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Clustering of diet and physical activity behaviours in adolescents across home and school area-level deprivation in Cameroon, South Africa, and Jamaica

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Abstract

Background Adolescence is a crucial period for establishing healthy behaviours that can reduce the risk of non-communicable diseases. However, limited data exist on the clustering of health-related behaviours, in adolescents from low- and middle-income countries (LMICs). This study examined how diet and physical activity behaviours cluster and how they are influenced by home and school area-level deprivation.

Methods The study surveyed 527 adolescents in Yaoundé (Cameroon), Kingston (Jamaica), and Cape Town (South Africa) and grouped them into three categories according to the socioeconomic status (SES) of their homes and school areas (low-low, low-high, and high-high). A k-median algorithm defined three clusters and measured dietary attributes including Dietary Habit Score (DHS), Healthy Food Score (HFS), Nutritional Knowledge Questionnaire (NKQ), moderate-to-vigorous physical activity (MVPA), and sedentary time using validated questionnaires. The clusters were ranked based on their physical activity levels and compared them within each city using statistical tests.

Results The scores on the NKQ and HFS indicated a poor level of both nutritional knowledge and healthy food consumption across sites. Cluster analysis revealed a consistent pattern of high screen time clustering with lower (less healthy) dietary scores across sites. This pattern was consistent regardless of SES in Kingston, and SES and school socioeconomic areas in Cape Town and Yaoundé.

Conclusion An inverse clustering of sedentary behaviour duration and eating habits remained consistent across different strata for at least two sites, suggesting that interventions to reduce sedentary time could have a ripple effect on multiple NCD risk factors in adolescence.

Keywords Clustering, Diet, Activity, Adolescents, Deprivation

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Introduction

Evidence suggests that unhealthy behaviours, such as smoking, harmful alcohol consumption, physical inactivity, and unhealthy eating habits, which increase the risk of noncommunicable diseases (NCDs), often develop during adolescence [1, 2]. Adolescence is a pivotal transition stage in human life and serves as a critical window for mitigating health-risk behaviours that frequently persist into adulthood [3, 4]. This is particularly crucial in Africa, which is home to the world's youngest population [5], as the region faces an escalating threat from NCDs, in part due to rising rates of unhealthy diets and physical inactivity driven by globalisation, urbanisation, and socioeconomic development [6]. Furthermore, Since the Caribbean region is experiencing a decline in its adolescent population [7], an increase in adolescents engaging in unhealthy behaviours, could exacerbate the burden of NCDs on the Caribbean healthcare system.

NCD risk behaviours, such as unhealthy eating habits and physical inactivity, frequently co-occur with a synergistic negative impact [1, 8]. Accordingly, there is a growing interest in the study of clustering of these health behaviours [9–12], to develop a more integrated approach to disease prevention [13]. Such insights have pivotal implications for public health; understanding which behaviours to target in tandem can underpin the design of more cost-effective NCD prevention programs [1].

Additionally, various settings, such as schools and home neighbourhood-built environments, significantly influence diet and physical activity behaviours [14]. Schools have been shown to affect students' diet, physical activity, and body composition [15]. Therefore, they represent promising avenues for interventions to reduce the risk of developing NCDs. Furthermore, economic, social, and environmental determinants, such as poverty, wealth inequality, and lack of education, are associated with increased NCD prevalence [16]. Rapid urbanisation in low- and middle-income countries (LMICs) intensifies these health inequalities [17].

Urban sprawl, characterised by the rapid geographic expansion of cities and towns, is considered obesogenic [18] and often promotes sedentary behaviour [19]. Studies from high-income countries indicate that greater distance to school does not necessarily influence overall physical activity or obesity rates, but may increase exposure to unhealthy environmental factors, such as food advertising [20, 21]. These varying experiences can differentially affect adolescents, even within the same city. This is particularly pertinent in LMIC cities where a legacy of colonialism and urban sprawl can result in adolescents from low-SES households commuting long distances to government schools in high-SES areas [22]. However, there is a dearth of research on how diet and physical activity behaviours cluster among adolescents and how these clusters are influenced by their home or school environments and journey to school in LMIC settings. A recent scoping review highlighted a critical lack of region-specific data for Africa and the Caribbean, hindering the development of targeted interventions to improve diet and physical activity [23].

To address these gaps, this study explored how diet and physical activity patterns cluster in two African and one Caribbean cities representing different stages of nutritional and epidemiological transition. We also sought to identify similarities and differences in these clustering patterns between and within different cities. Furthermore, we explored how these clustering patterns vary based on area-level deprivation.

Methods

Study setting and design

This study was nested in the Global Diet and Activity Research network project [24], and the rationale, design, and methodologies have been previously published [25]. We focused on three cities representing different stages of nutritional and epidemiological transition: Yaoundé, Cameroon, Kingston, Jamaica, and Cape Town, South Africa [26, 27].

Sampling strategy and data collection

Adolescents, aged 10–18 years, were recruited from secondary schools in these cities. To capture a diverse range of behaviours, the selection was based on the socioeconomic status of the neighbourhood where they lived and where their schools were located. The socioeconomic categorisation of households was determined using the number of household assets, and that of neighbourhoods was determined using land and property value indices [25]. We created three participant categories: (i) adolescents from low-income households attending schools in nearby predominantly low-income neighbourhoods (LL), (ii) adolescents from low-income households attending schools farther away in predominantly middle- to high-income neighbourhoods (LH), and (iii) adolescents from high-income households attending schools in nearby middle- to high-income neighbourhoods (HH).

Study constructs

Using validated and contextually adapted questionnaires, we measured dietary attributes (dietary habits, nutrition knowledge, and healthy food consumption), moderate-to-vigorous physical activity (MVPA) (total and domain-specific, i.e. school-related MVPA, private club MVPA, and active travel MVPA), and sedentary time.

Both the Dietary Habit Score (DHS) and the Healthy Food Score (HFS) were assessed using the Food Frequency Questionnaire (FFQ), adapted for each context from the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) study, a multi-country study of children from 12 countries in 6 continents [28]. The DHS was calculated as the sum of four questions in the FFQ related to unhealthy food snacking while watching TV, eating breakfast on weekdays and weekends, and having school lunches, with a higher number indicating a healthier diet (maximum score 43). The HFS was the sum of the healthy food types in the FFQ and one question on the frequency of eating outside the home (maximum score = 101). The Nutritional Knowledge Score (NKS) was calculated by adding the total scores using the General Nutritional Knowledge Survey (maximum score 63) adapted from two previously validated instruments [29, 30], that had not been used in these contexts previously. Internal consistency was assessed using inter-item analysis. Across all dietary constructs, a higher score represents a healthier eating pattern. Details of how the variables were calculated are included in Supplement 1.

The physical activity (PA) questionnaire was adapted for each setting using an instrument that has been validated against objectively measured physical activity in South African adolescents [31, 32]. The main adaptations included new sports like Baldi and Kai, and using colloquial names for different transport modes including Taxi-Bus and Taxi-Motorcycle. Total MVPA was calculated in minutes per week and was the sum of time spent in informal physical activity (activities during school breaks or outside school such as skipping, traditional games, and playing with a ball); school-related physical activity (structured physical education classes and school-related extramural/extracurricular activities); private club activities (sports team/club activities outside school); and active travel, defined as walking or cycling to school. To determine the level of physical activity, participants were asked to indicate whether the activity resulted in a change in their breathing. Light physical activity was stated as a slight increase in breathing. It requires standing up and moving around either in the home, workplace, or community. Moderate physical activity was described as leading to a noticeable increase in depth of breathing while still allowing for comfortable talking. Vigorous physical activity was described as leading to harder breathing or puffing and panting and not being able to speak more than a few words without pausing for breath [33]. Total Sedentary (SED) time (minutes per day) was calculated by summing the responses to questions related to time spent watching TV, playing video games, on the internet (for study and non-study purposes), and reading/drawing/studying.

Statistical analysis

To address the plausibility of the time spent on MVPA, values were truncated for three of the four domains based on evidence from the literature (informal, up to 1680 min/week; school-related, up to 1800 min/week; and private clubs, up to 1800 min/week) [34]. Additionally, the total MVPA value for all four domains was truncated to 2400 min/week [35], and sedentary time values were truncated to 960 min/day [36]. This resulted in truncated measures for 11 participants in the following domains: one for time spent in informal physical activity, six for school-related physical activity, and four for time spent participating in physical activity in private sports clubs. Summary statistics, including means, medians, and quartiles, were calculated for the overall sample and subgroups.

Cluster analysis was performed using the k-medians algorithm for each city. Euclidean distance was used as the dissimilarity measure. The five clustering variables were total MVPA, total sedentary time (SED), Nutritional Knowledge Score (NKQ), Dietary Habit Score (DHS), and Healthy Food Score (HFS). Before cluster analysis, MVPA and SED were log-transformed for normalisation, and logMVPA, logSED, NKS, DHS, and HFS were standardised in each city. For ease of interpretation, after creation, we ranked the clusters by their median MVPA, with Cluster 1 defined as the most active and Cluster 3 as the least active.

To compare the three clusters within each city, a nonparametric equality-of-medians test (for MVPA and SED) or ANOVA (for NKQ, DHS, and HFS) was applied. For comparisons between two clusters (1 vs. 2, 1 vs. 3, and 2 vs. 3), a nonparametric equality-of-medians test (for MVPA and SED) or t-test (for NKQ, DHS, and HFS) was applied, while the Bonferroni correction was applied for multiple testing (see Supplement 2). Two clusters were not compared if the 3-sample test was not significant. All analyses were conducted using Stata/SE version 14.0 with a significance level set at 0.05.

Results

Baseline characteristics

Sociodemographics

We studied 528 adolescents from Cape Town ($n = 143$), Yaoundé ($n = 227$), and Kingston ($n = 158$). We excluded one participant from Cape Town due to missing data. Table 1 highlights the key sociodemographic characteristics of the total sample categorised by cluster. For the total sample, most participants were female

Table 1 Site- and cluster-specific percentage distributions of sample characteristics

Site			Total		Cluster 1 (Most active)		Cluster 2		Cluster 3 (Least active)	
			n	%	n	%	n	%	n	%
Cape Town	Sex	Male	49	34.5	21	52.5	7	17.1	21	34.4
		Female	93	65.5	19	47.5	34	82.9	40	65.6
	Age	< 15yrs	56	39.4	22	55.0	19	46.3	15	24.6
		>=15yrs	86	60.6	18	45.0	22	53.7	46	75.4
	Home SES	Low	92	64.8	25	62.5	26	63.4	41	67.2
		High	50	35.2	15	37.5	15	36.6	20	32.8
	School SES	Low	51	35.9	16	40.0	8	19.5	27	44.3
		High	91	64.1	24	60.0	33	80.5	34	55.7
	Home- School SES	Low-Low	51	35.9	16	40.0	8	19.5	27	44.3
		Low-High	41	28.9	9	22.5	18	43.9	14	23.0
		High-High	50	35.2	15	37.5	15	36.6	20	32.8
Yaoundé	Sex	Male	77	33.9	22	33.3	29	38.2	26	30.6
		Female	150	66.1	44	66.7	47	61.8	59	69.4
	Age	< 15yrs	113	49.8	22	33.3	48	63.2	43	50.6
		>=15yrs	114	50.2	44	66.7	28	36.8	42	49.4
	Home SES	Low	171	75.3	46	69.7	59	77.6	66	77.6
		High	56	24.7	20	30.3	17	22.4	19	22.4
	School SES	Low	76	33.5	11	16.7	35	46.1	30	35.3
		High	151	66.5	55	83.3	41	53.9	55	64.7
	Home- School SES	Low-Low	76	33.5	11	16.7	35	46.1	30	35.3
		Low-High	95	41.9	35	53.0	24	31.6	36	42.4
		High-High	56	24.7	20	30.3	17	22.4	19	22.4
Kingston	Sex	Male	35	22.2	8	21.6	9	15.8	18	28.1
		Female	123	77.8	29	78.4	48	84.2	46	71.9
	Age	< 15yrs	64	40.5	18	48.6	21	36.8	25	39.1
		>=15yrs	94	59.5	19	51.4	36	63.2	39	60.9
	Home SES	Low	96	60.8	26	70.3	21	36.8	49	76.6
		High	62	39.2	11	29.7	36	63.2	15	23.4
	School SES	Low	67	42.4	22	59.5	10	17.5	35	54.7
		High	91	57.6	15	40.5	47	82.5	29	45.3
	Home- School SES	Low-Low	67	42.4	22	59.5	10	17.5	35	54.7
		Low-High	29	18.4	4	10.8	11	19.3	14	21.9
		High-High	62	39.2	11	29.7	36	63.2	15	23.4

SES Socioeconomic Status

(69.3%), with a median age of 15 (14–16) years. Cape Town and Kingston had more participants aged ≥ 15 years, whereas the ages in Yaoundé were more evenly distributed. More than two-thirds (68.0%) were from low-income households, and 63.3% attended schools in middle/high-income neighbourhoods. At each site, most participants were from low-income households and attended schools in high socioeconomic areas. Demographic characteristics of the three clusters in each city are presented in Table 1.

Dietary constructs Table 2 shows that all three sites had good Dietary Habits Scores (DHS), with an average score exceeding 50% of the maximum score of 43. However, Nutritional Knowledge Questionnaire (NKQ) scores were low in all sites with a mean score of 10.5–15.6 out of a maximum score of 63). Healthy Food Scores (HFS) were also low across sites with the mean being lowest in Kingston and highest in Cape Town.

Physical activity constructs Table 2 shows that Kingston participants had the highest level of physical activity, with a median of 420 min of MVPA per week, aligned with the

Table 2 Cluster analysis by country

Site	Cluster	*N* (%)	MVPA Median(IQR)	SED Median(IQR)	NKQ Mean(SD)	DHS Mean(SD)	HFS Mean(SD)
Cape Town	1	40(28.1)	400(218–763)	224(158–297)	13.3(4.2)	29.3(5.3)	36.5(12.5)
	2	41(28.9)	300(170–450)	441(277–660)	11.1(3.4)	16.1(6.3)	26.7(14.7)
	3	61(43.0)	296(150–540)	536(390–711)	17.8(2.7)	24.5(6.3)	30.7(14.1)
	Total	142	323(170–560)	404(249–617)	14.6(4.4)	23.4(7.8)	31.2(14.3)
Yaoundé	1	66(29.1)	150(60–360)	446(360–531)	12.5(3.7)	24.9(6.7)	28.4(8.6)
	2	76(33.5)	120(60–218)	231(144–283)	12.6(3.7)	31.8(4.1)	23.4(5.9)
	3	85(37.4)	60(4-120)	277(210–360)	7.0(2.5)	30.1(5.3)	16.6(5.5)
	Total	227	120(50–240)	291(210–437)	10.5(4.2)	29.1(6.1)	22.3(8.2)
Kingston	1	37(23.4)	720(312–1837)	257(219–321)	15.1(4.7)	22.5(7.3)	37.8(12.0)
	2	57(36.1)	375(150–1080)	223(189–270)	19.8(2.6)	31.4(4.9)	18.0(7.6)
	3	64(40.5)	330(47–878)	141(105–174)	12.0(5.2)	29.8(5.9)	14.7(8.2)
	Total	158	420(100–1115)	201(141–257)	15.6(5.5)	28.7(6.9)	21.3(12.9)

Data shown are the mean (SD) or median (IQR). *MVPA* moderate-to-vigorous physical activity, *SED* sedentary time (sedentary), *NKQ* Nutrition Knowledge Questionnaire (max score 63), *DHS* Dietary Health Score (max score 43), *HFS* Healthy Food Score (max score 101)

recommended WHO guidelines that children and adolescents should do at least an average of 60 min per day of moderate- to vigorous-intensity (approximately 420 min per week) [37, 38]. However, the median MVPA in Cape Town (323 min) and Yaoundé (120 min) did not meet the WHO recommendations.

Adolescents in Cape Town were the most sedentary, averaging 404 min of sedentary time per week, while Yaoundé and Kingston's adolescents' median screen time per week were 291 and 201 min, respectively.

Clustering of diet and activity patterns

Table 2 shows the cluster characteristics of each study site, ranked by their median MVPA from high (Cluster 1) to low (Cluster 3) MVPA.

Cape Town

In Cape Town, the MVPA levels were not significantly different across the clusters. However, sedentary time was lower in Cluster 1 than in Clusters 2 ($p<0.001$) and 3 ($p<0.001$) while no difference was found between Cluster 2 and 3. Eating habits were healthier in Cluster 1 than in Clusters 2 ($p<0.001$) and 3 ($p<0.001$), while Cluster 2 eating habits were unhealthier than in Cluster 3 ($p<0.001$).

Cape Town findings suggest that higher MVPA and lower screen time tended to cluster with healthiest eating habits (Cluster 1), but dietary knowledge did not seem to be associated with physical activity or eating habits, whereas higher sedentary time tended to cluster with poorer eating habits (Clusters 2 and 3).

Yaoundé

In Yaoundé, MVPA was higher in Cluster 1 than in Cluster 3 ($p<0.001$) and in Cluster 2 than in Cluster 3 ($p<0.018$), while no difference was observed between Cluster 1 and 2. Sedentary time was higher in Cluster 1 than in Cluster 2 ($p<0.001$) and 3 ($p<0.001$), but lower in Cluster 2 than in Cluster 3 ($p=0.005$). Eating habits were less healthy in Cluster 1 than in Clusters 2 ($p<0.001$) and 3 ($p<0.001$), while no difference was found between Clusters 2 and 3. These results suggest that lower sedentary time tended to cluster with healthiest eating habits (Cluster 2), whereas higher sedentary time tended to be associated with poorer eating habits (Cluster 1), as observed in Cape Town.

Kingston

In Kingston, there was no significant difference in MVPA across clusters. Sedentary time was lower in Cluster 3 than in Clusters 1 ($p<0.001$) and 2 ($p<0.001$), while no difference in sedentary time was found between Cluster 1 and 2. Eating habits were unhealthier in Cluster 1 than in Clusters 2 ($p<0.001$) and 3 ($p<0.001$), whereas no difference in eating habits was found between Clusters 2 and 3.

These results suggest a low sedentary level cluster with good eating habits (Cluster 3) and a high sedentary level cluster with poor eating habits (Cluster 1), as observed in both Cape Town and Yaoundé. However, Cluster 2 presented high sedentary behaviours (not significantly different from Cluster 1) clustering with healthier eating habits (not significantly different from Cluster 3), suggesting an unusually high sedentary healthy eating pattern unique to Kingston.

Stratified analysis of diet and activity clusters by home socioeconomic status

Overall sedentary time was higher among adolescents from high-SES households compared to those from low-SES households in Cape Town (454 [269–701] vs. 319 [206–549] mins/day; $p=0.0059$) minutes/week, while the inverse was seen in Yaoundé (283 [197–390] vs. 341 [236–491]; $p=0.034$) minutes/week. However, no significant difference was observed in the overall physical activity levels or eating habits between adolescents from low and high SES households at either sites. In Kingston, adolescents differed significantly in eating habits only, with high-SES adolescents having healthier eating habits (Mean DHS score (SD) = 30.3 (6.0) vs. 27.6 (7.2); $p=0.015$).

Cape Town

Table 3 shows that, among adolescents from low-SES households, sedentary time was significantly lower in Cluster 1 than in Cluster 2 ($p<0.001$) and Cluster 3 ($p<0.001$), while no significant difference in sedentary time was seen between Clusters 2 and 3. Additionally, eating habits were healthier in Cluster 1 than in Cluster 2 ($p<0.001$) and Cluster 3 ($p<0.006$), while Cluster 2 eating habits were unhealthier than in Cluster 3 ($p<0.001$). These results suggest that lower sedentary time tended to cluster with healthy eating habits (Cluster 1), whereas higher sedentary time tended to cluster with poorer eating habits (Clusters 2 and 3).

Among adolescents with High SES, sedentary time was significantly lower in Cluster 1 than in Cluster 2 ($p=0.032$), whereas no significant differences in sedentary time were found between Clusters 1 and 3 and Clusters 2 and 3. Eating habits were unhealthier in Cluster 2 than in Cluster 1 ($p<0.001$) and 3 ($p<0.001$), while there was no significant difference in eating habits between Clusters 1 and 3. These results suggest that low sedentary time tended to cluster with healthy eating habits (Clusters 1 and 3), whereas higher sedentary time tended to cluster with poorer eating habits (Cluster 2).

The results from Cape Town suggest that the clustering pattern identified in the city remained consistent even when stratified by home SES. We also note a shift of Cluster 3 from an unhealthy pattern in Low SES (high sedentary unhealthy eaters) to healthier patterns in High SES (Low sedentary time healthy eaters).

Yaoundé

Table 4 shows that, among low-SES adolescents from, the median MVPA level was lower in Cluster 3 than in Cluster 1 (0.006) and 2 (0.01). Sedentary time was higher in Cluster 1 than in Clusters 2 ($p<0.001$) and 3 ($p<0.001$), and eating habits were significantly unhealthier in Cluster 1 than in Clusters 2 ($p<0.001$) and 3 ($p<0.001$). Cluster 2 and 3 had no significant differences in sedentary time and eating habits, suggesting that lower sedentary time clustered with healthy eating habits (Clusters 2 and 3), while higher sedentary time clustered with unhealthy eating habits (Cluster 1).

Among high SES adolescents, sedentary time was significantly lower in Cluster 2 than in Clusters 1 ($p<0.001$) and 3 ($p=0.008$), and eating habits were significantly unhealthier in Cluster 1 than in Clusters 2 ($p=0.001$) and 3 ($p=0.02$). There were no significant differences

Table 3 Diet and activity cluster patterns in Cape Town according to the socioeconomic status (SES) of the home neighbourhood

SES category	Cluster	*N* (%)	MVPA Median(IQR)	SED Median(IQR)	NKQ Mean(SD)	DHS Mean(SD)	HFS Mean(SD)
Low SES	1	25(27.2)	325(210–505)	240(156–296)	12.8(4.4)	30.1(5.5)	39.1(13.0)
	2	26(28.3)	275(150–450)	409(300–716)	11.3(3.1)	17.2(6.5)	25.3(13.4)
	3	41(44.6)	255(120–480)	591(497–746)	17.4(2.7)	24.8(7.0)	32.6(15.1)
	Total	92(100)	275(158–455)	454(269–701)	14.4(4.3)	24.1(8.0)	32.3(14.9)
High SES	1	15(30.0)	665(355–840)	171(159–317)	14.0(3.8)	27.9(4.7)	32.2(10.9)
	2	15(30.0)	330(200–915)	566(256–660)	10.9(3.9)	14.3(5.9)	29.1(16.9)
	3	20(40.0)	435(203–758)	379(283–510)	18.6(2.5)	23.9(4.6)	26.8(11.0)
	Total	50(100)	445(255–790)	319(206–549)	14.9(4.6)	22.2(7.4)	29.1(12.9)
	P value*		0.87	0.0059	0.025	0.55	0.17

Data shown are the mean (SD) or median (IQR). *MVPA* moderate-to-vigorous physical activity, *SED* sedentary time (sedentary), *NKQ* Nutrition Knowledge Questionnaire (max score 63), *DHS* Dietary Health Score (max score 43), *HFS* Healthy Food Score (max score 101)

*For column N, chi-square test for cross tabulate table SES in each city; for MVPA and SED Wilcoxon rank-sum test was performed comparing the medians between SES groups; for others, the T-test to compare means between SES groups

For comparison within each category, we used a nonparametric test to compare three clusters (1 vs. 2 vs. 3) for MVPA and SED, and ANOVA was used for NKQ, DHS, and HFS. If the tests were significant, we performed two-cluster comparisons (1 vs. 2, 1 vs. 3, and 2 vs. 3), using a nonparametric test for MVPA and SED, and T-test for NKQ, DHS, and HFS, with Bonferroni correction for multiple testing. (results in Supplement 2)

Table 4 Diet and activity cluster patterns in Yaoundé by socioeconomic status (SES) of the home neighbourhood

SES category	Cluster	*N* (%)	MVPA Median(IQR)	SED Median(IQR)	NKQ Mean(SD)	DHS Mean(SD)	HFS Mean(SD)
Low SES	1	46(26.9)	150(60–360)	446(324–531)	12.2(3.6)	24.8(7.0)	28.8(8.9)
	2	59(34.5)	120(60–255)	231(129–287)	12.2(3.6)	31.8(4.2)	23.2(6.3)
	3	66(38.6)	60(3-120)	274(189–360)	7.0(2.6)	30.0(5.5)	16.6(5.3)
	Total	171(100)	120(45–240)	283(197–390)	10.2(4.1)	29.2(6.2)	22.1(8.3)
High SES	1	20(35.7)	150(65–360)	501(416–574)	13.1(3.9)	24.9(6.1)	27.4(8.2)
	2	17(30.4)	90(60–120)	214(180–249)	13.7(3.7)	31.6(3.6)	24.1(4.2)
	3	19(33.9)	60(4-120)	326(231–441)	7.0(2.2)	30.2(4.8)	16.4(6.0)
	Total	56(100)	115(60–180)	341(236–491)	11.2(4.5)	28.8(5.7)	22.7(7.9)
	P value*	0.45	0.90	0.034	0.13	0.61	0.69

Data shown are the mean (SD) or median (IQR). *MVPA* moderate-to-vigorous physical activity, *SED* sedentary time (sedentary), *NKQ* Nutrition Knowledge Questionnaire (max score 63), *DHS* Dietary Health Score (max score 43), *HFS* Healthy Food Score (max score 101)

*For column N, the chi-square test compared overall low SES versus overall SES; for MVPA and SED, the Wilcoxon rank-sum test was performed to compare the medians between SES groups; for other variables, the t-test was used to compare the means between SES groups

For comparison within each category, we used a nonparametric test to compare three clusters (1 vs. 2 vs. 3) for MVPA and SED, and ANOVA was used for NKQ, DHS, and HFS. If the tests were significant, we performed two-cluster comparisons (1 vs. 2, 1 vs. 3, and 2 vs. 3), using a nonparametric test for MVPA and SED, and T-test for NKQ, DHS, and HFS, with Bonferroni correction for multiple testing. (results in Supplement 2)

between Clusters 1 and 3 sedentary time and between Clusters 2 and 3 eating habits. These results also suggest that high sedentary time clustered with unhealthy eating habits (Cluster 1), and low sedentary time clustered with healthy eating habits (Cluster 2). However, Cluster 3 had an intermediate pattern, clustering higher sedentary time (not different from Cluster 1) and healthy eating habits (not different from Cluster 3).

The results from Yaoundé suggested that high sedentary time clusters with unhealthy eating habits in both SES groups, as seen in Cape Town. However, the sedentary time of Cluster 3 was high among adolescents from a high SES household, leading to an unusually high sedentary time healthy diet pattern.

Kingston

Among adolescents from low SES households, the physical activity level was significantly higher in Cluster 1 than in Cluster 3 ($p = 0.008$). Sedentary time was significantly lower in Cluster 3 than in Clusters 1 ($p < 0.001$) and 2 ($p < 0.001$), while no difference was found between Clusters 1 and 2 (Table 5). Eating habits were significantly

Table 5 Diet and activity cluster patterns in Kingston according to socioeconomic status (SES) of the home neighbourhood

SES category	Cluster	*N* (%)	MVPA Median(IQR)	SED Median(IQR)	NKQ Mean(SD)	DHS Mean(SD)	HFS Mean(SD)
Low SES	1	26(27.1)	810(420–2275)	240(210–283)	14.4(4.5)	20.6(6.2)	36.8(11.6)
	2	21(21.9)	375(60–870)	257(206–274)	19.3(2.7)	32.1(4.6)	17.2(7.9)
	3	49(51.0)	225(0-662)	141(107–167)	12.2(5.3)	29.4(6.0)	15.6(7.8)
	Total	96(100)	400(58-1154)	195(131–257)	14.3(5.4)	27.6(7.2)	21.7(12.9)
High SES	1	11(17.7)	390(70-1070)	274(240–326)	16.8(4.9)	27.1(7.9)	40.2(13.1)
	2	36(58.1)	405(170–1103)	216(169–264)	20.1(2.6)	31.0(5.1)	18.5(7.5)
	3	15(24.2)	600(240–1518)	141(86–193)	11.6(5.2)	30.9(5.8)	12.0(9.1)
	Total	62(100)	435(150–1115)	210(146–261)	17.5(5.2)	30.3(6.0)	20.8(13.0)
	P value*	0.00002	0.54	0.33	0.0004	0.015	0.66

Data shown are the mean (SD) or median (IQR). *MVPA* moderate-to-vigorous physical activity, *SED* sedentary time (sedentary), *NKQ* Nutrition Knowledge Questionnaire (max score 63), *DHS* Dietary Health Score (max score 43), *HFS* Healthy Food Score (max score 101)

*For column N, chi-square test was used for cross tabulate table SES in each city; for MVPA and SED Wilcoxon rank-sum test was performed comparing the medians between SES groups; for others, the T-test was performed to compare means between SES groups

For comparison within each category, we used a nonparametric test to compare three clusters (1 vs. 2 vs. 3) for MVPA and SED, and ANOVA was used for NKQ, DHS, and HFS. If the tests were significant, we performed two-cluster comparisons (1 vs. 2, 1 vs. 3, and 2 vs. 3), using a nonparametric test for MVPA and SED, and T-test for NKQ, DHS, and HFS, with Bonferroni correction for multiple testing. (results in Supplement 2)

unhealthy in Cluster 1 compared to Clusters 2 ($p < 0.001$) and 3 ($p < 0.001$), while no difference was found between Clusters 2 and 3. These results suggest that high sedentary time was clustered with unhealthy eating habits (Cluster 1), while lower sedentary time was clustered with healthier eating habits (Cluster 3). However, Cluster 2 displayed intermediate high sedentary time (similar to Cluster 1) and healthy eating (similar to Cluster 3).

Among adolescents from high-SES households, sedentary time was significantly higher in Cluster 1 than in Clusters 2 ($p = 0.008$) and 3 ($p = 0.001$) and in Cluster 2 than in Cluster 3 ($p = 0.02$). No significant differences were found in physical activity and eating habits among the three clusters, suggesting that no clustering pattern was found.

The results from Kingston suggested that contrary to what we found in Yaoundé and Cape Town, the clustering of higher sedentary time with an unhealthy diet was not consistent across both SES groups. However, we found an unusual clustering of high sedentary time with a healthy diet among Cluster 2 adolescents from low socioeconomic households, as observed among Cluster 3 adolescents from high socioeconomic households in Yaoundé.

Stratified analysis of diet and activity clusters by school socio-economic status

Overall MVPA was lower among adolescents attending schools in high socioeconomic areas compared to their peers attending schools in low socioeconomic areas in Cape Town ($p = 0.0012$), conversely to Yaoundé, where the inverse was found ($p = 0.037$). Overall Sedentary time was significantly higher among adolescents attending school in high socioeconomic areas in Yaoundé ($p < 0.001$). Eating habits were healthier among adolescents attending school in high socioeconomic area in both Cape Town ($p < 0.001$) and Yaoundé ($p = 0.0046$), conversely to Kingston where the inverse was found ($p < 0.001$).

Cape Town

Physical activity was not significantly different across the clusters among adolescents attending school in low socioeconomic areas (Table 6). However, sedentary time was significantly lower in Cluster 1 than in Clusters 2 (0.03) and 3 ($p < 0.001$), while no difference was found between Clusters 2 and 3. Eating habits were significantly healthier in Cluster 1 than in Clusters 2 ($p = 0.001$) and 3 ($p = 0.02$). These results suggest that low sedentary time clustered with healthy eating habits (Cluster 1), whereas sedentary time clustered with unhealthy eating habits (Clusters 2 and 3).

Among adolescents attending school in high socioeconomic areas, physical activity was also not significantly different across the clusters. Sedentary time was significantly lower in Cluster 1 than in Clusters 2 ($p < 0.001$) and 3 ($p < 0.001$), while no difference was found between Clusters 2 and 3. Eating habits were healthier in Cluster 1 than in Clusters 2 ($p < 0.001$) and3 ($p = 0.01$), and in Cluster 3 than in Cluster 2 ($p < 0.001$). These results also suggest that low sedentary time clustered with healthy eating habits (Cluster 1) while higher sedentary time clustered with unhealthy eating habits (Cluster 2 and 3).

Table 6 Diet and activity cluster patterns in Cape Town by socioeconomic status (SES) of the school neighbourhood

SES category	Cluster	*N* (%)	MVPA Median(IQR)	SED Median(IQR)	NKQ Mean(SD)	DHS Mean(SD)	HFS Mean(SD)
Low SES	1	16(31.4)	240(188–395)	261(208–362)	13.4(3.0)	31.6(5.5)	38.3(10.2)
	2	8(15.7)	287(135–450)	404(364–448)	10.3(3.0)	22.4(4.5)	28.6(10.9)
	3	27(52.9)	195(90–355)	585(476–746)	18.0(2.4)	26.2(6.4)	34.4(13.6)
	Total	51(100)	240(120–360)	454(317–591)	15.3(4.0)	27.3(6.6)	34.7(12.4)
High SES	1	24(26.4)	553(353–815)	168(140–273)	13.2(4.9)	27.7(4.6)	35.3(14.0)
	2	33(36.3)	300(170–455)	523(256–716)	11.4(3.5)	14.6(5.8)	26.2(15.6)
	3	34(37.4)	435(255–750)	480(313–694)	17.6(2.9)	23.2(6.0)	27.7(14.0)
	Total	91(100)	400(225–750)	369(206–639)	14.2(4.6)	21.3(7.7)	29.2(14.9)
	P value*	0.031	0.0012	0.15	0.14	5.6e-6	0.025

Data shown are the mean (SD) or median (IQR). *MVPA* moderate-to-vigorous physical activity, *SED* sedentary time (sedentary), *NKQ* Nutrition Knowledge Questionnaire, *DHS* Dietary Health Score, *HFS* Healthy Food Score

*For column N, chi-square test was used for cross tabulate table SES in each city; for MVPA and SED Wilcoxon rank-sum test was performed comparing the medians between SES groups; for others, the T-test was performed to compare means between SES groups

For comparison within each category, we used a nonparametric test to compare three clusters (1 vs. 2 vs. 3) for MVPA and SED, and ANOVA was used for NKQ, DHS, and HFS. If the tests were significant, we performed two-cluster comparisons (1 vs. 2, 1 vs. 3, and 2 vs. 3), using a nonparametric test for MVPA and SED, and T-test for NKQ, DHS, and HFS, with Bonferroni correction for multiple testing. (results in Supplement 2)

Yaoundé

Among adolescents attending school in low socioeconomic areas, there was no difference in physical activity levels across clusters (Table 7). However, sedentary time was higher in Cluster 1 than in Cluster 2, whereas no difference was found between Clusters 2 and 3. Eating habits were significantly unhealthier in Cluster 1 compared to Clusters 2 ($p < 0.001$) and 3 ($p = 0.004$) while no difference was found between Cluster 2 and 3. These results suggest that higher sedentary time was associated with unhealthy eating habits (Cluster 1) and vice versa (Clusters 2 and 3).

Adolescents attending schools in high socioeconomic areas. Physical activity was significantly higher in Cluster 1 than in Cluster 3 ($p < 0.001$). Sedentary time was significantly higher in Cluster 1 compared to Cluster 2 ($p < 0.001$) and Cluster 3 ($p < 0.001$), and in Cluster 3 than in Cluster 2 ($p < 0.001$). However, eating habits were unhealthier in Cluster 1 compared to Clusters 2 ($p < 0.001$) and 3 ($p < 0.001$), while no difference was found between Clusters 2 and 3. These results also suggest that higher sedentary time was clustered with unhealthy eating habits (Cluster 1) and vice versa (Clusters 2 and 3), as seen among adolescents attending school in low socioeconomic areas.

Kingston

Table 8 shows that, among adolescents attending school in low socioeconomic areas, physical activity was significantly higher in Cluster 1 than in Cluster 3 ($p = 0.04$). Sedentary time was significantly lower in Cluster 3 than in Clusters 1 ($p < 0.001$) and 2 ($p = 0.006$), while no difference was found between Clusters 1 and 2. However, eating habits were significantly unhealthier in Cluster 1 compared to Clusters 2 ($p < 0.001$) and 3 ($p < 0.001$), while no difference was found between Clusters 2 and 3.

Among adolescents attending school in high socioeconomic areas, there were no significant differences in physical activity levels across the clusters. However, sedentary time was significantly lower in Cluster 3 than in Clusters 1 ($p = 0.001$) and 2 ($p < 0.001$), while no difference was found between Cluster 1 and 2. Eating habits were significantly unhealthier in Cluster 1 compared to Clusters 2 ($p = 0.001$) and 3 ($p = 0.01$), while no difference was found between Clusters 2 and 3.

These results suggest that, in both high and low school socioeconomic areas, high sedentary time was clustered with unhealthy eating habits (Cluster 1) and low sedentary time with unhealthy eating habits (Cluster 3). However, Cluster 2 presented an intermediate high sedentary healthy eating pattern in both SES areas.

Stratified analysis of diet and activity clusters by home-school SES

In this section, we sought to characterise the behaviour clustering pattern of adolescents from low-income households attending schools in high socioeconomic areas (Low-High (LH)). We have already presented the results of adolescents from low socioeconomic households attending schools in low socioeconomic areas (Low-Low (LL)) (LL category corresponds to all adolescents attending school in low socioeconomic areas) and from high socioeconomic households attending schools in high socioeconomic areas (High-High (HH)) (HH

Table 7 Diet and activity cluster patterns in Yaoundé by socioeconomic status (SES) of school neighbourhoods

SES category	Cluster	*N* (%)	MVPA Median(IQR)	SED Median(IQR)	NKQ Mean(SD)	DHS Mean(SD)	HFS Mean(SD)
Low SES	1	11(14.5)	180(60–390)	386(249–510)	11.5 (3.0)	23.4(10.1)	27.4(7.5)
	2	35(46.1)	150(60–260)	223(120–283)	11.6 (3.5)	32.5(4.5)	24.3(6.7)
	3	30(39.5)	100(20–240)	219(137–274)	6.5 (2.5)	31.3 (4.8)	16.3(5.9)
	Total	76(100)	120(60–265)	231(152–298)	9.6(4.0)	30.7(6.4)	21.6(7.8)
High SES	1	55(36.4)	150(60–360)	454(369–540)	12.6(3.8)	25.2(5.9)	28.6(8.9)
	2	41(27.2)	80(50–140)	240(189–283)	13.3(3.6)	31.1(3.6)	22.6(5.1)
	3	55(36.4)	50(3-120)	326(249–446)	7.3(2.5)	29.4(5.5)	16.7(5.3)
	Total	151(100)	80(30–180)	330(241–454)	10.9(4.3)	28.3(5.7)	22.6(8.4)
	P value*	0.00096	0.037	8.3e-9	0.026	0.0046	0.39

Data shown are the mean (SD) or median (IQR). *MVPA* moderate-to-vigorous physical activity, *SED* sedentary time (sedentary), *NKQ* Nutrition Knowledge Questionnaire, *DHS* Dietary Health Score, *HFS* Healthy Food Score

*For column N, chi-square test was used for cross tabulate table SES in each city; for MVPA and SED Wilcoxon rank-sum test was performed comparing the medians between SES groups; for others, the T-test was performed to compare means between SES groups

For comparison within each category, we used a nonparametric test to compare three clusters (1 vs. 2 vs. 3) for MVPA and SED, and ANOVA was used for NKQ, DHS, and HFS. If the tests were significant, we performed two-cluster comparisons (1 vs. 2, 1 vs. 3, and 2 vs. 3), using a nonparametric test for MVPA and SED, and T-test for NKQ, DHS, and HFS, with Bonferroni correction for multiple testing. (results in Supplement 2)

Table 8 Diet and activity cluster patterns in Kingston according to socioeconomic status (SES) of the school neighbourhood

SES category	Cluster	*N* (%)	MVPA Median(IQR)	SED Median(IQR)	NKQ Mean(SD)	DHS Mean(SD)	HFS Mean(SD)
Low SES	1	22(32.8)	1080(420–2320)	255(210–321)	14.1(4.8)	20.9(6.0)	37.8(11.9)
	2	10(14.9)	585(240–1500)	238(201–270)	18.9(2.8)	31.5(6.0)	19.2(7.5)
	3	35(52.2)	240(0-960)	141(107–184)	10.9(5.5)	28.3(6.1)	15.2(8.1)
	Total	67(100)	500(60-1650)	193(129–261)	13.1(5.6)	26.4(7.2)	23.2(14.0)
High SES	1	15(16.5)	420(135–1070)	257(219–326)	16.7(4.2)	25.0(8.5)	37.7(12.6)
	2	47(51.6)	360(120–1080)	223(184–270)	20.0(2.6)	31.4(4.8)	17.7(7.7)
	3	29(31.9)	380(120–790)	141(90–167)	13.4(4.7)	31.4(5.4)	14.2(8.4)
	Total	91(100)	380(120–920)	206(141–257)	17.4(4.7)	30.4(6.1)	19.9(12.0)
	P value*		0.35	0.53	8.7e-7	0.00023	0.11

Data shown are the mean (SD) or median (IQR). *MVPA* moderate-to-vigorous physical activity, *SED* sedentary time (sedentary), *NKQ* Nutrition Knowledge Questionnaire, *DHS* Dietary Health Score, *HFS* Healthy Food Score

*For column N, chi-square test was used for cross tabulate table SESr in each city; for MVPA and SED Wilcoxon rank-sum test was performed comparing the medians between SES groups; for others, the T-test was performed to compare means between SES groups

For comparison within each category, we used a nonparametric test to compare three clusters (1 vs. 2 vs. 3) for MVPA and SED, and ANOVA was used for NKQ, DHS, and HFS. If the tests were significant, we performed two-cluster comparisons (1 vs. 2, 1 vs. 3, and 2 vs. 3), using a nonparametric test for MVPA and SED, and T-test for NKQ, DHS, and HFS, with Bonferroni correction for multiple testing. (results in Supplement 2)

corresponds to all adolescents from high socioeconomic households).

Cape Town

Among LH adolescents, there were no differences in physical activity levels across the clusters. However sedentary time was significantly lower in Cluster 1 than in Clusters 2 ($p=0.001$) and 3 ($p<0.001$) while no difference was found between Clusters 2 and 3 (Table 9). Eating habits were unhealthier in Cluster 2 than in Clusters 1 ($p<0.001$) and 3 ($p=0.015$), while no difference was found between Cluster 1 and 3. These results suggest that low sedentary time clustered with healthier eating habits (Cluster 1), while higher sedentary time clustered with

Table 9 Diet and activity cluster patterns in Cape Town stratified by the combination of socioeconomic status (SES) of home and school neighbourhoods

SES category	Cluster	*N* (%)	MVPA Median(IQR)	SED Median(IQR)	NKQ Mean(SD)	DHS Mean(SD)	HFS Mean(SD)
Low Low	1	16(31)	240(188–395)	261(208–362)	13.4(3.0)	31.6(5.5)	38.3(10.2)
	2	8(16)	287(135–450)	404(364–448)	10.3(3.0)	22.4(4.5)	28.6(10.9)
	3	27(53)	195(90–355)	585(476–746)	18.0(2.4)	26.2(6.4)	34.4(13.6)
	Total	51(100)	240(120–360)	454(317–591)	15.3(4.0)	27.3(6.6)	34.7(12.4)
Low High	1	9(22)	430(350–785)	159(118–257)	11.8(6.2)	27.3(4.6)	40.6(17.5)
	2	18(44)	275(165–405)	467(206–789)	11.7(3.1)	14.9(5.9)	23.8(14.4)
	3	14(34)	398(265–625)	690(497–789)	16.4(3.1)	22.1(7.6)	29.0(17.7)
	Total	41(100)	330(225–560)	489(227–737)	13.3(4.5)	20.1(7.9)	29.2(17.1)
High High	1	15(30)	665(355–840)	171(159–317)	14.0(3.8)	27.9(4.7)	32.2(10.9)
	2	15(30)	330(20’0-915)	566(256–660)	10.9(3.9)	14.3(5.9)	29.1(16.9)
	3	20(40)	435(203–758)	379(283–510)	18.6(2.5)	23.9(4.6)	26.8(11.0)
	Total	50(100)	445(255–790)	319(206–549)	14.9(4.6)	22.2(7.4)	29.1(12.9)
	P value*	0.058	0.0020	0.039	0.078	0.00014	0.083

Data shown are the mean (SD) or median (IQR). *MVPA* moderate-to-vigorous physical activity, *SED* sedentary time (sedentary), *NKQ* Nutrition Knowledge Questionnaire, *DHS* Dietary Health Score, *HFS* Healthy Food Score

*For column N, chi-square test was used for cross tabulate table SES in each city; for MVPA and SED, a nonparametric K-sample test on the equality of medians among SES groups; for others, ANOVA test was performed to compare means among SES groups

For comparison within each category, we used a nonparametric test to compare three clusters (1 vs. 2 vs. 3) for MVPA and SED, and ANOVA was used for NKQ, DHS, and HFS. If the tests were significant, we performed two-cluster comparisons (1 vs. 2, 1 vs. 3, and 2 vs. 3), using a nonparametric test for MVPA and SED, and T-test for NKQ, DHS, and HFS, with Bonferroni correction for multiple testing. (results in Supplement 2)

unhealthy eating habits (Cluster 2), with Cluster 3 presenting an intermediate pattern of high sedentary time and healthy eating habits.

Findings from LL and HH also suggested that low sedentary time was clustered with healthy eating habits (Cluster 1 in LL and Clusters 1 and 3 in HH), while high sedentary time was clustered with unhealthy eating habits (Cluster 2 and 3 in LL and Cluster 2 in HH), suggesting that low sedentary time clusters with healthy eating habits (Cluster 1), whereas higher sedentary time clusters with unhealthy eating habits (Cluster 2) across the three home school categories. However, Cluster 3 had a fluctuating pattern across categories, appearing unhealthier (highly sedentary and unhealthy eaters) in LL, intermediate in LH (highly sedentary and healthy eaters), and healthier (less sedentary and healthy eaters) in HH.

Yaoundé

Table 10 shows that, among LH adolescents, physical activity was significantly higher in Cluster 1 than in Cluster 3 ($p < 0.001$). Sedentary time was significantly higher in Cluster 1 than in Clusters 2 ($p < 0.001$) and 3 ($p = 0.019$), while it was lower in Cluster 2 than in Cluster 3 ($p = 0.025$). However, eating habits were unhealthier in Cluster 1 than in Clusters 2 ($p < 0.001$) and 3 ($p = 0.034$), while no difference was found between Clusters 2 and 3. These results suggest that higher sedentary time clustered with unhealthy eating habits (Cluster 1), whereas lower sedentary time clustered with healthy eating habits (Clusters 2 and 3).

Findings from LL and HH suggest that higher sedentary time was clustered with unhealthy eating habits (Cluster 1), while low sedentary time clustered with healthy eating habits (Cluster 2 and 3 in LL and Cluster 2 in HH). These results displayed a consistent clustering pattern of low sedentary time healthy eaters and high sedentary time unhealthy eaters across the three home-school categories.

Kingston

Among LH adolescents, there was no difference in physical activity levels across clusters. Sedentary time was higher in Cluster 2 than in Cluster 3 ($p < 0.001$), whereas no differences were found between the other clusters. However, eating habits were unhealthier in Cluster 1 than in Clusters 2 ($p = 0.001$) and 3 ($p = 0.004$), whereas no difference was found between Clusters 2 and 3. These results did not suggest distinct clustering patterns in this category.

Regarding findings from adolescents from low socioeconomic households attending schools in low socioeconomic areas, high sedentary time was clustered with unhealthy eating habits (Cluster 1) and low sedentary time with unhealthy eating habits (Cluster 3); however, Cluster 2 had intermediate higher sedentary time and healthy eating pattern. No clustering patterns were

Table 10 Diet and activity cluster patterns in Yaoundé stratified by the combination of the home-school SES socioeconomic status (SES) of home and school neighbourhoods

SES category	Cluster	*N* (%)	MVPA Median(IQR)	SED Median(IQR)	NKQ Mean(SD)	DHS Mean(SD)	HFS Mean(SD)
Low Low	1	11(14)	180(60–390)	386(249–510)	11.5(3.0)	23.4(10.1)	27.4(7.5)
	2	35(46)	150(60–260)	223(120–283)	11.6(3.5)	32.5(4.5)	24.3(6.7)
	3	30(39)	100(20–240)	219(137–274)	6.5(2.5)	31.3(4.8)	16.3(5.9)
	Total	76(100)	120(60–265)	231(152–298)	9.6(4.0)	30.7(6.4)	21.6(7.8)
Low High	1	35(37)	150(60–360)	446(334–531)	12.4(3.8)	25.3(5.9)	29.2(9.3)
	2	24(25)	78(38–150)	244(191–291)	13.1(3.7)	30.7(3.6)	21.5(5.5)
	3	36(38)	50(2–80)	328(249–446)	7.5(2.7)	28.9(5.9)	16.8(4.9)
	Total	95(100)	65(30–180)	326(249–454)	10.7(4.2)	28.1(5.8)	22.6(8.8)
High High	1	20(36)	150(65–360)	501(416–574)	13.1(3.9)	24.9(6.1)	27.4(8.2)
	2	17(30)	90(60–120)	214(180–249)	13.7(3.7)	31.6(3.6)	24.1(4.2)
	3	19(34)	60(4-120)	326(231–441)	7.0(2.2)	30.2(4.8)	16.4(6.0)
	Total	56(100)	115(60–180)	341(236–491)	11.2(4.5)	28.8(5.7)	22.7(7.9)
	P value*	0.0063	0.018	5.4e-6	0.067	0.014	0.69

Data shown are the mean (SD) or median (IQR). *MVPA* moderate-to-vigorous physical activity, *SED* sedentary time (sedentary), *NKQ* Nutrition Knowledge Questionnaire, *DHS* Dietary Health Score, *HFS* Healthy Food Score

*For column N, chi-square test was used for cross tabulate table SES in each city; for MVPA and SED, a nonparametric K-sample test on the equality of medians among SES groups; for others, ANOVA test was performed to compare means among SES groups

For comparison within each category, we used a nonparametric test to compare three clusters (1 vs. 2 vs. 3) for MVPA and SED, and ANOVA was used for NKQ, DHS, and HFS. If the tests were significant, we performed two-cluster comparisons (1 vs. 2, 1 vs. 3, and 2 vs. 3), using a nonparametric test for MVPA and SED, and T-test for NKQ, DHS, and HFS, with Bonferroni correction for multiple testing. (results in Supplement 2)

found among adolescents from high socioeconomic households.

These results suggest that all the previously described clustering patterns (low sedentary healthy eaters, high sedentary unhealthy eaters, and high sedentary healthy eaters) appeared only among adolescents attending school in low socioeconomic areas in Kingston, whereas no distinct clustering patterns appeared among adolescents attending school in high socioeconomic areas, regardless of their socioeconomic status.

Eating habits differed significantly between Cluster 1 and the remaining clusters (Cluster 1 vs. 2, $p=0.001$ and Cluster 1 vs. 3, $p=0.004$) while sedentary time differed only between clusters 2 and 3 ($p<0.001$) among adolescents in the LH category.

We did not find a distinct clustering pattern with healthy eating habits associated with both significantly high (Cluster 2) and low (Cluster 3) sedentary time and unhealthy eating with non-significant sedentary time (Cluster 1). As shown before, we did not observe any distinct clustering pattern among adolescents from high socioeconomic households (High-High). However, we found an inverse clustering relationship between sedentary behaviours and eating habits among adolescents attending schools in low socioeconomic areas (Low-Low).

The unique finding of a discrepancy in clustering patterns among different categories of the same strata identified in Kingston was further highlighted by the lack of a consistent pattern among the three home school categories (Table 11).

Discussion

This study examined the extent to which diet and activity patterns were clustered in three LMIC cities at different stages of nutritional and epidemiological transition. We found that more time spent in sedentary behaviours clustered with poor eating habits at all three sites. This pattern persisted across the strata in both cities and was associated with varying levels of physical activity.

Our results on sedentary patterns align with previous research [33]. Adolescents from low-SES households in Cape Town and Kingston spent more time on sedentary behaviours, whereas in Yaoundé, higher levels of sedentary behaviour were more prevalent among high-SES adolescents. A systematic review by Mielke et al. found a positive association between SES and sedentary behaviour in LMICs, and an inverse association in high-income countries [39]. In Kingston and Cape Town, both upper-middle-income countries cities, adolescents displayed sedentary behaviour like in high-income countries.

Consistent with Micklesfield et al.'s study in rural South African adolescents, higher SES was associated with more sedentary behaviours, such as watching television and reading [32]. In contrast, McVeigh et al. found that lower SES was associated with more television time

Table 11 Diet and activity cluster patterns in Kingston stratified by the combination of the home-school SES socioeconomic status (SES) of home and school neighbourhoods

SES category	Cluster	*N* (%)	MVPA Median(IQR)	SED Median(IQR)	NKQ Mean(SD)	DHS Mean(SD)	HFS Mean(SD)
Low Low	1	22(33)	1080(420–2320)	255(210–321)	14.1(4.8)	20.9(6.0)	37.8(11.9)
	2	10(15)	585(240–1500)	238(201–270)	18.9(2.8)	31.5(6.0)	19.2(7.5)
	3	35(52)	240(0-960)	141(107–184)	10.9(5.5)	28.3(6.1)	15.2(8.1)
	Total	67(100)	500(60-1650)	193(129–261)	13.1(5.6)	26.4(7.2)	23.2(14.0)
Low High	1	4(14)	765(450–1320)	223(178–236)	16.3(2.1)	19.3(8.1)	31.0(9.0)
	2	11(38)	290(30–565)	266(206–339)	19.7(2.6)	32.6(3.1)	15.4(8.1)
	3	14(48)	135(0-450)	131(107–167)	15.3(3.2)	32.0(5.0)	16.6(7.1)
	Total	29(100)	290(45–565)	197(141–257)	17.1(3.5)	30.5(6.6)	18.1(9.2)
High High	1	11(18)	390(70–1070)	274(240–326)	16.8(4.9)	27.1(7.9)	40.2(13.1)
	2	36(58)	405(170–1103)	216(169–264)	20.1(2.6)	31.0(5.1)	18.5(7.5)
	3	15(24)	600(240–1518)	141(86–193)	11.6(5.2)	30.9(5.8)	12.0(9.1)
	Total	62(100)	435(150–1115)	210(146–261)	17.5(5.2)	30.3(6.0)	20.8(13.0)
	P value*	1.3e-5	0.17	0.75	5.5e-6	0.0011	0.19

Data shown are the mean (SD) or median (IQR). *MVPA* moderate-to-vigorous physical activity, *SED* sedentary time (sedentary), *NKQ* Nutrition Knowledge Questionnaire, *DHS* Dietary Health Score, *HFS* Healthy Food Score

*For column N, chi-square test was used for cross tabulate table SES in each city; for MVPA and SED, a nonparametric K-sample test on the equality of medians among SES groups; for others, ANOVA test was performed to compare means among SES groups

For comparison within each category, we used a nonparametric test to compare three clusters (1 vs. 2 vs. 3) for MVPA and SED, and ANOVA was used for NKQ, DHS, and HFS. If the tests were significant, we performed two-cluster comparisons (1 vs. 2, 1 vs. 3, and 2 vs. 3), using a nonparametric test for MVPA and SED, and T-test for NKQ, DHS, and HFS, with Bonferroni correction for multiple testing. (results in Supplement 2)

in a younger urban South African cohort [40]. A South African study on adolescents of the same cohort as the current study showed that walkability index was lower in adolescents from low SES with high crime rate, inadequate places for walking, cycling and playing and poor aesthetic contributory factors. These contributory factors may also be associated with higher sedentary behaviours in adolescents from lower SES as they are more likely to be spent more time indoor than adolescents when compared with their higher SES counterpart [33]. The poorer setting in Yaoundé compared to Cape Town may explain the sedentary patterns among low-SES individuals. In Kingston, a unique pattern emerged based on SES, with a positive association between sedentary behaviour and physical activity in the high-SES group and an inverse association in the low-SES group. Adolescents from low-SES households may engage in less activity due to safety concerns or limited access to outdoor areas [41], and instead may use after-school hours to generate additional income for their families, increasing their activity, and reducing their sedentary patterns [42].

Our findings support previous research indicating an association between sedentary behaviours and unhealthy diets [1, 43], regardless of SES. During adolescence, parents play a significant role in shaping behaviours such as watching television, playing computer games, and eating at home [8, 44]. Research has consistently shown that high screen time, including TV, computer, and video game use, is linked to negative health outcomes [45]. The co-occurrence of unhealthy diet and sedentary behaviours suggests that being at risk for one behaviour increases the likelihood of being at risk for another [46]. Television viewing may be associated with increased food intake, especially if children have access to snacks and drinks while watching [8]. Additionally, high screen time is associated with increased consumption of junk food, reduced intake of fruits and vegetables [47], increased loneliness and depression [48], decreased social interactions [49], and poor sleeping patterns [50]. These findings highlight the importance of interventions targeting adolescent screen time to address risk factors for NCDs [51, 52].

Unhealthy snacking habits and sedentary behaviour were prevalent among urban adolescents in Cape Town, Yaoundé, and Kingston, highlighting the need for culturally appropriate initiatives that promote healthier behaviours in this age group [53]. Research has shown that these habits tend to persist into adulthood and are interconnected [46], suggesting that interventions targeting multiple behaviours simultaneously may be the most efficient approach. In so doing, it is important to recognise the potential impact of educational, cultural, and social sedentary activities on adolescents' lives, as they can have positive effects on their academic performance and mental health [54]. However, finding a balance between sedentary and physical activity is crucial.

The journey from home to school is an overlooked context that presents opportunities for intervention. Urban sprawl, characterised by the rapid geographic expansion of LMIC cities, may increase the distance to school [55] and thus increase exposure to unhealthy environmental factors for school-going adolescents [56]. These varying experiences can differentially affect adolescents, even within the same city. Given this reality, we used three categories as proxies for these differing home and school SES experiences: adolescents from low-income households attending schools located in low-income or high-income settings and adolescents from high-income households attending schools in similar SES contexts. Although the importance of school and home environments has been documented previously [27], little attention has been paid to the exposure encountered during this daily commute. SES plays a role in the consumption of street food and fast food, with the urban poor predominantly affected by their purchasing power [57]. Our study underscores that socioeconomic status significantly influences dietary behaviours and, thus, potentially food security among urban residents [58]. The availability and quality of food options are shaped not only by the urbanisation level but also by the specific school and community environments [59, 60]. These environments often disproportionately offer unhealthy foods while limiting healthier alternatives [56, 61]. In Yaoundé, hygiene concerns have led to regulations discouraging fresh produce in schools, paradoxically promoting processed foods that compromise health [62, 63]. For example, until recently, soft drinks in Cameroon were labelled as hygienic drinks, signalling "healthiness" to consumers. This reduction in the availability of healthy food and switching to cheaper processed food heightens the exposure of lower-SES students to obesogenic environments [64, 65]. However, low-SES students attending higher-SES schools may find more diverse food options unaffordable and, therefore, inaccessible [60, 66]. Moreover, evidence from high-income countries posits that the socioeconomic locale of schools plays a crucial role in shaping adolescent activity levels. However, elements such as school social cohesion also affect adolescent behaviour [44]. Therefore, interventions should adopt a multilayered approach to address the intricate interplay of school environments in shaping physical and dietary habits [67]. Our study underscores the critical need for targeted interventions that improve adolescent health, focusing not only on home and school environments but also on daily dynamic exposures that may influence behaviour. Specifically, our findings illuminate the varying intervention needs across cities and socioeconomic strata, as well as during commutes from home to school. Efficacious strategies from a systematic review conducted by Racey et al. include interventions of six weeks to five months targeting school environments [68] and multifaceted approaches involving peers, media education, and individualised computer-based feedback [69, 70]. Reducing sedentary time to the recommended level can have an impact on a wide range of risk factors for noncommunicable diseases at the household level. Our findings suggest that school-based interventions to improve diet and physical activity should be cognisant of the potential impact of students' household SES and the potential modifying influence of their journey from home to school.

Our study revealed a universal deficit in nutritional knowledge and suboptimal consumption of healthy foods, highlighting the multiple contributing factors that require a nuanced approach. Limited access to reliable nutritional information and affordability challenges are key barriers, often exacerbated by cultural norms and societal influences that favour unhealthy choices. Advertising campaigns magnify these issues by associating unhealthy products with their desirable attributes. Exposure to such marketing strategies may differ depending on household and school SES strata and the mode and duration of the journey from home to school. In today's fast-paced world, individual constraints, such as time and cooking skills, further compromise nutrition, as processed foods offer seemingly convenient but unhealthy alternatives. Addressing this complex issue necessitates multifaceted multilevel interventions, including educational initiatives to bolster nutritional literacy and systemic changes to enhance food accessibility and reduce NCD risk at this critical life stage.

Strength and limitations

This study offers valuable insights into the clustering of diet, PA, and sedentary behaviour among adolescents, particularly focusing on the influence of SES levels in residential and school neighbourhoods. A key strength lies in our use of cluster analysis, which allows for a holistic understanding beyond isolated behaviours. However, this study has some limitations. The sampling design inherently introduces data dependency, as students from the same school (or class) are more likely to exhibit similar behaviours owing to shared environments and norms. However, existing research suggests low intra-class correlation at the school level, particularly since we focused on behaviours outside school [71]. Self-reported measures of PA and nutrition have known limitations [72], although our instruments have demonstrated reliability and validity in LMIC [29, 30, 32]. The three home school SES categories were assumed to have different environmental influences; however, their environmental features were not measured. Furthermore, the retrospective nature of data collected might induce a recall bias. Future studies should consider sex-specific analyses to understand different sedentary behaviours and their correlates. A prospective cohort study could further clarify the stability and evolution of these behavioural clusters and their sociodemographic and environmental determinants.

Conclusion

This study revealed complex behavioural clustering patterns that significantly impact the risk of NCDs among adolescents in three LMIC cities: Cape Town, Yaoundé, and Kingston. Our key finding that screen time and eating habits frequently cluster indicates that targeted interventions to reduce sedentary time could have a ripple effect on multiple NCD risk factors, including diet, physical activity, and mental health. Interestingly, we observed variations in how sedentary behaviours and eating patterns clustered, especially when comparing adolescents from different socioeconomic households and school areas in Kingston. These intricate interactions underscore the need for multifaceted interventions that transcend a one-size-fits-all approach. Efforts must be tailored to address the complexities of individual behaviours, environmental influences, and socio-demographic factors to optimise the impact and cost-effectiveness of interventions aimed at preventing obesity. Longitudinal studies are vital for understanding the evolving nature of obesogenic behaviours, studying dynamically changing environments to better understand exposure, and refining strategies to protect and promote health at this critical life stage.

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

YW and LT led the conceptualisation, initial drafting, and overall drafting of the manuscript, supported by FW and CMT. TO (senior author) co-led the conceptualisation of the research proposal and contributed to drafting the manuscript. LM, JS and LF co-led the drafting of the significant components of the manuscript and the overall drafting process. EVL, CF, and JL drafted and edited the manuscript subsections. JCM and FA contributed to manuscript editing and finalisation.

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Data availability
The data presented in this study are available upon request from the corresponding author.

Declarations

Ethics approval and consent to participate
Ethical approval was obtained from the Centre Regional Ethics Committee of the Human Health Research (CE No. 1836 CRERSHC/2020) in Yaoundé) and relevant education departments such as the school district administration and principals of selected schools. This study was conducted in accordance with the Declaration of Helsinki and the Association for Adolescent Health Research Guidelines [73] Written. Informed assent was obtained from all adolescents (aged < 18 years), and written informed consent was obtained from their parents or caregivers.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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