Co-occurrence of and factors associated with health risk behaviors among adolescents: a multi-center study in sub-Saharan Africa, China, and India

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eClinicalMedicine
2024;70: 102525

Published Online xxx
https://doi.org/10.1016/j.eclinm.2024.102525

Summary

Background Despite lifelong and detrimental effects, the co-occurrence of health risk behaviors (HRBs) during adolescence remains understudied in low- and middle-income countries. This study examines the co-occurrence of HRBs and its correlates among adolescents in sub-Saharan Africa, China, and India.

Methods A multi-country cross-sectional study was conducted in 2021–2022, involving 9697 adolescents (aged 10–19 years) from eight countries, namely Burkina Faso, China, Ethiopia, India, Ghana, Nigeria, Tanzania, and Uganda. A standardized questionnaire was administered to examine five types of HRBs – physical inactivity, poor dietary habits, smoking, alcohol consumption, and risky sexual behavior. Latent class analysis was employed to identify clustering patterns among the behaviors, and logistic regression was used to identify the correlates of these patterns.

Findings Three clusters of HRBs were identified, with Cluster 1 (27.73%) characterized by the absence of any specific risky behavior, Cluster 2 (68.16%) characterized by co-occurrence of physical inactivity and poor dietary habits, and Cluster 3 (4.11%) characterized by engagement in smoking, alcohol consumption, and risky sexual behavior. Relative to Cluster 1, being in Cluster 2 was associated with being female (aOR 1.20, 95% CI 1.09–1.32), not enrolled in education (aOR 0.84, 95% CI 0.71–0.99), and not engaged in paid work (aOR 1.23, 95% CI 1.08–1.41). Compared with those Cluster 1, adolescents in Cluster 3 were less likely to be female (aOR 0.41, 95% CI 0.32–0.54), be engaged in paid work (aOR 0.54, 95% CI 0.41–0.71), more likely to be older (aOR 7.56, 95% CI 5.18–11.03), not be enrolled in educational institution (aOR 1.74, 95% CI 1.27–2.38), and more likely to live with guardians other than parents (aOR 1.56, 95% CI 1.19–2.05).

Interpretation The significant clustering patterns of HRBs among adolescents in sub-Saharan Africa, China, and India highlights the urgent need for convergent approaches to improve adolescent health behaviors. Early life and school-based programs aimed at promoting healthy behaviors and preventing risky and unhealthy behaviors should be prioritized to equip adolescents with the tools and skills for lifelong well-being.

Funding Fondation Botnar (Grant #INV-037672) and Harvard T.H. Chan School of Public Health, partially funded this study.

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Keywords: Health risk behavior; Co-occurrence; Adolescents; Sub-Saharan Africa; Latent class analysis

Research in context

Evidence before this study

Adolescent health risk behaviors intricately cluster, involving behaviors like cigarette and alcohol use, poor eating habits, sedentary lifestyles, and risky sexual behaviors. Uncovering these patterns and their determinants, especially in LMICs, is crucial for developing effective preventive measures that address the interconnected nature of these behaviors.

Added value of this study

We examined the cooccurrence of health risk behaviors and their correlates among adolescents aged 10–19 years old using cross-sectional data collected in community- and school-based settings in six countries in sub-Saharan Africa and two countries in Asia. We found that nearly three-fourth of adolescents engaged in 2–3 risk behaviors, with a predominant clustering of physical inactivity and poor dietary habits among the majority of adolescents. Additionally, a minority cluster emerged due to the co-occurrence of smoking, alcohol consumption, and risky sexual behavior. Socio-economic factors including age, sex, educational enrolment, work experience, and family cohabitants were significant correlates of these two clusters.

Implications of all the available evidence

Our findings underscore the urgent need for high-quality, multi-pronged programs in schools and communities to prevent multiple health risk behaviors. Education and behavior change strategies should be combined in these programs to prevent unhealthy and risky behaviors and promote healthy lifestyles.

Introduction

Health risk behaviors (HRBs) are prevalent during adolescence (10–19 years old), typically occurring between the ages of 10 and 19 years old.[1–3] These behaviors encompass a wide range of activities, including smoking, poor nutrition, alcohol consumption, and physical inactivity, collectively known as "SNAP" risk factors.[4] These factors can contribute to the development of non-communicable diseases later in their life and significantly increase the morbidity and mortality in low-income countries.[4,5] The World Health Organization's Global Burden of Disease study estimated that HRBs account for approximately two-thirds of all premature deaths in adults that are associated with childhood risk behaviors.[6] Besides, risky sexual behaviors also pose a substantial health concern for adolescents on a global scale. For example, it was estimated that 21%–64% unmarried adolescents did not use contraception during their sexual activity in sub-Saharan Africa.[7] Such behaviors can not only lead to early pregnancy and childbirth complications which are the primary causes of mortality among girls aged 15–19 years, but also result in sexually transmitted diseases which are infected by one million people every day.[8,9] Specifically, there were 93,000 African adolescents aged 15–19 infected with HIV in 2022, accounting for over 70% of HIV new infections globally.[10]

Co-occurrence of HRBs refers to the phenomenon where adolescents engage in multiple types of HRBs simultaneously.[11] This can include various combinations of substance use, unhealthy dietary habits, physical inactivity and risky sexual behaviors. The clustering of HRBs poses significant health risks during adolescence and later during adulthood as the cumulative effects of multiple unhealthy behaviors can increase vulnerability to chronic diseases including physical and psychosocial health issues.[12] In reality, HRBs seldom occur in isolation but tend to co-occur, often in a synergistic manner.[11] Some classical theories have illustrated the mechanism of HRBs co-occurrence. Gateway theories posit that involvement in one form of risk behavior can increase the exposure and desire for additional risky behaviors, and diminish the perceived danger of other risky behaviors.[13] The problem behavior theory posits a set of shared risk factors for engaging in risky behaviors, with protective factors diminishing the likelihood of problem behavior while risk factors augment it.[13] Substantial evidence suggests when HRBs co-occur among adolescents, their combined effects can be more detrimental than when they occur independently.[11] For instance, the heightened prevalence of four common risk factors has been associated with a significant 3.35-fold increase in non-communicable disease mortality.[12] These effects are particularly pronounced in low- and middle-income countries (LMICs).[14]

Consequently, preventing the co-occurrence of HRBs assumes paramount significance. Addressing individual risk behaviors in isolation is unlikely to yield enduring results,[15] and addressing multiple HRBs concurrently is proved to be more cost-effective, particularly in light of constrained healthcare resources.[16] Currently, most health policies regarding adolescent HRBs are managed in a nonoverlapping risk-specific way.[17] Shifting to preventive approaches that focus on shared risk factors is essential for effectively addressing multiple risk behaviors.[17,18] For instance, school-based education has been advocated as an effective approach to mitigate multiple HRBs in adolescents by teaching life skills that target

these risk factors and by fostering personal assets like positive mental health and health-related attitudes.[17,18] Additionally, family-targeted interventions addressing family connectedness, parental attitudes and involvement in HRBs have been trialed in various countries to mitigate multiple HRBs in adolescents.[17,18] However, the majority of such interventions aimed with multiple HRBs simultaneously are primarily available in only high-income countries.[17–19]

To enhance the interventions of multiple HRBs among adolescents in LMICs, there is a pressing need to consolidate scientific evidence regarding their potential co-occurrence of HRBs. In Asia, a cross-sectional study involving 3578 adolescents across 11 districts in Malaysia revealed that one-third of adolescents exhibited the co-occurrence of two or more HRBs.[20] Similarly, in Nepal, a cross-sectional survey of 1108 adolescents revealed a prevalence of 40.7% having co-occurrence of HRBs.[5] In China, a cross-sectional study involving 4625 adolescents indicated that 67.7% of males and 58.1% of females were engaged in multiple HRBs.[21] The situation is even more pronounced in sub-Saharan Africa, home to the largest proportion of adolescents and youths, where an estimated 89.2% of adolescents were reported to engage in at least 2 HRBs, based on data pooled from nine countries.[22] In Liberia, a cross-sectional study found 65.2% of middle school students were at moderate or high risk of having multiple HRBs,[23] while in Kenya, this figure stood at 77.1%.[24] In Ghana, a cross-sectional survey with 1763 senior high school students aged 11–19 years found that 94.8% had more than one HRBs.[25] Across the world, a global school-based research with 304,779 adolescents aged 11–17 years old from 89 countries found that over 30% had 3 or more HRBs.[26] These findings highlight the importance of designing effective and efficient interventions that take advantage of the age of opportunities and the triple dividend of investing in adolescent health.[27,28]

It is also imperative to identify the specific risk factors contributing to this complex phenomenon. Several multi-center studies have underscored variations in the influence of sex and age on the co-occurrence of HRBs.[22,26,29] Notably, both male and female adolescents had evident physical inactivity and poor diet, but males were more likely to have substance use.[26] And older adolescents had higher odds of reporting co-occurrence of HRBs.[26] Besides, a series of national-level evidence from African countries like Liberia, Ghana, and Kenya examined risk factors among distinct clusters of adolescents based on their HRBs and lifestyles.[23–25] It was found that school attendance and level of parental monitoring were significantly associated with the risk of adolescent HRBs clustering.[24] A lower socio-economic status was also associated with higher risk of co-occurrence of HRBs among adolescents.[23]

However, there is still a critical knowledge gap on HRBs among adolescents in LMICs, where 90% of all adolescents reside in.[3] Most of evidence was inferred from school-based sampling frameworks, normally focusing on middle-school adolescents, resulting in a gap of understanding for out-of-school, migrant, younger, and vulnerable adolescents. Therefore, the objectives of this study, as a multi-center analysis integrating adolescents from both schools and communities, are to describe the prevalence of co-occurrence of HRBs among adolescents in six sub-Saharan African countries and two Asian countries, encompassing smoking, alcohol consumption, poor dietary habits, physical inactivity, and risky sexual behavior, as well as identify the shared risk factors.

Methods

Study design

We conducted a multi-country cross-sectional survey with 9697 adolescents aged 10–19 years in eight countries from November 2021 to August 2022.[3] Conducted under the aegis of the Africa Research, Implementation Science and Education (ARISE) Network, this study is part of the first year of a prospective longitudinal cohort study on the health and well-being of adolescents in LMICs.[30] The cross-sectional survey was conducted in six sub-Saharan African countries (i.e., Nouna, Burkina Faso; Harar, Ethiopia; Shai Osudoku/Ningo Prampram, Ghana; Ibadan, Nigeria; Dar es Salaam, Tanzania; and Iganga, Uganda) and two Asian countries (i.e., Funan County, China; and Pune, India). Among them, three sites were urban (Tanzania, Ethiopia, and Nigeria), while the remaining were rural. Each site recruited around 1200 participants.

Participants in Nigeria and China were recruited in schools, while in the other countries, they were recruited from communities which were chosen based on existing Health and Demographic Surveillance Systems (HDSSs). In Nigeria, the sampling framework was based on a virtual health demographic surveillance platform with 30 randomly selected secondary schools in Ibadan. In China, the survey was nested in an existing open prospective cohort study of adolescents from grades 5–7 (10–13 years old), conducted in eight schools in Funan County.[31] This county represents a resource constraint setting in China because of low per capita gross domestic product.[31]

Data collection procedure

The questionnaire was administered by trained interviewers using Research Electronic Data Capture (REDCap) tools. Interviews were programmed in English and local languages in each study context. In community-based settings, for households with multiple adolescents, one adolescent per household was selected at random. The school-based setting went for the same strategy. If multiple students were from the same household, only one was chosen randomly. Site-

wise sampling and data collection procedures are described elsewhere.[30]

Health risk behaviors

This study investigated five HRBs among adolescents, including physical inactivity, poor dietary habits, smoking, alcohol consumption, and risky sexual behaviors.[30] Such a variable selection is consistent with previous studies which focused on the key issues of adolescent HRBs.[5,11,17,23,24] Each behavior was organized as a categorical variable.

The level of physical activity was determined by the response to a question: "During the past seven days, how many days were you physically active for at least 1 hour per day?" In line with the WHO recommendation for adolescents, physical activity is defined as engaging in any activity for at least 60 minutes per day that raises the heart rate and causes shortness of breath.[32] Examples include sports, running, brisk walking, cycling, playing with friends, dancing, or manual labor, among others. Accordingly, those who answered "7 days" were classified as physically active, while those who did not were classified as physically inactive.

The Global Diet Quality Score (GDQS) questionnaire was used to assess the quality of participants' diet.[33] The GDQS consists of 25 food groups, including 16 healthy food groups, 7 unhealthy food groups, and 2 food groups that are considered unhealthy when consumed excessively (i.e., red meat and high-fat dairy). The questionnaire assigns weighted scores to each group based on how frequently respondents consume them over the past month. Scores range from 0 to 49, with scores above 23 indicating a low risk of poor diet quality, scores between 15 and 23 indicating a moderate risk of poor diet quality, and scores below 15 indicating a high risk of poor diet quality.[33] Both moderate- and high-risk of poor diet quality were regarded as HRBs.

Smoking and alcohol consumption were assessed using two closed-ended questions "Have you ever smoked cigarettes?", and "Have you ever had a drink containing alcohol?". Consistent with previous research, both smoking and drinking alcohol are considered unhealthy behaviors.[4] Therefore, participants who reported ever smoking or drinking alcohol were classified as having the relevant HRBs. To evaluate the robustness of findings based on ever-use, sensitivity analyses were conducted using the past 30-day behavior.

Risky sexual behavior was defined based on early sexual debut and contraception use. Participants were asked about their age at first sexual intercourse. The report of sexual debut before the age of 15 is considered early sexual debut and thus risky.[34] Additionally, participants were asked whether they used contraception during their last sexual encounter. Either early sexual debut or unprotected sexual intercourse was considered as a risky sexual behavior.[35]

Correlates

We included sex, age, education, engagement in paid work, people whom participants lived with, and self-perceived socio-economic status of the household. The set of correlates was selected for the regression analyses based on the literature on risk factors of HRBs and the availability of data in our study.[5,11,30]

We categorized age into two groups: 10–14 years and 15–19 years. Education enrolment is a bivariate variable regarding whether the participant is currently in an educational institution. Engagement in paid work is defined based on whether the participant engaged in any kind of work in the last 12 months prior to the survey. By work, we mean any activity done by them to earn money, obtain food or any other form of payment, or any work in the family. People whom participants lived with were categorized into three groups: with parents, with other guardians, and alone. Self-perceived economic and social status was evaluated using the MacArthur Scale of Subjective Social Status,[36] and we categorized it into three groups: lower social status (score of 0–3), middle social status (score of 4–6), and higher social status (score of 7–10). All correlates were treated as categorical variables.

Statistical analyses

We used descriptive statistics to summarize the characteristics of the study participants. Categorical variables were presented as percentages and tested using either the chi-square test or Fisher's exact test. Continuous variables were presented as means with standard deviations or medians with interquartile ranges, depending on their distribution, and differences were tested using either the Student's t-test or the Kruskal–Wallis test. We considered a P-value of <0.05 as statistically significant in two-sided tests. Co-occurrences of HRBs were determined by counting the number of the above mentioned five behaviors.

To identify patterns of co-occurrence of HRBs, we used latent class analysis (LCA) to classify participants based on five types of behaviors: physical activity, diet quality, smoking cigarettes, consuming alcohol, and risky sexual behavior.[37] With a set of categorical behavior variables, LCA assists in identifying subgroups within a population sharing similar patterns of HRBs. In this study, we set group number from 2 to 10, and used the Akaike Information Criterion (AIC) to determine the optimal number of clusters.[38] For each group number, we conducted LCA ten times with random initial values and calculated AIC values of each. Among ten values, the lowest one would be chosen as the AIC value of this group number. For different group number from 2 to 10, the final cluster number would be chosen as the lowest AIC value appeared.[37,38]

We used logistic regression to identify the factors associated with different HRB clusters. We used multinomial logistic regression to compare different

clusters. We adopted two models. Model 1 included all correlates as independent variables, and model 2 added country as a covariate to test the robustness of the results across different countries. Association was presented by adjusted odds ratio (aOR) with 95% confidence interval (CI).

As the missing rates of all included variables were under 5%, we used multiple imputations to fill in missing values through R package "*MICE*".[39]

Ethics statement

The Institutional Review Board at Harvard T. H. Chan School, United States (protocol IRB 21–0696) provided ethical approval for the entire study. IRB approval was also obtained at each site from the local authorities responsible for conducting the study. Both parental consent and adolescent assent were required for minor adolescents while adults had to consent. The privacy of personal information was protected throughout the study via anonymous data collection, and confidentiality was maintained by asking participants to provide honest answers.

Role of the funding source

The funders had no role in the study design, decision to publish, or preparation of the manuscript. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Table 1 presents the overall and by country demographic characteristics and HRBs of participants. Of the 9697 participants included in the analysis, 52.28% were females and the median age of the participants was 14.00 years (interquartile range [IQR] 12.00–16.00). The distribution of age and sex among the participants in each country is shown in the Supplementary Table S1. The majority of the individuals were enrolled in an educational institution (88.42%), were not engaged in paid work in the past 12 months (80.14%), and lived with their parents (72.66%). Based on the MacArthur Scale of Subjective Social Status, around two thirds of the participants belonged to the middle social status (65.88%). Of the 9697 participants, 8779 (90.53%) participants had at least one HRB, and 5267 (54.32%) had two or more HRBs concurrently.

Using LCA, we identified three distinct clusters with the lowest AIC, as shown in Supplementary Figure S1. The distribution of HRBs across the three clusters is depicted in Table 2. The observed P-values indicate statistically significant differences in HRBs among three clusters ($P < 0.05$). Furthermore, Supplementary Table S2 specifically displays the P-values derived from the pairwise comparisons performed using multiple chi-square tests among different clusters. Cluster 1 was

Variable	Overall	Males	Females
	N = 9697	(N = 4627)	(N = 5070)
Country			
Burkina Faso	1196 (12.33)	677 (14.63)	519 (10.24)
China	1179 (12.16)	631 (13.63)	548 (10.81)
Ethiopia	1200 (12.37)	462 (9.98)	738 (14.56)
Ghana	1235 (12.74)	569 (12.29)	666 (13.14)
India	1246 (12.85)	674 (14.56)	572 (11.28)
Nigeria	1258 (12.97)	504 (10.89)	754 (14.87)
Tanzania	1183 (12.20)	516 (11.15)	667 (13.16)
Uganda	1200 (12.37)	595 (12.86)	605 (11.94)
Age (Median [IQR])			
	14.00 [12.00, 16.00]	14.00 [12.00, 16.00]	14.00 [12.00, 16.00]
Educational enrolment			
Yes	8574 (88.42)	4073 (88.01)	4501 (88.79)
No	1123 (11.58)	555 (11.99)	568 (11.21)
Being engaged in paid work			
Yes	1729 (17.83)	1045 (22.58)	684 (13.49)
No	7771 (80.14)	3492 (75.45)	4279 (84.42)
Living with			
Parents	7046 (72.66)	3319 (71.72)	3727 (73.53)
Other guardians	1933 (19.93)	871 (18.82)	1062 (20.95)
Alone	718 (7.40)	438 (9.46)	280 (5.52)
Socio-economic status			
Low	1863 (19.21)	894 (19.32)	969 (19.12)
Middle	6388 (65.88)	3029 (65.45)	3359 (66.27)
High	1446 (14.91)	705 (15.23)	741 (14.62)
Physical activity			
Active	2884 (29.74)	1463 (31.61)	1421 (28.03)
Inactive	6813 (70.26)	3165 (68.39)	3648 (71.97)
Dietary habits			
Low risk	3791 (39.09)	1863 (40.25)	1928 (38.04)
Moderate risk	5181 (53.43)	2417 (52.23)	2764 (54.53)
High risk	725 (7.48)	348 (7.52)	377 (7.44)
Smoking			
No	9399 (96.93)	4368 (94.38)	5031 (99.25)
Yes	298 (3.07)	260 (5.62)	38 (0.75)
Alcohol consumption			
No	8185 (84.41)	3771 (81.48)	4414 (87.08)
Yes	1512 (15.59)	857 (18.52)	655 (12.92)
Risky sexual behavior			
No	9029 (93.11)	4324 (93.43)	4705 (92.82)
Yes	668 (6.89)	304 (6.57)	364 (7.18)
Number of co-occurrence			
0	918 (9.47)	442 (9.55)	476 (9.39)
1	3512 (36.22)	1665 (35.98)	1847 (36.44)
2	4268 (44.01)	1988 (42.96)	2280 (44.98)
3	858 (8.85)	431 (9.31)	427 (8.42)
4	130 (1.34)	93 (2.01)	37 (0.73)
5	11 (0.11)	9 (0.19)	2 (0.04)

Tables are presented as number (percentage). Number of co-occurrence was added by the existence of above five behaviors, where dietary habits were regarded as HRB for both moderate and high risk categories.

Table 1: **Background characteristics and health risk behaviors of 9697 adolescents who participated in the cross-sectional survey in sub-Saharan Africa, China and India.**

Health risk behavior	Cluster 1	Cluster 2	Cluster 3	P value
	n = 2689	n = 6609	n = 399	
Physical activity (%)				
Active	2689 (100.00)	0 (0.00)	195 (48.87)	<0.0001
Inactive	0 (0.00)	6609 (100.00)	204 (51.13)	
Dietary quality (%)				
Low risk of poor diet quality	1170 (43.51)	2442 (36.95)	179 (44.86)	<0.0001
Moderate risk of poor diet quality	1345 (50.02)	3644 (55.14)	192 (48.12)	
High risk of poor diet quality	174 (6.47)	523 (7.91)	28 (7.02)	
Ever smoked cigarettes (%)				
No	2689 (100.00)	6529 (98.79)	181 (45.36)	<0.0001
Yes	0 (0.00)	80 (1.21)	218 (54.64)	
Ever consumed alcohol (%)				
No	2230 (82.93)	5903 (89.32)	52 (13.03)	<0.0001
Yes	459 (17.07)	706 (10.68)	347 (86.97)	
Risky sexual behavior (%)				
No	2576 (95.80)	6314 (95.54)	139 (34.84)	<0.0001
Yes	113 (4.20)	295 (4.46)	260 (65.16)	

Table 2: **Distribution of health risk behaviors for the three clusters of participants in sub-Saharan Africa, China and India.**

regarded as a "Healthy" group. It was comprised of 2689 (27.73%) participants characterized by the absence of HRBs, where all members were physically active, 93.53% were at low to moderate risk of poor diet quality, none of the members had ever smoked, 82.93% had not consume alcohol ever, and 95.80% didn't engage in risky sexual behavior. Cluster 2 was regarded as at high risk of "Physical inactivity and poor diet quality" group. It consisted of 6609 (68.16%) participants with physical inactivity and poor diet quality. Among them, 100% were physically inactive, 55.14% were at moderate risk and 7.91% were at severe risk of poor diet quality. Other HRBs were distributed scarcely, with 1.21% participants ever smoked cigarettes, 10.68% consumed alcohol, and 4.46% engaged in risky sexual behavior. Notably, among all 6813 physically inactive participants, 6609 (97.01%) were distributed in cluster 2, and among all 725 participants with high risk of poor dietary habits, 523 (72.14%) were also in cluster 2. Cluster 3 was regarded as at high risk of "Smoking, alcohol consumption and risky sexual behavior" group. It comprised of 399 (4.11%) participants with smoking, alcohol consumption, and risky sexual behavior. Among them, 54.64% had smoked cigarettes, 86.97% had drunk alcohol, and 65.16% had engaged in risky sexual behavior. We also used questions about substance use during last 30 days as a sensitivity analysis. The cluster result was shown in Supplementary Table S3. Similarly, it can be inferred that physical inactivity was also grouped with poor diet in Cluster 2, and risky sexual behavior was also grouped with smoking and alcohol consumption in Cluster 3.

Table 3 shows the results of regression models. Compared to Cluster 1, membership in Cluster 2 was negatively associated with older age (aOR 0.90, 95% CI 0.82–0.99) and having a high socio-economic status (aOR 0.80, 95% CI 0.68–0.93), but positively associated with being female (aOR 1.15, 95% CI 1.05–1.26), not being engaged in paid work (aOR 1.26, 95% CI 1.11–1.42), and living alone (aOR 1.46, 95% CI 1.21–1.76). After adjusting countries as the covariate, the role of older age (aOR 0.96, 95% CI 0.86–1.07), living alone (aOR 0.99, 95% CI 0.80–1.22) and high socio-economic status (aOR 1.01, 95% CI 0.85–1.19) were not significant, while other factors have similar results. Membership in Cluster 3 was negatively associated with being female (aOR 0.43, 95% CI 0.34–0.55), not being engaged in paid work (aOR 0.67, 95% CI 0.52–0.86), but positively associated with older age (aOR 3.99, 95% CI 3.06–5.21), not being enrolled in an educational institution (aOR 1.98, 95% CI 1.51–2.59), and living with guardians other than parents (aOR 1.93, 95% CI 1.49–2.50). After adjusting countries as the covariate, the significance of the factors kept the same.

Discussion

We examined the co-occurrence of health risk behaviors (HRBs) and its determinants among adolescents in six sub-Saharan African countries and two Asian countries. We found a high burden of HRBs among adolescents in these countries. Three distinct clusters of HRBs were identified: "healthy," "physical inactivity and poor dietary quality," and "smoking, alcohol consumption and risky sexual behavior". Moreover, our findings demonstrated that several factors including sex, age, educational enrolment, engagement in paid work, and family cohabitants were associated with the presence of HRBs.

Our findings indicated a remarkably high prevalence of HRBs, with more than 90% of adolescents engaged in at least one HRB, with nearly 55% engaged in two or more HRBs. This level of co-occurrence of HRBs aligns with previous reports from high-income countries such as the United States of America, United Kingdom, and Netherlands, reporting the prevalence of two or more HRBs co-occurrence between 50% and 70%.[11] Our findings corroborate a study conducted across 89 countries, which similarly reported a high prevalence of co-occurrence of HRBs, affecting 82.4% of adolescents.[26] This pervasive co-occurrence of HRBs can be attributed, in part, to a dearth of health knowledge among adolescents, contributing to the high prevalence of poor dietary quality and physical inactivity in sub-Saharan Africa. Additionally, risk behaviors such as cigarette use and excessive alcohol consumption may be perceived as less harmful by society and policymakers, resulting in uncertainty about acceptable tolerance levels for these risk behaviors within the community.[40]

In our study, the majority of participants exhibited a pattern of physically inactivity and consumed unhealthy foods, which aligns with a substantial body of literature exploring the interconnectedness between diet and

	Risk factor	Model 1			Model 2		
		OR	95% CI	P value	OR	95% CI	P value
Logit 1 Cluster 2 v.s. Cluster 1 (base outcome)	**Age in years**						
	10–14	Ref			Ref		
	15–19	0.90	(0.82, 0.99)	0.0241	0.96	(0.86, 1.07)	0.4105
	Sex						
	Male	Ref			Ref		
	Female	1.15	(1.05, 1.26)	0.0021	1.20	(1.09, 1.32)	0.0002
	Educational enrolment						
	Yes	Ref			Ref		
	No	0.87	(0.75, 1)	0.0545	0.84	(0.71, 0.99)	0.0360
	Being engaged in paid work						
	Yes	Ref			Ref		
	No	1.26	(1.11, 1.42)	0.0002	1.23	(1.08, 1.41)	0.0020
	Participants living with						
	Parents	Ref			Ref		
	Other guardians	1.03	(0.92, 1.16)	0.5851	0.97	(0.86, 1.1)	0.6714
	Alone	1.46	(1.21, 1.76)	0.0001	0.99	(0.8, 1.22)	0.9129
	Socio-economic status						
	Low	Ref			Ref		
	Middle	1.03	(0.91, 1.15)	0.6652	1.04	(0.92, 1.18)	0.5358
	High	0.80	(0.68, 0.93)	0.0039	1.01	(0.85, 1.19)	0.9347
Logit 2 Cluster 3 v.s. Cluster 1 (base outcome)	**Age in years**						
	10–14	Ref			Ref		
	15–19	3.99	(3.06, 5.21)	<0.0001	7.56	(5.18, 11.03)	<0.0001
	Sex						
	Male	Ref			Ref		
	Female	0.43	(0.34, 0.55)	<0.0001	0.41	(0.32, 0.54)	<0.0001
	Educational enrolment						
	Yes	Ref			Ref		
	No	1.98	(1.51, 2.59)	<0.0001	1.74	(1.27, 2.38)	0.0005
	Being engaged in paid work						
	Yes	Ref			Ref		
	No	0.67	(0.52, 0.86)	0.0017	0.54	(0.41, 0.71)	<0.0001
	Participants living with						
	Parents	Ref			Ref		
	Other guardians	1.93	(1.49, 2.5)	<0.0001	1.56	(1.19, 2.05)	0.0015
	Alone	0.97	(0.62, 1.54)	0.9083	1.57	(0.92, 2.68)	0.0972
	Socio-economic status						
	Low	Ref			Ref		
	Middle	0.85	(0.65, 1.12)	0.2553	0.85	(0.64, 1.13)	0.2663
	High	0.81	(0.56, 1.18)	0.2642	0.98	(0.66, 1.46)	0.9368

OR is the odds ratio, CI is the confidence interval. Ref is the reference group. Model 1 involves independent variables as dshown above, while model 2 adjusted the country as a covariate. Cluster 1 represents the "Healthy" group. Cluster 2 represented the "Physical inactivity and poor dietary habits" group. Cluster 3 represented high risk of "Smoking, alcohol consumption and risky sexual behavior" group.

Table 3: **Multinomial logistic regression for health risk behavior clusters.**

physical activity. This trend may be partially attributed to the socio-economic status of both households and neighborhoods.[41] Previous studies have consistently demonstrated that higher socio-economic status can positively influence both diet quality and physical activity levels simultaneously.[42] Besides, our findings regarding the impact of school enrollment are in harmony with existing research that underscores the effectiveness of interventions targeting both dietary habits and physical activity. Consequently, there has been a persistent call for the implementation of school-based programs aimed at addressing these two interconnected HRBs.[43]

While the number of participants who smoked cigarettes, consumed alcohol, and engaged in risky sexual behavior was relatively small, these three HRBs exhibited a tendency to co-occur. This clustering of HRBs during adolescence is a cause for heightened concern,

as it aligns with gateway theories, suggesting that the increasing association between risk behaviors during adolescence may pave the way for the aggregation of more risky behaviors as individuals transition into adulthood.[44] Previous studies have consistently reported a robust association between former smoking and alcohol use.[45] Some researchers have posited that the association may be attributed to the physiological effects of nicotine stimulation, while others have suggested the possibility of reverse causation, wherein alcohol disinhibits smoking behavior.[46] Furthermore, smoking and alcohol use have been jointly regarded as a means of socialization. However, individuals who use these substances and exhibit better psychosocial functioning than non-users may paradoxically engage in riskier sexual behaviors, often characterized by reduced condom use and an elevated risk of sexually transmitted diseases.[47]

Our study also found that socio-demographic factors were significantly associated with the co-occurrence of HRBs. Consistent with prior research, female adolescents were physically less active than their male counterparts.[48] This discrepancy may attributed to less social support girls received to engage in physical activities.[49] Besides, compared to boys, girls also perceived less enjoyment when taking physical education.[50] Moreover, an analysis focused on obesogenic clusters also identified a cluster characterized by poor nutrition status and physical inactivity that was specific to girls in America.[51] Similar to south Africa, this is primarily attributed to dietary habits like increased exposure to sugar sweetened beverages and salty food, changes in snacking habits, and also physical activity habits like sedentary lifestyles.[52,53] Our study also identified significant correlates between socioeconomic factors and HRBs. Adolescents who lived without parental care or in low socio-economic settings were at a high risk of poor diet quality and physical inactivity. These findings are consistent with the earlier reports from Europe where adolescents from low socioeconomic settings were more likely to engage in multiple HRBs.[54–56] Importantly, this finding is particularly salient for LMICs, where poverty-related issues and poor nutrition remain a critical public health concern.[57] Consistent with previous research, our results indicated sex and age differences in HRBs. Male and older adolescents were more likely to smoke cigarettes and alcohol, as well as engage in risky sexual behaviors.[58] Similar HRB patterns have been observed in high-income countries such as the United Kingdom and Australia.[54,59] Moreover, attending at an educational institution emerged as a protective factor against HRBs. According to the Social Control Theory, strong bonds with educational institutions can foster traditional social values and discourage substance use.[60] The Social development model also supports the importance of schools in preventing HRBs.[60] What's more, our findings also indicated that adolescents engaged in paid work and those living with non-parental guardians were more prone to engaging in these HRBs. Prior studies have similarly revealed that factors such as low parental monitoring, peer influence, and socio-economic disadvantage contribute to an increased risk of substance use and risky sexual behaviors.[46]

This study has multiple methodological, theoretical, and practical strengths. From the methodological aspect, we used LCA to identify the clusters of HRBs among adolescents. In contrast to traditional methods that involve merely counting the number of different behaviors, LCA enabled us to reduce the dimensionality of variables, facilitating a more explainable and practical analysis. Additionally, LCA is adept at categorizing individuals into exclusive subgroups or latent classes based on multiple categorical variables, offering more nuanced and dynamic insights than other alternative methods.[61] From a theoretical aspect, this study contributes significantly to addressing the dearth of evidence regarding the co-occurrence of HRBs in LMICs. Specifically, it differs from many previous ones that primarily collected adolescent data in schools. This study used two population-based settings to collect data including the Health and Demographic Surveillance System and schools. In addition, this study uses data from multiple sites to understand the clustering of risk behaviors. From a practical aspect, our findings offer valuable insights for informing prevention in LMICs. The identification of distinct clusters of HRBs and their factors provides a crucial framework for designing tailored preventive policies and programs. By addressing the interplay between social determinants and health behaviors, we can effectively prevent the burden of multiple lifestyle risk factors and their long-term health and well-being consequences. Specifically, policies should support adolescent girls with more physical activity and higher quality of diet, while motivate boys to stay away from substance use and risky sexual behavior. Our research underscores the importance of implementing behavior change communication initiatives in both schools and communities to prevent multiple HRBs. To address the research gap in this field, more efforts should be made to invest in and develop scientific evidence in Sub-Saharan Africa to better understand the co-occurrence and interplay of various HRBs among adolescents. It is imperative to establish comparative studies across varying income levels to gauge the prevalence of HRB co-occurrence, clusters, and associations. Additionally, expanding community-based evidence inclusive of all adolescent age groups is crucial for a comprehensive understanding.

Our study has some limitations. First, our survey involved school-based and community-based settings. Although the survey strategies and procedures were strictly controlled to be the same in both settings, there is an omission of out-of-school children in school-based settings compared to community-based settings. To

examine whether different sampling settings affect the clustering of HRBs, we conducted two separate LCAs for school- and community-based participants. As shown in Supplementary Tables S4 and Table S5, the clustering patterns among participants from these two different settings did not vary. Secondly, all HRBs and socio-demographical information were self-reported by the participants, introducing the potential for recall and social desirability biases. In particular, participants may have provided inaccurate estimates while responding to sensitive questions related to age at first sexual intercourse, contraceptive methods usage, smoking cigarette, and alcohol consumption. Thirdly, the age distribution participants in China were younger than others because it was based on an existing open prospective cohort study focused on younger adolescents. Consequently, direct comparisons of adolescent HRBs among countries, especially for age-related features like substance use and risky sexual behavior, were not feasible. Therefore, a sensitivity analysis was performed by excluding the Chinese participants from the analytical sample, however, the three clusters of HRB were consistent, regardless of their distribution (Supplementary Table S6). Specifically, the percentage if participants in Cluster 1 decreased and the percentage of participants increased in Cluster 3. Last but not least, there is room for improvement in the measurement HRBs among teenagers. Concerning substance use, if participants had ever smoked cigarettes or had alcoholic drink, they may have already quit these behaviors. But if measuring their behavior with a shorter time window like last 30 days, we may potentially exclude individuals who had such a habit but not took it during the survey. We conducted sensitivity analyses using both measurements to estimate this bias.

This multi-country study provides valuable insights into the high prevalence of co-occurrence of HRBs among adolescents in LMICs. Our findings reveal distinct clustering patterns for five different HRBs and highlight the socio-demographic covariates associated with each cluster. Our study sheds light on the potential shared risk factors of HRBs and underscores the need for tailored interventions that target multiple HRBs in early life. We hope that our findings can inform evidence-informed policies and interventions to promote healthy behaviors and reduce the risk of non-communicable diseases among adolescents in LMICs.

Contributors

WWF led the study design and instrument development and all authors contributed to it. XL completed the statistical analysis and wrote the first draft. HZ examined and verified the data. YD, SS, and KT revised the manuscript. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Data sharing statement

The data that support the findings of this study are available upon reasonable request from the ARISE network. The data is not publicly available due to research ethics board restrictions.

Declaration of interests

We declare no conflicts of interest.

Acknowledgements

We thank all the partners in the Africa Research, Implementation Science, and Education (ARISE) Network for their support and guidance. The most important acknowledgement is to the participants of the study and the members of the survey teams in each country, and the project development and management teams based at Harvard in the USA, and the national centers. Fondation Botnar (Grant #INV-037672) and Harvard T.H. Chan School of Public Health, partially funded this study.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.eclinm.2024.102525.

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