross validated error variables were chosen over the variables which were
261 selected using the one standard error rule from the LASSO adjustment. The adjusted variables selected
262 are the same in both Model 1 and 2.

263 Ethical considerations

264 The data from the primary information source was collected once ethical clearance approved by the
265 Institutional Review Board or Ethics Committee of all participating institutions. No participants were dealt

with in the present secondary data analysis study, only the data obtained from the primary study. Therefore, no further involvement was required from the participants for the present study. Informed consent was initially obtained from all 2506 participants for their data collected during the primary study (which is included in the appendices). Therefore, no further consent from participants were required for the present study [26]. Observations and information for each participant is stored according to their participant identifying number. Therefore, all participants remain anonymous in the present study.

Results

A total of 2506 participants (1339, 53% males and 1167, 47% females) with complete data available were included in this analysis. The median age between all five sites is similar among males (35, 30-40 years) and females (35, 29-40 years). US participants had the largest proportion of regular/occasional smokers (230, 46%), followed by SA participants (172, 34%). SA participants also had the largest proportion of individuals reporting long (> 9 hours) sleep hours (369, 73%) with US participants having the highest frequency of individuals reporting short (< 7 hours) sleep hours (218, 44%). SA participants also reported the heaviest alcohol use (84, 17%), while the remaining four populations only reported between three to five percent. Of the males, 42% (n = 489) were regular or occasional smokers, while only 12% (n = 158) of females were regular or occasional smokers. Across all sites, 9% (n = 104) of males were heavy alcohol drinkers and 4% (n = 53) of females were heavy alcohol drinkers. The highest prevalence of obesity was found in the US participants (263, 52%) along with the highest median body fat percentage (39, 29-46). SA participants had the second highest obesity prevalence in the cohort (162, 32%). Men had a lower median BMI (24, 21-28) compared to females (26, 22-31). Table 1.1 and 1.2 (Supplementary file) presents the population characteristics per site, among males and females, respectively.

The objectively measured PA across all five sites captured from 8 days of monitoring, for males and females respectively are presented in Table 2.1 and 2.2 (Supplementary file). Across five sites, males had a higher mean duration of MVPA minutes per day (34, 17-56) compared to females (18, 8-30). South African men had the highest duration of MVPA (48, 31-76), while, among women, Ghanaian women had the highest duration of MVPA per day (22, 14-34). US males and females had the lowest amount of MVPA per day, (21, 10-43) and (9, 4-19), compared to males and females from the other sites, respectively.

Prevalence of metabolic syndrome

The prevalence of metabolic syndrome is outlined for each site in Table 3 (Supplementary file). Overall, the prevalence of metabolic syndrome was 17% (n = 431). The prevalence of the component risk factors of metabolic syndrome across all five sites was 47% for large waist circumference (n = 1166), 41% for low HDL (n = 893), 29% for hypertension (n =734), 24% for diabetes (n = 604) and 9% for elevated triglycerides (n = 214). Participants from the US had the highest prevalence of metabolic syndrome (n = 149, 30%), followed by Seychellois (n = 108, 24%), South Africans (n = 83, 17%), Jamaicans (n = 64, 14%) and, lastly, Ghanaians (n = 27, 5%).

The prevalence of metabolic syndrome is presented in Table 4 (Supplementary file). In four of the five sites (Ghana, SA, Jamaica, US), females had statistically significantly higher prevalence of metabolic syndrome compared to males. Large waist circumference and low HDL had a statistically significantly higher prevalence in females compared to males, in all five sites. However, males had statistically higher prevalence of elevated triglycerides in three of the five sites; Ghanaians, South Africans and Seychellois. Hypertension was significantly more prevalent in males compared to females in the Ghana, SA, Seychelles and US cohorts, whereas the opposite was found in Jamaican participants. Males also had a

significantly higher prevalence of diabetes compared to females in the Jamaica, Seychelles and US cohorts.

Table 5 (Supplementary file) summarises the lifestyle characteristics of each site by the presence of metabolic syndrome. One of the risk factors associated with metabolic syndrome is increased age, which was statically significant in all five populations, with increased risk among individuals above the age of 35 years old in South Africans, Seychellois and US participants. A statistically significant increased risk among individuals who are regular or occasional smokers are seen in South Africans and Jamaicans. Even though sleep was identified in prior research as being associated with metabolic syndrome, it was not associated with metabolic syndrome in any of the sites. On the other hand, a prominent statistically significant risk factor consistent in all five sites was increased BMI, specifically in those who were considered obese with a BMI ≥ 30 kg/m^2. Similarly, increased fat mass and increased body fat percentage were both statistically significant risk factors of metabolic syndrome across all five sites.

Association between physical activity and metabolic syndrome

The multivariable regression models of the association between PA and metabolic syndrome, adjusting for the *a priori* determined variables, are presented in Table 6 (Supplementary file). MVPA (as a continuous variable) was not associated with metabolic syndrome after controlling for additional demographic and lifestyle characteristics (aOR = 1.00, 0.99-1.00). Age was shown to be positively associated with metabolic syndrome (aOR = 1.08, 1.05-1.10). BMI and body fat percentage were also associated with metabolic syndrome (aOR = 1.05, 1.02-1.08 and aOR = 1.11, 1.07-1.15, respectively). Males were found to have 66% reduced odds of metabolic syndrome compared to females (aOR = 0.34, 0.21-0.55) in this pooled analysis. Individuals with longer sleep duration (> 9 hours) had 1.61 times increases odds of metabolic syndrome compared to those with normal sleep duration (aOR = 1.61, 1.04-2.49). The prevalence of metabolic syndrome was the highest among US participants, however, after adjusting for lifestyle factors, individuals from Seychelles had 1.52 times increased odds of metabolic syndrome compared to those from US (aOR = 1.52, 1.05-2.20). Individuals from Ghana, SA and Jamaica had reduced odds of metabolic syndrome compared to those from US (aOR = 0.63, 0.36-1.06 ; aOR = 0.65, 0.40-1.07 ; aOR = 0.85, 0.57-1.26 respectively), however, not statistically significant.

In the model using the PA guideline as a categorical variable (≥ 30 minutes of MVPA per day vs <30 minutes MVPA per day), the odds of having metabolic syndrome was 24% lower in participants meeting the PA guidelines compared to those who do not meet the guideline however this association is not statistically significant (aOR = 0.76, 0.57-1.01) (Table 6, Model 2). Apart from the different exposure measures of MVPA in Model 1 and 2, the aOR associations of the remaining covariates in both models were nearly identical.

Discussion

This study aimed to explore the prevalence of metabolic syndrome in 5 African-origin populations, and evaluate its association with PA. Overall, the prevalence of metabolic syndrome was 18%, with large waist circumference being the most prevalent risk factor, particularly among women. This finding aligns with the global prevalence of metabolic syndrome, which ranges from 12.5% to 31.4%. In low- and middle-income countries (LMICs), the prevalence is reported as 26.2%, with a range of 22.6% to 30.1%, according to a global study that analysed data from 28 million individuals to quantify the geographic distribution of metabolic syndrome [43]. The main finding of the study is that PA, specifically MVPA, was not significantly associated with metabolic syndrome, once other lifestyle and basic demographic characteristics were adjusted for.

352 The lack of an association between metabolic syndrome and PA is notable, as found in previous studies
353 [14-16, 19, 20]. A comparison of MVPA when measured by self-reported questions from the National
354 Health and Nutrition Examination Survey and accelerometery was done on a US sample of adults aged
355 20 years and older. The study examined multiple models where different combinations of lifestyle and
356 basic demographic factors were adjusted for. Among both males and females, accelerometery-measured
357 MVPA was not associated with metabolic syndrome in models adjusted for factors including age, smoking
358 and BMI. While self-reported MVPA was only significantly associated with metabolic syndrome among
359 females and not males, also in models adjusted for the same factors. Additionally, characterising risk
360 factors of metabolic syndrome, namely: fasting glucose levels and triglycerides levels among males;
361 fasting glucose and HDL cholesterol among females, were not associated with accelerometery-measured
362 MVPA either [21]. The Generation 100 study based on a Norwegian population explored the association
363 between PA and metabolic syndrome by using accelerometers to quantify numerous objective PA
364 measures, one of which was MVPA [20]. The accelerometer captured both absolute and relative intensity.
365 Absolute intensity was calculated using work energy expenditure, while relative intensity is relative to the
366 individual cardiorespiratory fitness (CRF). The study concluded that a higher proportion of individuals
367 achieved the recommended PA guidelines when MVPA is assessed with relative intensity compared to
368 absolute intensity. Notably, the study found no association between metabolic syndrome and absolute
369 MVPA in various models adjusted for different combinations of lifestyles factors including age, smoking,
370 alcohol consumption and history of CVD and CRF [20]. A cross-sectional study in a Canary Island
371 population quantified MVPA using a 79-item self-reported questionnaire to examine the contribution to
372 metabolic syndrome. The study found that increasing intensity of MVPA was associated with a gradual
373 reduction in the odds of metabolic syndrome, however, the recommended PA guideline levels were not
374 associated with the prevalence of metabolic syndrome [19].

375 Much of the existing evidence is based on participants of European ancestry, whereas the population of
376 the present study is of African origin. Similar to our findings, a 2017 longitudinal study assessing the
377 incidence of obesity and metabolic syndrome in an urban-dwelling population of black African-origin
378 women in SA found an increase in obesity from 2002/2003 to 2012/2013, despite most women being
379 adequately active (≥ 150 minutes of MVPA per week as per guidelines). The increase in obesity was
380 linked to levels of adiposity (adiponectin) and its interaction with cardiometabolic diseases [44, 45]. In
381 2016, another longitudinal African-origin based study exploring PA, body composition, and metabolic risk,
382 the Physical Activity and Health Study (PAHLS), reported that there was no significant relationship
383 observed between PA measures (including MVPA) and markers of metabolic syndrome [46]. These
384 findings suggest that other environmental and lifestyle factors, or unexplored prior health conditions (such
385 as heart attack, heart disease, stroke, cancer, osteopathological disorders or renal disorders) may play
386 a more prominent role in the risk of metabolic syndrome than PA in this population.

387 Our results suggest that urbanisation may be one such factor. We found that the prevalence of metabolic
388 syndrome tended to increase with increased country transition, represented in this study by the study
389 site's national United Nations Human Development Index (HDI) ratings [47]. For instance, the highest
390 prevalence of metabolic syndrome (30%) was found in urban US (very high HDI) [48], whereas the lowest
391 prevalence (5%) was seen in rural Ghana, which has a low-middle socio-economic development.
392 Urbanization is characterized by energy-dense, low-nutrient diets, increased energy intake, increased
393 sedentary behaviour, and a rise in obesity, and may be a driver of the high prevalence of metabolic
394 syndrome in this study. This finding is in agreement with a 2020 meta-analysis by Jaspers Faijer-
395 Westerink, Kengne [49], which found that the prevalence of metabolic syndrome was higher in semi-
396 urban and urban areas compared to rural areas [49]. With Ghana and the US on either end of the ongoing
397 epidemiologic transition, these findings indicate the need for urgent attempts to manage the detrimental

398 health effects of trends such as urbanisation and the nutrition transition [49, 50]. Nutrition and dietary
399 patterns, such as the consumption of processed foods, sugar and access to fresh produce, are known to
400 influence risk factors of metabolic syndrome, specifically large waist circumference and elevated fasting
401 glucose [51].

402 The prevalence of metabolic syndrome was higher among females compared to males across all five
403 sites. This is in agreement with multiple recent systematic reviews conducted in 2020 and 2023 across
404 diverse sub-Saharan and African populations [49, 50, 52]. In the current study, large waist circumference,
405 a marker for central obesity, seemed to be the main risk factor contributing to the higher prevalence of
406 metabolic syndrome among women, with a prevalence ranging from 59% among Jamaicans to as high
407 as 85% among South Africans. One reason is the sex differences related to the accumulation of visceral
408 fat and the distribution of fat tissues in the abdominal region [53]. The low HDL observed in women
409 compared to men may also have contributed to the high prevalence of metabolic syndrome in women
410 [35]. This signals a need for resources and interventions aimed at improving the metabolic health of
411 women of African origin.

412 One lifestyle factor found to be positively associated with metabolic syndrome in this study was smoking.
413 This finding is consistent with broader literature which has documented adverse metabolic effects of
414 smoking in adults [54-56]. Smoking is known to increase insulin resistance, cause unfavorable changes
415 in blood lipids, and exacerbate abdominal obesity, all of which are components of metabolic syndrome.
416 The biological mechanisms behind these effects include the promotion of inflammatory processes,
417 oxidative stress, and alterations in adipokine levels, which collectively contribute to the development of
418 metabolic abnormalities [56, 57]. Individuals who smoke cigarettes have an increased likelihood of
419 developing metabolic syndrome due to both the direct and indirect impacts smoking has on the criteria
420 used to characterize metabolic syndrome. Although there is evidence indicating that cigarette smoking
421 adversely influences factors such as obesity, blood pressure, glucose levels, and blood lipids [56, 57],
422 further studies are necessary to explore the mechanisms behind these changes [57]. According to the
423 WHO, smoking, specifically tobacco, is one of the most prominent public health epidemics resulting in
424 over 8 million global death per year with approximately 80% of the worlds tobacco smokers live in low to
425 middle income countries where the burden of tobacco-related illnesses and death is the highest, with a
426 greater prevalence among males compared to females [58]. Since e-cigarettes contain nicotine and other
427 toxic chemicals, there are still considered as harmful, determining the conclusive long-term effects of e-
428 cigarettes usage and exposure remains uncertain [58]. Our findings accentuate the urgency of sustained
429 initiatives aimed at reducing smoking rates and exploring the long-term effects of e-cigarettes as to
430 indirectly reduce the prevalence of metabolic syndrome.

431 Long sleep duration was another lifestyle factor found to increase the risk of metabolic syndrome. This
432 association is somewhat more complex, as both short and long sleep durations have been linked with
433 adverse metabolic outcomes in previous research [59, 60]. The relationship between sleep duration and
434 CVD risk factors, including obesity, insulin resistance, T2D, and overall CVD is supported by multiple
435 studies [59, 61, 62]. Lower socioeconomic status has been linked to overall shortened sleep durations
436 and impaired sleep quality, while higher levels of education and income were associated with improved
437 sleep quality, efficiency and duration [63].

438 No association was found between heavy alcohol use and metabolic syndrome, which aligns with some
439 studies which have found no association between amount of alcohol consumption or number of years of
440 alcohol consumption and metabolic syndrome [64, 65]. However, alcohol use has previously been found
441 to be associated with components of metabolic syndrome such as arterial hypertension, dyslipidemia and
442 T2D and obesity [66, 67]. Due to the disparity and differing results, further research is necessary to

443 explore the mechanisms of alcohol consumption using longitudinal designs and precise biomarkers for
444 alcohol use [67].

445 **Limitations of the study and future research**

446 The use of cross-sectional data posed a limitation to the present study as causal inferences cannot be
447 easily made. Temporal changes associated with PA, diet changes or reduced abdominal obesity over
448 time may have a different association to metabolic syndrome. In addition, dietary patterns are found to
449 be an important lifestyle factor [51, 68] in the association with metabolic syndrome, which was not
450 accounted for in the present study. This may be of particular interest since the five sites are likely to have
451 very different dietary patterns due to cultural factors, socioeconomic development, and being rural vs
452 urban. Within METS, these factors are being explored in ongoing longitudinal and cross-sectional
453 analyses.

454 ## Conclusion

455 This study demonstrates the urgency of conducting further research to explain the underlying
456 mechanisms of metabolic syndrome, as objective accelerometery-measured PA was not found to be an
457 independent associated risk factor for metabolic syndrome. Our results indicate that in this particular
458 population, PA may not be as influential in the development of metabolic syndrome as other lifestyle
459 factors, such as smoking, sleep patterns, diet, socioeconomic environment and prior health conditions.
460 These lifestyle and biological factors need to be explored alongside PA to provide insight to effective
461 interventions. A deeper understanding will allow for the development of tailored interventions to alleviate
462 the widespread burden of metabolic syndrome. This will not only reduce the burden of disease on the
463 population but on health care system as well. Future studies should consider a longitudinal study design
464 which is able to incorporate objective measures of PA in living environments, diet, medial conditions and
465 biomarkers for T2D and CVD.

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468 originates from.

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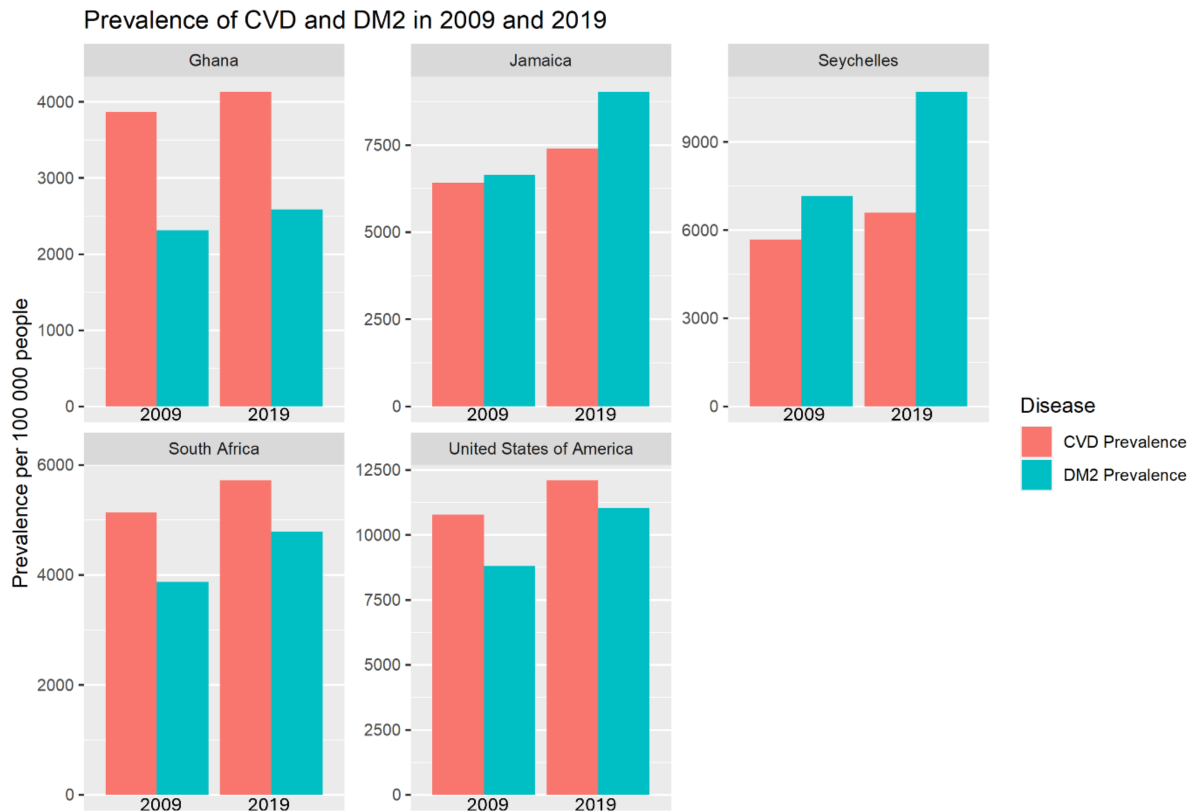

Figure 1. Prevalence of metabolic syndrome indicators (cardiovascular disease, CVD, and diabetes mellitus type 2, DM2) across five diverse populations with African descent, both sexes and all ages, 2009 and 2019.

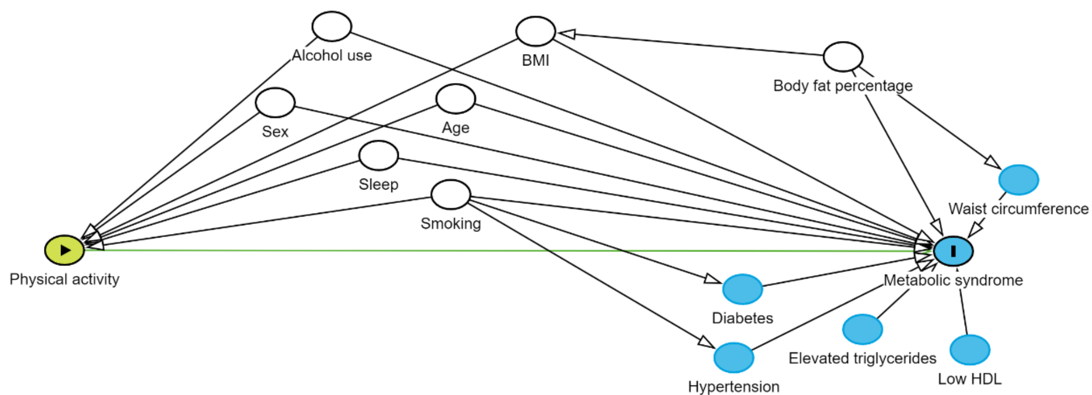

Figure 2. Directed acyclic diagram of exposure-outcome relationship showing the adjustment of additional lifestyle factors; smoking, alcohol use and sleep. Physical activity is the main exposure on the outcome of metabolic syndrome. Potential biological and lifestyle confounding factors are controlled for, represented in white icons. No adjusted is required for characterizing risk factors of metabolic syndrome represented with blue icons.

Table 1.1. Lifestyle factors and body composition among all five sites among males.

Males	Overall (N = 1 167)	GHA (n = 207)	SA (n = 236)	JAM (n = 249)	SEYC (n = 230)	USA (n = 245)
Sociodemographic characteristics (n, %)						
Age (median, IQR) years	35.0 (30.0, 40.0)	35.0 (28.0, 41.0)	34.0 (29.0, 38.3)	33.0 (29.0, 39.0)	37.0 (33.0, 40.0)	36.0 (30.0, 41.0)
≤ 35	621 (53%)	108 (52%)	140 (59%)	152 (61%)	101 (44%)	120 (49%)
> 35	546 (47%)	99 (48%)	96 (41%)	97 (39%)	129 (56%)	125 (51%)
BMI (kg/m^2)	23.6 (20.9, 27.5)	21.7 (20.3, 23.7)	21.5 (19.9, 24.2)	22.4 (20.3, 26.0)	26.0 (22.9, 29.1)	27.9 (24.2, 32.9)
Obese (BMI ≥ 30)	190 (16%)	3 (1%)	13 (6%)	26 (10%)	49 (21%)	99 (40%)
Regular / occasional smoker [1]	489 (42%)	13 (6.3%)	152 (64%)	87 (35%)	85 (37%)	152 (62%)
Heavy alcohol use [2]	104 (9%)	12 (5.8%)	63 (27%)	9 (3.6%)	8 (3.5%)	12 (4.9%)
Sleep						
Short (< 7 hours)	334 (29%)	34 (17%)	6 (2.5%)	103 (41%)	82 (36%)	109 (44%)
Normal (7 – 9 hours)	608 (52%)	145 (71%)	56 (24%)	127 (51%)	146 (63%)	134 (55%)
Long (> 9 hours)	221 (19%)	24 (12%)	174 (74%)	19 (7.6%)	2 (0.9%)	2 (0.8%)
Anthropometrics and body composition (median, IQR)						
Waist circumference (cm)	81 (74, 93)	77 (73, 81)	78 (73, 86)	77 (72, 87)	89 (81, 97)	94 (82, 107)
Fat-free mass (kg)	56 (51, 61)	53 (49, 56)	50 (46, 53)	57 (53, 61)	59 (54, 64)	61 (57, 68)
Fat mass (kg)	15 (10, 24)	9 (8, 13)	13 (10, 18)	14 (9, 20)	20 (14, 26)	25 (18, 38)
Body fat percentage (%)	22 (16, 29)	16 (12, 19)	21 (17, 26)	19 (15, 25)	25 (20, 30)	29 (23, 37)
Fasted blood glucose (mg/dL)	97 (88, 105)	101 (94, 108)	85 (78, 93)	95 (89, 102)	101 (96, 112)	100 (92, 109)
HDL cholesterol (mmol/L)	1.20 (1.00, 1.50)	1.10 (0.90, 1.40)	1.30 (1.00, 1.60)	1.20 (1.00, 1.40)	1.20 (1.00, 1.40)	1.20 (1.00, 1.50)
Triglyceride (mmol/L)	0.90 (0.60, 1.20)	0.90 (0.70, 1.20)	0.90 (0.63, 1.20)	0.70 (0.60, 1.00)	0.90 (0.60, 1.30)	0.90 (0.60, 1.30)

GHA, Ghana; SA, South Africa; JAM, Jamaica; SEYC, Seychelles; USA, United States of America; HDL, high-density lipoprotein; cm, centimeters; kg, kilograms; m, meters; mg/dL, milligrams per deciliter; mmol/L, millimoles per liter; μmol/L, micromoles per liter

[1] Currently smoking ≥1 cigarette per day, or currently smoking ≥1 cigarette per week.
[2] Eight or more drinks per week for women and fifteen or more drinks per week for men.

Table 1.2. Lifestyle factors and body composition among all five sites among females.

Females	Overall (N = 1 339)	GHA (n = 293)	SA (n = 268)	JAM (n = 251)	SEYC (n = 270)	USA (n = 257)
Sociodemographic characteristics (n, %)						
Age (median, IQR) years	35.0 (29.0, 40.0)	34.0 (28.0, 40.0)	33.0 (27.0, 38.0)	35.0 (29.0, 40.0)	36.0 (31.0, 41.0)	35.0 (30.0, 40.0)
≤ 35	739 (55%)	174 (59%)	169 (63%)	131 (52%)	127 (47%)	138 (54%)
> 35	600 (45%)	119 (41%)	99 (37%)	120 (48%)	143 (53%)	119 (46%)
BMI (kg/m^2)	26 (22, 31)	23 (21, 26)	25 (21, 32)	25 (21, 30)	26 (23, 30)	30 (26, 37)
Obese (BMI ≥ 30)	561 (42%)	48 (16%)	149 (56%)	115 (46%)	85 (31%)	164 (64%)
Regular / occasional smoker [1]	158 (12%)	0 (0%)	20 (7.5%)	43 (17%)	17 (6.3%)	78 (30%)
Heavy alcohol use [2]	53 (4%)	2 (0.7%)	21 (7.8%)	7 (2.8%)	8 (3.0%)	15 (5.8%)
Sleep						
Short (< 7 hours)	291 (22%)	37 (13%)	4 (1.5%)	73 (29%)	68 (25%)	109 (43%)
Normal (7 – 9 hours)	756 (57%)	215 (74%)	69 (26%)	142 (57%)	192 (71%)	138 (54%)
Long (> 9 hours)	290 (22%)	40 (14%)	195 (73%)	36 (14%)	10 (3.7%)	9 (3.5%)
Anthropometrics and body composition (median, IQR)						
Waist circumference (cm)	90 (81, 102)	83 (75, 91)	96 (85, 107)	91 (82, 101)	87 (79, 95)	101 (89, 113)
Fat-free mass (kg)	44 (39, 50)	40 (37, 44)	44 (40, 50)	46 (42, 51)	43 (39, 48)	49 (43, 56)
Fat mass (kg)	30 (21, 40)	22 (17, 28)	35 (26, 45)	31 (23, 38)	26 (20, 34)	40 (30, 52)
Body fat percentage (%)	40 (35, 45)	35 (31, 39)	44 (39, 48)	40 (36, 44)	38 (34, 42)	45 (41, 49)
Fasted blood glucose (mg/dL)	92 (83, 100)	99 (92, 106)	81 (71, 89)	91 (85, 96)	93 (86, 100)	94 (85, 102)
HDL cholesterol (mmol/L)	1.20 (1.00, 1.40)	1.20 (1.00, 1.40)	1.10 (0.90, 1.30)	1.20 (1.00, 1.30)	1.20 (1.00, 1.40)	1.30 (1.00, 1.60)
Triglyceride (mmol/L)	0.70 (0.60, 1.00)	0.80 (0.60, 1.00)	0.80 (0.60, 1.00)	0.70 (0.60, 0.90)	0.60 (0.50, 0.90)	0.90 (0.60, 1.35)

GHA, Ghana; SA, South Africa; JAM, Jamaica; SEYC, Seychelles; USA, United States of America; HDL, high-density lipoprotein; cm, centimeters; kg, kilograms; m, meters; mg/dL, milligrams per deciliter; mmol/L, millimoles per liter; μmol/L, micromoles per liter

[1] Currently smoking ≥1 cigarette per day, or currently smoking ≥1 cigarette per week.
[2] Eight or more drinks per week for women and fifteen or more drinks per week for men.

Table 2.1. Objective PA measures among males in all five sites measured in mean minutes per day.

Males	Overall (N = 1 167)	GHA (n = 207)	SA (n = 236)	JAM (n = 249)	SEYC (n = 230)	USA (n = 245)
Physical activity (median, IQR)						
Duration moderate and vigorous PA (mean), mins	34 (17, 56)	45 (27, 62)	48 (31, 76)	25 (12, 41)	32 (17, 50)	21 (10, 43)
PA guidelines met	606 (56%)	129 (71%)	177 (77%)	91 (41%)	121 (57%)	88 (38%)
Duration moderate PA (mean), mins	30 (15, 50)	42 (25, 59)	41 (28, 64)	22 (12, 38)	29 (15, 43)	18 (8, 39)
Duration vigorous PA (mean), mins	2 (0, 5)	1 (0, 4)	4 (1, 10)	1 (0, 3)	2 (0, 7)	1 (0, 4)
Duration sedentary PA (mean), mins	201 (172, 238)	189 (166, 229)	200 (177, 232)	223 (192, 252)	192 (162, 225)	203 (172, 234)
Duration light sedentary PA (mean), mins	202 (151, 252)	239 (180, 280)	166 (132, 220)	196 (144, 239)	219 (166, 277)	202 (148, 245)
Intensity count on wear periods (mean), mins	200 (139, 289)	239 (173, 301)	229 (156, 322)	169 (111, 230)	220 (148, 306)	157 (110, 247)

mins, minutes

Table 2.2. Objective PA measures among males in all five sites measured in mean minutes per day.

Females	Overall (N = 1 339)	GHA (n = 293)	SA (n = 268)	JAM (n = 251)	SEYC (n = 270)	USA (n = 257)
Physical activity (median, IQR)						
Duration moderate and vigorous PA (mean), mins	18 (8, 30)	22 (14, 34)	20 (9, 29)	16 (7, 28)	22 (13, 30)	9 (4, 19)
PA guidelines met	322 (26%)	96 (36%)	66 (25%)	55 (24%)	69 (29%)	36 (15%)
Duration moderate PA (mean), mins	18 (8, 29)	22 (14, 33)	18 (9, 28)	16 (7, 27)	22 (12, 30)	9 (4, 17)
Duration vigorous PA (mean), mins	0.00 (0.00, 0.50)	0.14 (0.00, 0.43)	0.00 (0.00, 0.50)	0.00 (0.00, 0.20)	0.17 (0.00, 0.86)	0.14 (0.00, 0.82)
Duration sedentary PA (mean), mins	201 (170, 231)	193 (164, 217)	218 (190, 249)	205 (174, 239)	185 (153, 218)	205 (172, 231)
Duration light sedentary PA (mean), mins	207 (162, 256)	247 (199, 289)	187 (147, 228)	198 (157, 238)	216 (162, 265)	191 (156, 239)
Intensity count on wear periods (mean), mins	145 (103, 191)	176 (134, 222)	127 (99, 170)	136 (99, 184)	166 (128, 210)	118 (87, 160)

mins, minutes

Table 3. Prevalence of metabolic syndrome in each of the five sites.

	Overall (N = 2 506)	GHA (n = 500)	SA (n = 504)	JAM (n = 500)	SEYC (n = 500)	USA (n = 502)
METABOLIC SYNDROME DIAGNOSING CHARACTERISTICS						
Large waist circumference [1]	1 166 (47%)	188 (38%)	256 (51%)	159 (32%)	281 (56%)	282 (56%)
Elevated triglycerides [2]	214 (9%)	38 (8%)	44 (9%)	16 (4.0%)	43 (9%)	73 (15%)
Low HDL [3]	893 (41%)	223 (45%)	213 (43%)	183 (46%)	122 (40%)	152 (31%)
Hypertension [4]	734 (29%)	68 (14%)	193 (38%)	130 (26%)	128 (26%)	215 (43%)
Diabetes [5]	604 (24%)	5 (1%)	52 (10%)	122 (24%)	215 (43%)	210 (42%)
METABOLIC SYNDROME						
Any three of five characteristics present	431 (17%)	27 (5%)	83 (17%)	64 (14%)	108 (24%)	149 (30%)

GHA, Ghana; SA, South Africa; JAM, Jamaica; SEYC, Seychelles; USA, United States of America; HDL, high-density lipoprotein; cm, centimeters; kg, kilograms; m, meters; mg/dL, milligrams per deciliter; mmol/L, millimoles per liter; μmol/L, micromoles per liter

[1] ≥ 94 cm for men and ≥ 80 cm for women, using specifically for a population of Sub-Saharan origins, with cut-points of ≥ 102 cm for males, and females ≥ 88 cm for females among Jamaica and US-based populations.
[2] ≥ 150 mg/dL).
[3] < 40 mg/dL or current drug treatment for reduced HDL-C.
[4] ≥ 130 Hg systolic and/or ≥ 85 Hg diastolic or current treatment for hypertension.
[5] Elevated fasting glucose levels with a cutoff point of ≥ 100 mg/dL or drug treatment for high glucose.

Table 4. Prevalence of metabolic syndrome and characterising risk factors in each site stratified by sex.

	METABOLIC SYNDROME	Large waist circumference	Elevated triglycerides	Low HDL	Hypertension	Diabetes
GHA (N = 500)						
Males (n = 207)	5 (2%)	10 (5%)	24 (12%)	67 (32%)	36 (17%)	1 (<1%)
Females (n = 293)	22 (8%)	177 (60%)	12 (4%)	156 (53%)	32 (11%)	4 (1%)
p-value[1]	**0.015**	**<0.001**	**0.006**	**<0.001**	**0.047**	0.4
SA (N = 504)						
Males (n = 236)	21 (9%)	25 (11%)	34 (14%)	37 (16%)	113 (48%)	28 (12%)
Females (n = 268)	62 (23%)	229 (85%)	10 (4%)	176 (66%)	80 (30%)	24 (9%)
p-value[1]	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.3
JAM (N = 500)						
Males (n = 249)	7 (3%)	11 (4%)	5 (2%)	27 (11%)	54 (22%)	85 (34%)
Females (n = 251)	57 (23%)	148 (59%)	11 (4%)	156 (62%)	76 (30%)	37 (15%)

p-value[1]	**<0.001**	**<0.001**	0.6	**<0.001**	**0.032**	**<0.001**
SEYC (N = 500)						
Males (n = 231)	49 (21%)	81 (9%)	35 (15%)	26 (11%)	74 (32%)	139 (60%)
Females (n = 270)	59 (22%)	200 (74%)	8 (3%)	96 (36%)	54 (20%)	76 (28%)
p-value[1]	>0.9	**<0.001**	**<0.001**	**<0.001**	**0.002**	**<0.001**
USA (n = 502)						
Males (n = 245)	62 (25%)	85 (35%)	33 (13%)	42 (17%)	121 (49%)	127 (52%)
Females (n = 257)	87 (34%)	196 (76%)	40 (16%)	110 (43%)	94 (37%)	83 (32%)
p-value[1]	**0.040**	**<0.001**	0.5	**<0.001**	**0.004**	**<0.001**

GHA, Ghana; SA, South Africa; JAM, Jamaica; SEYC, Seychelles; USA, United States of America; HDL, high-density lipoprotein; cm, centimeters; kg, kilograms; m, meters; mg/dL, milligrams per deciliter; mmol/L, millimoles per liter; μmol/L, micromoles per liter

[1] Fisher's exact test

Table 5. Lifestyle factors and body composition stratified by the presence of metabolic syndrome in each of the five sites.

GHANA	**Overall** N (%)	**No metabolic syndrome** n (%)	**Metabolic syndrome** n (%)	**p-value[1]**
Total for Ghana	**500**	**473 (95%)**	**27 (5%)**	
Sociodemographic characteristics				
Age (median, IQR) years	35 (28, 40)	34 (28, 40)	39 (32, 42)	**0.043**
≤ 35	282 (56%)	271 (57%)	11 (41%)	0.11
> 35	218 (44%)	202 (43%)	16 (59%)	
Gender				**0.015**
Male	207 (41%)	202 (43%)	5 (19%)	
Female	293 (59%)	271 (57%)	22 (81%)	
Regular/occasional smoker	13 (3%)	13 (3%)	0 (0%)	>0.9
Heavy alcohol use	14 (3%)	12 (3%)	2 (7%)	0.2
Sleep				0.7
Short (< 7 hours)	71 (14%)	66 (14%)	5 (19%)	
Normal (7 – 9 hours)	360 (73%)	342 (73%)	18 (67%)	
Long (> 9 hours)	64 (13%)	60 (13%)	4 (15%)	
Anthropometrics and body composition (median, IQR)				
BMI (kg/m^2)	23.2 (20.9, 26.4)	23.0 (20.8, 25.9)	28.0 (25.6, 31.0)	**<0.001**
Obese (BMI ≥ 30)	51 (10%)	42 (9%)	9 (33%)	**<0.001**

Waist circumference (cm)	79 (74, 87)	79 (74, 87)	92 (88, 100)	**<0.001**
Fat-free mass (kg)	45 (39, 53)	45 (39, 53)	45 (43, 53)	0.3
Fat mass (kg)	17 (10, 23)	16 (10, 23)	28 (22, 32)	**<0.001**
Body fat percentage (%)	29 (17, 36)	28 (17, 36)	38 (34, 42)	**<0.001**

SOUTH AFRICA	**Overall** N (%)	**No metabolic syndrome** n (%)	**Metabolic syndrome** n (%)	**p-value**[1]
Total for South Africa	**504**	**421 (84%)**	**83 (16%)**	
Sociodemographic characteristics				
Age (median, IQR) years	34 (28, 38)	33 (28, 37)	36 (30, 41)	**0.001**
≤ 35	309 (61%)	271 (64%)	38 (46%)	**0.002**
> 35	195 (39%)	150 (36%)	45 (54%)	
Gender				**<0.001**
Male	268 (53%)	206 (49%)	62 (75%)	
Female	236 (47%)	215 (51%)	21 (25%)	
Regular/occasional smoker	172 (34%)	160 (38%)	12 (14%)	**<0.001**
Heavy alcohol use	84 (17%)	76 (18%)	8 (10%)	0.075
Sleep				0.8
Short (< 7 hours)	10 (2%)	8 (2%)	2 (2%)	
Normal (7 – 9 hours)	125 (25%)	106 (25%)	19 (23%)	
Long (> 9 hours)	369 (73%)	307 (73%)	62 (75%)	
Anthropometrics and body composition (median, IQR)				
BMI (kg/m^2)	25 (21, 32)	24 (21, 31)	32 (29, 37)	**<0.001**
Obese (BMI ≥ 30)	162 (32%)	109 (26%)	53 (64%)	**<0.001**
Waist circumference (cm)	86 (77, 100)	83 (75, 95)	101 (92, 111)	**<0.001**
Fat-free mass (kg)	47 (43, 52)	47 (43, 51)	49 (44, 57)	**0.001**
Fat mass (kg)	23 (13, 37)	20 (12, 33)	36 (29, 45)	**<0.001**
Body fat percentage (%)	34 (22, 45)	31 (21, 43)	44 (35, 48)	**<0.001**

JAMAICA	**Overall** N (%)	**No metabolic syndrome** n (%)	**Metabolic syndrome** n (%)	**p-value**[1]
Total for Jamaica	**500**	**436 (87%)**	**64 (13%)**	
Sociodemographic characteristics				
Age (median, IQR) years	34 (29, 39)	34 (29, 39)	36 (30, 42)	**0.027**
≤ 35	217 (43%)	183 (42%)	34 (53%)	0.11
> 35	283 (57%)	253 (58%)	30 (47%)	
Gender				**<0.001**

Male	249 (50%)	242 (56%)	7 (11%)	
Female	251 (50%)	194 (44%)	57 (89%)	
Regular/occasional smoker	130 (26%)	122 (28%)	8 (13%)	**0.009**
Heavy alcohol use	16 (3%)	14 (3%)	2 (3%)	>0.9
Sleep				0.2
Short (< 7 hours)	176 (35%)	159 (36%)	17 (27%)	
Normal (7 – 9 hours)	269 (54%)	232 (53%)	37 (58%)	
Long (> 9 hours)	55 (11%)	45 (10%)	10 (16%)	
Anthropometrics and body composition (median, IQR)				
BMI (kg/m^2)	25.2 (21.5, 30.5)	24.4 (21.1, 29.2)	33.3 (29.5, 37.0)	**<0.001**
Obese (BMI ≥ 30)	141 (28%)	95 (22%)	46 (72%)	**<0.001**
Waist circumference (cm)	84 (74, 95)	82 (74, 92)	103 (94, 111)	**<0.001**
Fat-free mass (kg)	52 (45, 58)	52 (45, 58)	51 (47, 55)	>0.9
Fat mass (kg)	23 (13, 32)	20 (12, 29)	38 (32, 47)	**<0.001**
Body fat percentage (%)	30 (19, 41)	28 (19, 39)	43 (39, 46)	**<0.001**
SEYCHELLES	**Overall** N (%)	**No metabolic syndrome** n (%)	**Metabolic syndrome** n (%)	**p-value**[1]
Total for Seychelles	**500**	**392 (78%)**	**108 (22%)**	
Sociodemographic characteristics				
Age (median, IQR) years	36 (32, 41)	35 (31, 40)	40 (35, 43)	**<0.001**
≤ 35	228 (46%)	200 (51%)	28 (26%)	**<0.001**
> 35	272 (54%)	192 (49%)	80 (74%)	
Gender				>0.9
Male	230 (46%)	181 (46%)	49 (45%)	
Female	270 (54%)	211 (54%)	59 (55%)	
Regular/occasional smoker	102 (20%)	85 (22%)	17 (16%)	0.2
Heavy alcohol use	16 (3%)	14 (4%)	2 (2%)	0.5
Sleep				0.7
Short (< 7 hours)	150 (30%)	115 (29%)	35 (32%)	
Normal (7 – 9 hours)	338 (68%)	268 (68%)	70 (65%)	
Long (> 9 hours)	12 (2%)	9 (2%)	3 (3%)	
Anthropometrics and body composition (median, IQR)				
BMI (kg/m^2)	26.5 (22.9, 30.4)	25.3 (22.0, 28.2)	30.6 (28.3, 34.6)	**<0.001**
Obese (BMI ≥ 30)	134 (27%)	70 (18%)	64 (59%)	**<0.001**

Waist circumference (cm)	88 (80, 96)	85 (78, 92)	99 (92, 105)	**<0.001**
Fat-free mass (kg)	51 (42, 59)	49 (41, 58)	54 (47, 63)	**<0.001**
Fat mass (kg)	23 (17, 31)	21 (15, 28)	31 (26, 40)	**<0.001**
Body fat percentage (%)	32 (25, 39)	31 (24, 38)	38 (31, 42)	**<0.001**

USA	**Overall** N (%)	**No metabolic syndrome** n (%)	**Metabolic syndrome** n (%)	**p-value**[1]
Total for USA	**502**	**353 (70%)**	**149 (30%)**	
Sociodemographic characteristics				
Age (median, IQR) years	35.0 (30.0, 41.0)	35.0 (29.0, 40.0)	38.0 (32.0, 42.0)	**<0.001**
≤ 35	258 (51%)	196 (56%)	62 (42%)	**0.005**
> 35	244 (49%)	157 (44%)	87 (58%)	
Gender				**0.040**
Male	245 (49%)	183 (52%)	62 (42%)	
Female	257 (51%)	170 (48%)	87 (58%)	
Regular/occasional smoker	230 (46%)	166 (47%)	64 (43%)	0.4
Heavy alcohol use	27 (5%)	22 (6%)	5 (3%)	0.3
Sleep				0.4
Short (< 7 hours)	218 (44%)	151 (43%)	67 (45%)	
Normal (7 – 9 hours)	272 (54%)	195 (55%)	77 (52%)	
Long (> 9 hours)	11 (2.2%)	6 (1.7%)	5 (3.4%)	
Anthropometrics and body composition (median, IQR)				
BMI (kg/m^2)	30 (26, 37)	28 (24, 33)	36 (32, 42)	**<0.001**
Obese (BMI ≥ 30)	263 (52%)	137 (39%)	126 (85%)	**<0.001**
Waist circumference (cm)	97 (86, 110)	91 (81, 103)	110 (102, 125)	**<0.001**
Fat-free mass (kg)	56 (48, 63)	54 (47, 61)	59 (52, 67)	**<0.001**
Fat mass (kg)	33 (22, 47)	27 (20, 41)	44 (36, 54)	**<0.001**
Body fat percentage (%)	39 (29, 46)	36 (26, 44)	44 (38, 48)	**<0.001**

GHA, Ghana; SA, South Africa; JAM, Jamaica; SEYC, Seychelles; USA, United States of America; HDL, high-density lipoprotein; cm, centimeters; kg, kilograms; m, meters; mg/dL, milligrams per deciliter; mmol/L, millimoles per liter; μmol/L, micromoles per liter

[1] Fisher's exact test; Wilcoxon rank sum test

[2] Adjusted for age, sex, sleep, smoking status, alcohol use and BMI

Table 6. Logistic regression model showing the association of MVPA adjusted for lifestyle factors in individuals with and without metabolic syndrome across all five sites. PA was included as a continuous variable in Model 1 (MVPA, mean minutes per day), and as a categorical variable in Model 2 (meeting PA guidelines of ≥ 30 minutes MVPA per day, or not).

All sites	**Overall** N (%)	**No metabolic syndrome** n (%)	**Metabolic syndrome** n (%)	**Model 1** **MVPA (mins)** aOR (95% CI), p-value	**Model 2** **Meeting PA guidelines** aOR (95% CI), p-value
Total for all sites	**2 506**	**2 075 (%)**	**431 (%)**		
Physical activity					
Duration moderate and vigorous PA (mean), mins	24 (11, 41)	26 (13, 43)	17 (7, 29)	1.00 (0.99, 1.00), 0.13	-
PA guideline met (≥ 30 mins per day)				-	0.76 (0.57, 1.01), 0.064
Site					
Ghana	500 (20%)	473 (23%)	27 (6.3%)	0.63 (0.36, 1.06), 0.088	0.63 (0.36, 1.06), 0.088
South Africa	504 (20%)	421 (20%)	83 (19%)	0.65 (0.40, 1.07), 0.091	0.65 (0.40, 1.07), 0.091
Jamaica	500 (20%)	436 (21%)	64 (15%)	0.85 (0.57, 1.26), 0.4	0.85 (0.57, 1.26), 0.4
Seychelles	500 (20%)	392 (19%)	108 (25%)	1.52 (1.05, 2.20), 0.025	1.52 (1.05, 2.20), 0.025
USA	502 (20%)	353 (17%)	149 (35%)	-	-
Age	35 (29, 40)	34 (29, 39)	38 (32, 42)	1.08 (1.05, 1.10), <0.001	1.08 (1.05, 1.10), <0.001
Gender					
Male	1,167 (47%)	1,023 (49%)	144 (33%)	0.34 (0.21, 0.55), <0.001	0.34 (0.21, 0.55), <0.001
Female	1,339 (53%)	1,052 (51%)	287 (67%)	-	-
BMI (kg/m^2)	26 (22, 31)	25 (21, 29)	33 (29, 38)	1.05 (1.02, 1.08), 0.003	1.05 (1.02, 1.08), 0.003
Body fat percentage (%)	33 (22, 41)	30 (21, 39)	42 (36, 46)	1.11 (1.07, 1.15), <0.001	1.11 (1.07, 1.15), <0.001
Regular/occasional smoker [1]	647 (26%)	546 (26%)	101 (23%)	1.25 (0.90, 1.74), 0.2	1.25 (0.90, 1.74), 0.2
Heavy alcohol use [2]	157 (6%)	138 (7%)	19 (4%)	0.77 (0.41, 1.35), 0.4	0.77 (0.41, 1.35), 0.4
Sleep					
Short (< 7 hours)	625 (25%)	499 (24%)	126 (29%)	0.97 (0.72, 1.30), 0.8	0.97 (0.72, 1.30), 0.8
Normal (7 – 9 hours)	1,364 (55%)	1,143 (55%)	221 (51%)		
Long (> 9 hours)	511 (20%)	427 (21%)	84 (19%)	1.61 (1.04, 2.49), 0.033	1.61 (1.04, 2.49), 0.033

[1] Currently smoking ≥1 cigarette per day, or currently smoking ≥1 cigarette per week.
[2] Eight or more drinks per week for women and fifteen or more drinks per week for men.