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Insufficient Physical Activity and Cardiovascular Disease Mortality Across Countries: A Cross-National Ecological Analysis

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ABSTRACT:

Background: Insufficient physical activity is a known cardiovascular risk factor, but national inactivity prevalence may relate differently to cardiovascular mortality than individual-level associations. This study assessed these relationships across 193 countries in 2021.

Methods: This cross-sectional ecological analysis linked WHO estimates of age-standardized insufficient physical activity prevalence among adults aged 18 years and older with age-standardized cardiovascular mortality rates for both sexes. Analyses included unweighted descriptive statistics, Pearson and Spearman correlations, and ordinary least-squares regression. The adjusted model included WHO region, and regression inference used HC3 heteroskedasticity-robust standard errors.

Results: The mean inactivity prevalence was 27.07%, and mean cardiovascular mortality was 250.50 deaths per 100,000 population. Inactivity prevalence was inversely correlated with mortality (Pearson's $r = -0.198$; $p = .006$; Spearman's $\varrho = -0.244$; $p < .001$). After adjusting for region, a 10-percentage-point increase in inactivity prevalence was associated with 18.73 fewer cardiovascular deaths per 100,000 population (95% CI, −35.92 to −1.53; $p = .033$). The unadjusted and adjusted models explained 3.9% and 19.0% of between-country mortality variation, respectively.

Conclusion: Higher national inactivity prevalence was associated with lower cardiovascular mortality. This modest ecological association does not establish causality or indicate a protective effect of inactivity. Limited adjustment and contemporaneous

measurements restrict interpretation. Future studies should consider socioeconomic conditions, healthcare access, longitudinal exposure, and uncertainty in national estimates to investigate this association better.

INTRODUCTION

Cardiovascular disease (CVD) remains a leading cause of mortality worldwide, with significant variation in its burden across countries. The Global Burden of Disease 2019 study reported notable geographic differences in cardiovascular mortality and related risk factors, emphasizing the need to consider demographic, behavioral, and socioeconomic factors when examining cardiovascular health.[1] Physical activity is a key element of cardiovascular prevention. The World Health Organization (WHO) recommends that adults engage in 150–300 minutes of moderate-intensity aerobic activity, 75–150 minutes of vigorous-intensity activity, or an equivalent combination each week.[2] Insufficient physical activity, defined as not meeting these minimum recommendations, is an important indicator for population health surveillance.

The cardiovascular benefits of regular activity are supported by both physiological and epidemiological evidence. Exercise improves endothelial function, blood pressure regulation, insulin sensitivity, and cardiovascular adaptation, offering mechanisms for its positive impact on cardiovascular health.[3] An umbrella review for the Physical Activity Guidelines Advisory Committee found consistent evidence that higher physical activity is linked to lower cardiovascular mortality and incident CVD.[4] The Prospective Urban Rural Epidemiology (PURE) study showed that higher physical activity is associated with lower mortality and fewer major cardiovascular events across 17 countries with varying income levels.[5] A dose–response meta-analysis of large prospective studies also found lower risks of cardiovascular disease and mortality with greater non-occupational activity, with significant benefits observed when moving from inactivity to modest activity levels.[6] These findings provide individual-level evidence to inform interpretation of associations between national indicators.

Population-level assessments show that insufficient activity contributes to a significant, preventable disease burden. Lee and colleagues estimated the impact of physical inactivity on coronary heart disease, other major non-communicable diseases, and premature mortality using comparative risk assessment methods.[7] However, international surveillance reveals persistent and unevenly distributed inactivity. A pooled analysis of 358 population-based surveys found that 27.5% of adults worldwide were insufficiently active in 2016, with notable differences between countries and sexes.[8] A later analysis of 507 surveys with about 5.7 million participants estimated a global age-standardized prevalence of 31.3% in 2022 and noted an increase over time.[9] These estimates come from different analytical releases and should not be interpreted as a direct trend between the two publications. In addition to health consequences, physical inactivity leads to increased healthcare costs and productivity losses, further supporting the need for sustained population prevention.[10]

National inactivity prevalence reflects more than individual behavior. Opportunities for movement depend on employment, transport systems, neighborhood environments, and access to recreational facilities. An international study in 14 cities found that objectively measured physical activity was associated with environmental factors such as residential density, street connectivity, public transport density, and park access.[11] Additionally, activity in different settings may have distinct cardiovascular associations. The Copenhagen General Population Study found contrasting associations for leisure-time and occupational physical activity.[12] National indicators based solely on meeting minimum activity thresholds may mask differences in activity domain, intensity, and working conditions. This heterogeneity is important when comparing countries, though it does not alone explain associations between inactivity prevalence and mortality.

Cardiovascular mortality is influenced by a broader range of social and clinical factors beyond physical activity. The PURE study identified socioeconomic inequalities in cardiovascular outcomes across countries with different income levels.[13] Other research has shown international differences in disease occurrence, hospital admissions, and mortality, indicating that population mortality patterns depend on both disease burden and how disease is managed.[14] Additional multinational analyses have found that behavioural, metabolic, socioeconomic, and environmental risk factors contribute to cardiovascular disease and death.[15] International differences in hypertension detection, treatment, and control further show that risk-factor management varies widely between populations.[16] As a result, countries with similar inactivity prevalence may have different cardiovascular mortality rates, and countries with higher inactivity prevalence may have other factors linked to lower mortality. These possibilities require direct investigation rather than assumptions based solely on geographic adjustment.

Measurement and timing add complexity to comparisons between national indicators. A systematic review found substantial discrepancies between self-reported and directly measured physical activity, with no consistent pattern across studies .[17] While harmonization and statistical modelling improve comparability, they cannot eliminate all measurement error. The pandemic period adds another consideration: a systematic review found widespread changes in physical activity and sedentary behaviour during COVID-19 restrictions.[18] When using 2021 estimates, caution is needed in interpreting contemporaneous exposure and mortality data. Cardiovascular deaths result from disease processes and exposures over many years, so matching observation years does not confirm that measured inactivity preceded mortality.

Ecological analysis describes how population health indicators vary together across geographic units. It is useful for identifying contextual patterns and generating hypotheses about population determinants.[19] However, associations between national inactivity prevalence and national cardiovascular mortality differ from those between individual activity and cardiovascular risk. Aggregation, unmeasured confounding, and within-country distribution differences can lead to ecological associations that differ in magnitude or direction from individual-level relationships.[20] Age standardization addresses differences in age composition but does not remove socioeconomic, behavioral, or healthcare-related confounding. Similarly, adjusting for WHO region accounts for broad geographic differences but does not ensure comparability across all determinants of cardiovascular mortality.

Given this context, the present study examined the country-level association between age-standardized insufficient physical activity prevalence among adults aged 18 and older and age-standardized cardiovascular disease mortality for both sexes across 193 countries in 2021. The study described the distribution of both indicators, compared unweighted country averages across the six WHO regions, and assessed their association using Pearson and Spearman correlations and linear regression. A secondary regression model adjusted for WHO region to determine whether the association persisted after accounting for broad geographic differences. The study aimed to characterize an ecological pattern and inform further investigation, rather than estimate the causal effect of physical inactivity or infer individual cardiovascular risk from national averages.

METHODOLOGY

Study design and setting

An exploratory cross-sectional ecological study was conducted to examine the association between national prevalence of insufficient physical activity and cardiovascular disease mortality in 2021. Countries were the units of analysis. Exposure and outcome estimates were matched to the same year to describe contemporaneous differences. The analysis aimed to characterize population-level associations, not individual cardiovascular risk or causal effects.

Data sources

Physical activity estimates were obtained from the World Health Organization (WHO) Global Health Observatory using indicator NCD_PAA, which reports the age-standardized prevalence of insufficient physical activity among adults aged 18 years and older. These estimates were derived from population-based surveys and harmonized using WHO's statistical modelling procedures.

Cardiovascular mortality estimates were obtained from the WHO Global Health Estimates via the Our World in Data dataset titled Death rate from cardiovascular diseases. The series reports age-standardized cardiovascular deaths per 100,000 population for both sexes from 2000 to 2021. The source release was WHO Global Health Estimates 2021, published in 2024. Both datasets were downloaded on 21 October 2026. The year 2021 was selected as it was the latest available in the mortality series.

Eligibility criteria and analytical sample

Countries were eligible if both physical inactivity prevalence and cardiovascular mortality estimates were available for 2021 and for both sexes combined. Global, regional, and income-group aggregates were excluded. Records from other years and sex-specific physical activity estimates were not included in the principal analysis.

Physical activity estimates were available for 195 countries or territories, and mortality estimates for 194 countries. Linking the two sources produced an analytical sample of 193 countries. Puerto Rico and Palestine lacked matching mortality observations, and Monaco lacked a matching physical activity observation. All eligible countries were included; no random sampling or a priori sample-size calculation was performed.

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Exposure measurement

The exposure was the age-standardized prevalence of insufficient physical activity among adults aged 18 years and older, expressed as a percentage. Insufficient activity was defined as not achieving at least 150 minutes of moderate-intensity, 75 minutes of vigorous-intensity physical activity, or an equivalent combination per week.

The underlying surveys assessed self-reported activity across occupational or household, transport, and leisure domains. Age-standardized estimates were used as supplied by WHO, without further standardization. Prevalence was analyzed as a continuous variable. For regression analyses, prevalence was divided by 10 so the coefficient represented the mortality rate difference associated with a 10-percentage-point higher prevalence, rather than a 10% relative increase.

Outcome measurement

The outcome was the age-standardized cardiovascular disease mortality rate per 100,000 population for both sexes combined. Rates were used as provided in the mortality dataset. The outcome represented total cardiovascular mortality and was not limited to deaths attributed to physical inactivity.

The exposure and outcome retained their respective source population definitions. Physical activity estimates referred to adults aged 18 years and older, while cardiovascular mortality followed the population coverage specified in the source mortality series. Individual records and age-specific exposure–outcome pairs were not linked.

Geographic classification and covariate adjustment

Countries were assigned to the six WHO regions using the classification accompanying the physical activity data: Africa, the Americas, Eastern Mediterranean, Europe, South-East Asia, and Western Pacific.

WHO region was included as a categorical covariate in the adjusted regression model to account for broad geographic differences. Adjustment was limited to this variable. National income, smoking, hypertension, diabetes, healthcare access, and other potential determinants of cardiovascular mortality were not included. Therefore, the adjusted model was interpreted as a region-adjusted ecological association, not as an estimate independent of all relevant confounding factors.

Data management

The datasets were restricted to eligible observations and linked using three-letter country codes. Country-code uniqueness was verified before a one-to-one merge, and unmatched records were identified.

The matched dataset was examined for duplicate country codes and missing exposure or outcome values. No duplicates or missing values for either principal variable remained among the 193 included countries. No imputation was performed, and countries with extreme observed values were retained. Source files, metadata, the matched dataset, analysis code, and statistical outputs were preserved to support reproducibility.

Statistical analysis

Physical inactivity prevalence and cardiovascular mortality were summarized using means, sample standard deviations, medians, interquartile ranges, and minimum and maximum values. Regional summaries included the number of countries and the mean and standard deviation of each indicator. All analyses assigned equal weight to each country, regardless of population size. Therefore, overall and regional means represented averages across countries rather than population-weighted estimates.

Pearson's correlation coefficient was calculated to assess the linear association between physical inactivity prevalence and cardiovascular mortality. Its 95% confidence interval was calculated using Fisher's z transformation. Spearman's rank correlation coefficient was also calculated as a complementary measure of monotonic association.

Two ordinary least-squares regression models were fitted. The unadjusted model included physical inactivity prevalence alone. The adjusted model included WHO region as a categorical covariate, represented by five indicator variables. The adjusted model was specified as:

$$Y_i = \beta_0 + \beta_1 \left(\frac{P_i}{10}\right) + \sum_{k=1}^{5} \gamma_k R_{ik} + \varepsilon_i$$

where Y_i was the age-standardized cardiovascular mortality rate per 100,000 population in country i, P_i was physical inactivity prevalence expressed in percentage points, and R_{ik} represented WHO-region indicators. The coefficient β_1 estimated the difference in cardiovascular mortality associated with a 10-percentage-point higher inactivity prevalence.

HC3 heteroskedasticity-robust standard errors were used for both regression models. Regression confidence intervals and two-sided p-values were calculated using the t-distribution with the corresponding residual degrees of freedom. Model fit was summarized using ordinary R^2. For the adjusted model, R^2 described the variation accounted for by inactivity prevalence and WHO region jointly.

A nominal significance threshold of .05 was used. No adjustment for multiple testing was applied because the analyses were exploratory. The study was not preregistered. Calculations were performed in Python using pandas, NumPy, and SciPy libraries.

National exposure and outcome estimates were treated as fixed inputs. Consequently, regression confidence intervals did not incorporate uncertainty in the underlying WHO estimates. Spatial dependence between countries was not modeled. Population-weighted analyses, formal influence diagnostics, nonlinear models, and longitudinal analyses were not performed.

Ethical considerations

The study used publicly available, aggregated country-level data. No participants were recruited, and no identifiable personal information or individual medical records were accessed. Institutional ethics approval or exemption determination was not documented for this analysis.

RESULTS

Country coverage and descriptive characteristics

The analysis included 193 countries with matched estimates of insufficient physical activity and cardiovascular disease mortality for 2021. Physical activity estimates were available for 195 countries or territories, and mortality estimates for 194 countries.

The mean age-standardized prevalence of insufficient physical activity was 27.07% (SD 12.61), with a median of 25.78% (IQR 17.67–35.74). Prevalence ranged from 2.92% in Malawi to 65.39% in the United Arab Emirates. The mean age-standardized cardiovascular mortality rate was 250.50 deaths per 100,000 population (SD 122.86), and the median was 241.38 (IQR 159.30–316.44). Mortality rates ranged from 56.50 per 100,000 in San Marino to 784.54 in Nauru (Table 1).

Table 1. Country-level descriptive characteristics, 2021

Variable	Countries, n	Mean (SD)	Median (IQR)	Minimum–maximum
Insufficient physical activity, age-standardized prevalence (%)	193	27.07 (12.61)	25.78 (17.67–35.74)	2.92–65.39
Cardiovascular mortality, age-standardized deaths per 100,000 population	193	250.50 (122.86)	241.38 (159.30–316.44)	56.50–784.54

Both indicators represented both sexes combined. Physical activity prevalence concerned adults aged ≥18 years. Statistics were unweighted summaries of country estimates. SD = standard deviation; IQR = interquartile range, presented as the 25th–75th percentiles.

Regional distribution

The European Region included the most countries (n = 52), followed by the African Region (n = 47) and the Region of the Americas (n = 35). The Western Pacific, Eastern Mediterranean, and South-East Asia regions included 28, 21, and 10 countries, respectively.

The Eastern Mediterranean Region had the highest mean prevalence of insufficient physical activity (39.48%; SD 14.37), followed by the Americas (37.21%; SD 8.40). The African Region had the lowest mean prevalence (17.87%; SD 8.07). The remaining regions ranged from 24.72% in Europe to 25.62% in the Western Pacific.

The regional distribution of cardiovascular mortality differed from inactivity prevalence. The Western Pacific Region had the highest mean mortality rate at 325.27 deaths per 100,000 population (SD 174.32), followed by the Eastern Mediterranean Region at 295.31 (SD 104.73). The Americas had the lowest mean mortality rate at 183.19 deaths per 100,000 (SD 70.02), despite the second-highest mean inactivity prevalence (Table 2).

Table 2. Insufficient physical activity and cardiovascular mortality by WHO region, 2021

WHO region	Countries, n	Insufficient physical activity (%), mean (SD)	Cardiovascular deaths per 100,000 population, mean (SD)
Africa	47	17.87 (8.07)	278.87 (68.69)
Americas	35	37.21 (8.40)	183.19 (70.02)
Eastern Mediterranean	21	39.48 (14.37)	295.31 (104.73)
Europe	52	24.72 (9.99)	209.92 (131.49)
South-East Asia	10	25.03 (11.60)	260.35 (111.18)
Western Pacific	28	25.62 (11.44)	325.27 (174.32)

Both indicators were age-standardized. Regional values reflect unweighted averages of country estimates rather than population-weighted figures. Regional comparisons are descriptive; no formal statistical tests were conducted.

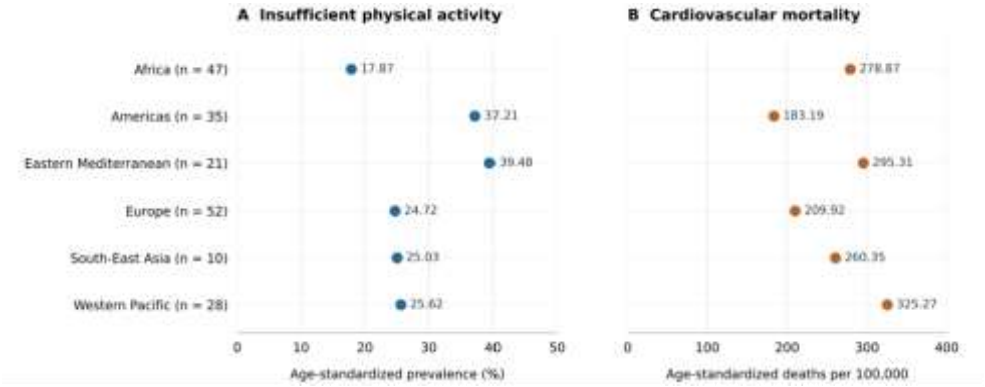

Figure 1 Regional mean insufficient physical activity prevalence (A) and cardiovascular mortality (B), 2021. Points represent unweighted averages of age-standardized country estimates. Panels use separate numerical scales.

Association between insufficient physical activity and cardiovascular mortality

Physical inactivity prevalence showed a modest inverse linear association with cardiovascular mortality across countries (Pearson's $r = -0.198$; 95% CI −0.330 to −0.059; $p = .006$). Spearman's correlation also indicated an inverse association ($\rho = -0.244$; $p < .001$).

In the unadjusted regression model, each 10-percentage-point increase in insufficient physical activity prevalence corresponded to 19.30 fewer cardiovascular deaths per 100,000 population ($\beta = -19.30$; 95% CI −31.49 to −7.11; $p = .002$). This model explained 3.9% of the between-country variation in cardiovascular mortality.

After adjusting for WHO region, the inverse association persisted with minimal change in the point estimate. Each 10-percentage-point increase in inactivity prevalence was linked to 18.73 fewer deaths per 100,000 population ($\beta = -18.73$; 95%

CI −35.92 to −1.53; p = .033). The adjusted model had a wider confidence interval. Including both inactivity prevalence and WHO region, the model explained 19.0% of the between-country variation in mortality (Table 3).

Table 3. Country-level association between insufficient physical activity and cardiovascular mortality, 2021

Analysis	Estimate	95% CI	p value	R^2
Pearson correlation, r	−0.198	−0.330 to −0.059	.006	—
Spearman correlation, ϱ	−0.244	—	<.001	—
Unadjusted linear regression, β	−19.30	−31.49 to −7.11	.002	.039
WHO-region-adjusted linear regression, β	−18.73	−35.92 to −1.53	.033	.190

Analyses included 193 countries, each weighted equally. Regression coefficients indicate the difference in cardiovascular deaths per 100,000 population for each 10-percentage-point increase in inactivity prevalence. Confidence intervals and p-values were calculated using HC3 heteroskedasticity-robust standard errors with t-based inference. The Pearson confidence interval was calculated using Fisher's z transformation. A confidence interval was calculated for Spearman's correlation. The adjusted model included WHO region as a categorical covariate, and its R^2 refers to the full model. CI = confidence interval.

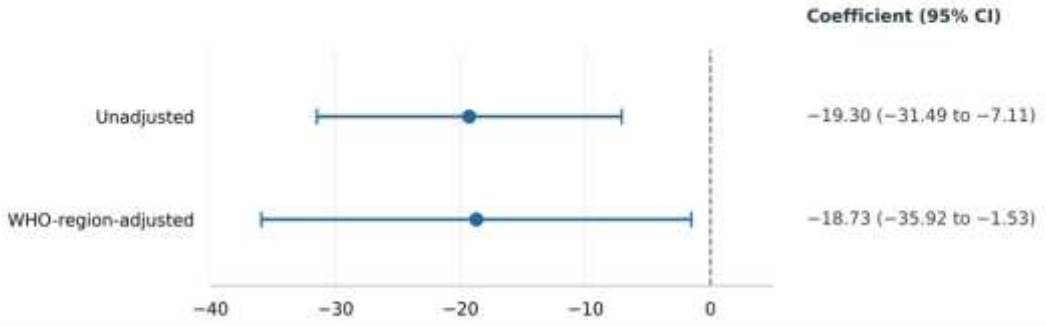

Figure 2 Unadjusted and WHO-region-adjusted associations between insufficient physical activity and cardiovascular mortality across 193 countries, 2021. Points indicate mortality differences per 10-percentage-point increase in inactivity prevalence; horizontal lines represent 95% confidence intervals. The dashed vertical line indicates no association.

Key Findings: Country-Level Association and Model Explanatory Power

In 193 countries, higher prevalence of insufficient physical activity was modestly and inversely associated with cardiovascular mortality, as shown by Pearson's correlation (r = −0.198; p = .006) and Spearman's correlation (ϱ = −0.244; p < .001). In the unadjusted model, each 10-percentage-point increase in inactivity prevalence corresponded to 19.30 fewer cardiovascular deaths per 100,000 population (95% CI −31.49 to −7.11; p = .002). Adjusting for WHO region had minimal impact (coefficient = −18.73; 95% CI −35.92 to −1.53; p = .033), though the confidence interval widened, indicating less precision. Including WHO region increased model explanatory power from 3.9% to 19.0%, highlighting the combined effects of inactivity prevalence and regional differences. However, most between-country mortality variation remained unexplained. These results indicate an inverse ecological association but do not establish causality or a protective effect of physical inactivity.

DISCUSSION

This cross-national ecological analysis of 193 countries found a modest inverse association between insufficient physical activity prevalence and age-standardized cardiovascular mortality in 2021. This association appeared in both Pearson and Spearman correlations and remained after adjusting for WHO region. In the adjusted model, a 10-percentage-point increase in inactivity prevalence corresponded to 18.73 fewer cardiovascular deaths per 100,000 population. However, inactivity prevalence explained only 3.9% of the between-country variation in mortality. These findings reflect an association between national indicators and should not be interpreted as evidence that physical inactivity lowers individual cardiovascular risk.

The direction of the ecological association differed from what individual-level studies typically report. Sattelmair et al. found that greater leisure-time physical activity was linked to lower coronary heart disease risk, even at levels below the recommended minimum.[21] Ramakrishnan et al. similarly reported an inverse association between accelerometer-measured physical activity and incident cardiovascular disease among 90,211 UK Biobank participants without prior or concurrent cardiovascular disease.[22] Ekelund et al. also found that greater device-measured activity was associated with lower all-cause mortality, though this outcome was broader than cardiovascular mortality.[23] Collectively, these studies show that the present country-level findings should not replace evidence supporting the cardiovascular benefits of physical activity.

Distinguishing between individual and population comparisons is key to understanding this discrepancy. Rose noted that factors driving differences in disease occurrence between populations may differ from those distinguishing individuals within a population.[24] Diez-Roux also emphasized the need to consider both contextual and individual characteristics in population health research.[25] In this study, national activity estimates were not linked to individuals who experienced cardiovascular deaths. Countries with higher inactivity prevalence may have other characteristics associated with lower mortality. Adjusting for WHO region did not address this limitation or show that inactive individuals had better cardiovascular outcomes within countries.

Differences in healthcare and socioeconomic conditions may explain the findings, though this remains untested. The PURE study by Yusuf et al. found that major cardiovascular events and case fatality were higher in lower-income countries, despite a lower measured risk-factor burden.[26] Khatib et al. also reported significant international inequalities in the availability and affordability of cardiovascular medicines and their association with medicine use.[27] These findings illustrate why national mortality may not directly reflect the prevalence of a single behavioral risk factor. Countries with higher inactivity prevalence may also have more effective prevention or treatment services, but this analysis did not include indicators to assess that possibility.

The difference between cardiovascular disease occurrence and mortality further limits interpretation. Mortality reflects both disease development and survival after onset. Ford et al., in their analysis of declining coronary mortality in the United States, attributed significant contributions to both changes in risk factors and medical or surgical treatments.[28] Although that study focused on a different population and period, it shows why mortality cannot be interpreted solely as an indicator of behavioral exposure. This analysis could not determine whether countries differed mainly in cardiovascular incidence, case fatality, or both.

Regional comparisons further highlighted the limited correspondence between inactivity prevalence and cardiovascular mortality. The Americas had a relatively high mean inactivity prevalence of 37.21% but the lowest mean mortality rate at 183.19 deaths per 100,000 population. In contrast, the Western Pacific had the highest mean mortality rate at 325.27 deaths per 100,000, despite a lower mean inactivity prevalence of 25.62%. These were descriptive comparisons of unweighted country averages, not population-weighted regional estimates. No formal tests of regional differences were conducted, and the observed patterns do not identify the mechanisms behind these differences.

Variation in activity domains may also complicate comparisons. The exposure indicator summarized whether adults met a minimum activity threshold, without separately estimating the cardiovascular associations of occupational, transport, and leisure-time activity. Holtermann et al. suggested several mechanisms by which occupational activity could differ from leisure-time exercise, such as prolonged physical demands and inadequate recovery.[29] This supports investigating activity domains separately. However, this study did not include domain-specific exposure analysis and could not determine whether occupational activity contributed to the inverse association.

Measurement limitations require further consideration. The international validation study of the International Physical Activity Questionnaire showed the feasibility of standardized surveillance but also identified limitations in agreement with objective activity measurements.[30] This evidence does not validate every survey used in the WHO estimates, but it highlights the challenges of measuring activity consistently across populations. Differences in death registration and cause-of-death information are also important: Mikkelsen et al. found substantial variation in the performance of civil registration and vital statistics systems.[31] Although harmonized national estimates improve comparability, this study did not assess whether differences in source-data quality affected the association. Additionally, treating national estimates as fixed inputs meant that regression intervals did not account for uncertainty in the underlying exposure and mortality estimates.

Using 2021 estimates added another temporal limitation. Tison et al. reported reductions in smartphone-recorded steps during the early COVID-19 pandemic, with significant variation between countries.[32] That study involved selected smartphone users

and an earlier period, so it does not directly explain the present findings. However, it shows that activity patterns could change rapidly during the pandemic. Matching exposure and mortality to 2021 ensured calendar-year consistency but did not establish temporal ordering. Cardiovascular deaths in that year may reflect exposures accumulated over many years, while national activity estimates may not fully capture short-term behavioral changes.

The statistical findings also require careful interpretation. Regional adjustment changed the inactivity coefficient only slightly, from −19.30 to −18.73, but widened its confidence interval. The adjusted interval, from −35.92 to −1.53 deaths per 100,000 population, indicates uncertainty about the association's magnitude. The increase in model R^2 from .039 to .190 reflects adding WHO region alongside inactivity, not a greater contribution from inactivity alone. Most between-country variation remained unexplained. As Greenland et al. emphasized, statistical significance should be considered with effect estimates, uncertainty, and model assumptions; it does not establish causality or eliminate bias.[33]

The study's strengths included broad country coverage, matched observation years, age-standardized indicators, explicit reporting of unmatched records, and complementary correlation analyses. HC3 standard errors addressed heteroskedasticity in regression inference but did not address residual confounding, measurement error, or spatial dependence. Equal country weighting was suitable for describing an average relationship across countries, though it gave countries with very different population sizes equal influence. Formal influence diagnostics, population-weighted sensitivity analyses, and nonlinear models were not conducted. Therefore, the similar directions of Pearson and Spearman correlations should not be interpreted as evidence that influential observations or model specification had no effect.

Future research should use a prespecified causal framework to select covariates and distinguish potential confounders from mediators. VanderWeele's principles of confounder selection offer guidance and caution against relying solely on statistical selection procedures.[34] National income, education, tobacco exposure, and healthcare access should be considered, while metabolic factors should be included based on their assumed causal roles. Repeated country observations, lagged activity estimates, assessment of spatial dependence, and accounting for source-estimate uncertainty would strengthen evaluation of the ecological relationship. Individual-level longitudinal or multilevel studies are needed to examine how personal activity and national context jointly relate to cardiovascular outcomes.

These findings do not justify reducing efforts to promote physical activity. Evidence on implementing activity interventions at scale supports coordinated approaches tailored to local social, economic, and environmental conditions.[35] Such efforts should complement cardiovascular prevention and access to effective treatment. This study's contribution is identifying a modest inverse association between national surveillance indicators, whose explanation remains unresolved, rather than evidence of a protective effect of inactivity.

CONCLUSION

This ecological analysis of 193 countries found that, overall, insufficient physical activity was negatively but slightly associated with national rates of age-standardized cardiovascular mortality in 2021. The association was not explained by WHO region and the between-country variance in mortality explained by inactivity prevalence was 3.9%.

These results are of a country level relationship. However, the cross-sectional design, the lack of adjustment for covariates and the use of aggregate estimates preclude causal interpretation. The findings may also be due to unmeasured factors, such as socioeconomic factors, health care access, and other cardiovascular factors. Additional studies projecting the association after wider adjustment and exposure assessment conducted longitudinally and sensitivities analyses should be performed. Although these findings do not support an adjustment to the recommendations on physical activity, it is an indication of a nationwide trend that should be further explored.

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