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The role of environmental access to exercise opportunities in cardiovascular mortality: evidence from a nationwide study

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Abstract

Background Environmental access to exercise opportunities plays a crucial role in determining the level of physical activity within a population. However, it is unclear how environmental factors contribute to disparities in physical activity and health outcomes. We explored the associations between county-level access to exercise opportunities and cardiovascular disease (CVD) mortality across US counties.

Methods We conducted an ecological analysis using aggregated data from two primary sources: the County Health Rankings and Roadmaps data and CDC WONDER mortality data. We compared county-level age-adjusted CVD mortality across county-level quartiles of access to exercise opportunities and physical inactivity. Stratification was performed based on age, sex, race, and urbanization variables. The rate ratio (RR) for CVD mortality was also calculated using generalized linear models.

Results We observed significant variations in CVD mortality across different levels of exercise opportunities access and physical inactivity, which was consistent across all demographic subgroups ($P < 0.001$). Access to exercise opportunities was significantly associated with a reduced risk of CVD mortality (RR = 0.93 [0.91–0.95]), and the association was most pronounced for acute myocardial infarction (AMI) mortality (RR, 0.80 [0.76–0.85]). The county-level physical inactivity was significantly associated with an increased risk of CVD mortality (RR, 1.16 [1.14–1.17]), especially for ischemic heart disease (IHD) (RR, 1.35 [1.31–1.38]) and AMI (RR, 1.32 [1.25–1.38]). All demographic subgroups demonstrated similar benefits in reducing the risk of CVD by improving the county-level indicators of physical activity.

Conclusions Counties have the potential to make significant environmental strides in improving the cardiovascular health of their populations by enhancing access to exercise opportunities in the context of urbanization.

Keywords Access to exercise opportunities, Physical inactivity, Cardiovascular disease, Nationwide study

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Background

Cardiovascular disease (CVD) stands as the foremost global cause of death. Since the 2000, the total number of global CVD-related deaths has increased by a quarter, reaching 17.9 million in 2019, accounting for 32.2% of all global deaths [1]. In the USA, CVD, particularly ischemic heart disease (IHD), ranks as the primary cause of death for males, females, and individuals across diverse racial and ethnic groups. In 2021, CVD claimed the lives of 1 in 5 people in the USA, and it also imposes an annual cost of approximately $250 billion on the US economy during 2018 to 2019 [2]. Given these figures, preventing and controlling CVD becomes imperative to curtail both mortality rates and the associated disease burden.

Engaging in regular physical activity is a highly effective method for the primary prevention of CVD, which fits within a comprehensive lifestyle strategy and complements medication treatment [3, 4]. Physical activity offers numerous cardiovascular benefits, including improving cardiovascular fitness, promoting better blood vessel function, and regulating blood pressure and cholesterol levels [5, 6]. According to the Department of Health and Human Services, adults are recommended to do at least 75 to 150 min of vigorous-intensity aerobic physical activity per week or an equivalent combination of moderate- and vigorous-intensity aerobic activity [7]. Greater reductions in CVD risk can be achieved through higher volumes and intensities of physical activity [8]. Research indicates that adults can significantly decrease their mortality risk and CVD events by increasing individual physical activity, regardless of existing CVD risk factors [9]. Adhering to and sustaining activity levels in line with public health guidelines can reduce the risk of mortality linked to physical inactivity [10, 11].

The level of physical activity within a population may be directly influenced by access to exercise opportunities [12–14]. Nonetheless, the prevalence of physical inactivity in high-income Western countries, including the USA, has reached as high as 36.8% of the population [15]. To effectively promote CVD prevention at the local level, it is imperative to create environments that support physical activity and mitigate barriers to exercise. However, county-level variation in physical activity and its association with CVD mortality remains undetermined. Herein, we conducted an ecological analysis of the national mortality database to examine the association of access to exercise opportunities and physical inactivity with CVD mortality across US counties, stratified by their demographic characteristics.

Methods

Study design

We conducted an ecological analysis to investigate the association between environmental access to exercise opportunities, physical inactivity, and CVD mortality outcomes across the USA from 2016 to 2020, emphasizing county-level inferences.

Data source for mortality outcome

The US county-level mortality and population data spanning from 2016 to 2020 were sourced from the Underlying Cause of Death database, which is part of the Centers for Disease Control and Prevention (CDC) Wide-Ranging Online Data for Epidemiological Research (WONDER) platform (https://wonder.cdc.gov/). The data are derived from death certificates of US residents, which are legally mandated documents verified by medical professionals or forensic experts [16, 17]. Each certificate records a single underlying cause of death with demographic details, including sex, race, age, and urbanization categories.

The age-adjusted mortality rates and 95% confidence intervals (CIs) for all related deaths attributed to CVD and its subtypes were obtained according to the International Classification of Diseases 10th Revision (ICD-10). The CVD subtypes include IHD (I20–I25), acute myocardial infarction (AMI) (I21–I22), heart failure (HF) (I50), and cerebrovascular diseases (I60–I69) [18]. The mortality rates are presented per 100,000 adults with 95% CIs. We then classified by sex (male and female), age (45–64, $\geq$65), race (White, American Indian or Alaska Native, Black or African American), and urbanization categories (large fringe metro, medium metro, small metro, noncore). The urbanization categories are based on the National Center for Health Statistics (NCHS) classification, which categorizes US counties into large central metro, large fringe metro, medium metro, small metro, micropolitan, and noncore, according to the population size and urban characteristics, as detailed elsewhere [19].

Exposures

In the present study, the county-level exposure of physical activity metrics included access to exercise opportunities and physical inactivity, which are extracted from the County Health Rankings and Roadmaps data (https://www.countyhealthrankings.org/explore-health-rankings/rankings-data-documentation/national-data-documentation-2010-2019). The data were provided on health factors at the county level across the USA. It aggregates information from various nationally recognized datasets and has been validated through published studies demonstrating its reliability and accuracy in health-related research [20–22].

Access to exercise opportunities

Access to exercise opportunities is defined as the percentage of the population with adequate access to locations for physical activity. These facilities are identified through Standard Industry Classification codes as defined by the US Securities and Exchange Commission and include parks, sidewalks, or recreational facilities like gyms, community centers, dance studios, pools, and other exercise facilities. Access to exercise opportunities is considered adequate for individuals if they meet any of these conditions: residing in a census block located within half a mile of a park, living within one mile of a recreational facility in an urban area, or being situated within three miles of a recreational facility in a rural area. This index ranges from 0 to 1, with higher values exhibiting higher access to exercise opportunities than the lower values. Then, we classified the percentile rankings for the access to exercise opportunities values into quartiles (from 1st, 0–0.25 [lowest inactivity] to 4th, 0.75–1.00 [highest inactivity]) based on their distribution among all US counties.

Physical inactivity

Physical inactivity is originally based on responses to Behavioral Risk Factor Surveillance System (BRFSS) surveys. Physical inactivity was defined as the percentage of adults aged 18 and over reporting no leisure-time physical activity (age-adjusted). This index ranges from 0 to 1, with higher values exhibiting physical inactivity than the lower values. Similarly, we classify the index for physical inactivity into quartiles (from 1st, 0–0.25 [lowest inactivity] to 4th, 0.75–1.00 [highest inactivity]) on the basis of their distribution among all US counties.

Covariates

In this study, several conventional cardiovascular risk factors were considered as covariates to control for potential biases in the analysis. These covariates were all sourced from County Health Rankings and Roadmaps (Table S1). These confounders were considered in both classifying the population as well as in model adjustments: (1) demographics: percentage of female (% Female), percentage of Hispanic (% Hispanic), percentage of rural population (% Rural), percentage of population over the age of 65 years (% 65 and older). The percentages of other racial/ethnic groups were not included since the information was not available in the database. Socioeconomic and environmental factors: percentage of uninsured population, ratio of population to primary care physician, household income inequality, adults smoking prevalence, obesity prevalence, and diabetes prevalence.

Statistical analysis

We included only the counties that had complete and comprehensive data on access to exercise opportunities, physical inactivity, and CVD mortality. Counties missing any of these key data points were excluded from the analysis to ensure accuracy and reliability in our findings. No missing values were identified for the covariates. Finally, a total of 3069 (97.6%) US counties were included in the analyses throughout this study. To visualize these county-level physical activity metrics (access to exercise opportunities and physical inactivity) and CVD mortality rates, we utilized the ggplot2 package in R for map visualization. The generalized linear model (GLM) was used to compare CVD mortality across quartiles of these physical activity metrics. These calculations were then stratified by groups, specifically targeting the group-specific CVD mortality rates based on demographic characteristics and levels of urbanization.

In addition, we calculated rate ratios (RR) and corresponding 95% confidence intervals (CIs) by comparing the mortality rates for both total and specific CVDs (IHD, AMI, HF, and cerebrovascular diseases) between the fourth and first quartiles of the population. The GLM was employed to determine the association between access to exercise opportunities, physical inactivity, and CVD mortality. Specifically, we used a GLM with a quasi-Poisson distribution, incorporating log (Population) as an offset to address overdispersion and to accurately model event rates relative to population size. This analysis was conducted using the R glm function from the R stats package [23, 24]. Model 1 is a univariate analysis with adjustments for year. Model 2 is a fully adjusted model that further accounts for covariates accompanying the exposure data, including percentage of female, percentage of Hispanic, percentage of rural population, percentage of population over the age of 65 years, percentage of uninsured population, ratio of population to primary care physician, household income inequality, adults smoking prevalence, obesity prevalence, and diabetes prevalence.

Several stratified and sensitivity analyses were conducted. Since income levels can influence both access to resources, such as exercise facilities, and health outcomes, analyses were conducted by comparing the association of access to exercise opportunities and physical inactivity with CVD mortality between counties with low and high median household income. Similarly, since physical activity and CVD mortality vary according to sex, we further compared the association of access to exercise opportunities and physical inactivity with CVD mortality between counties with different sex distribution. We divided counties into two groups based on sex distribution: those with females comprising 50% or more of the population (female-dominated counties) and those with less than 50% female population (male-dominated counties). In sensitivity analyses, to account for potential clustering effects at the state level, we added state as a random intercept in our model. We used the glmer() function from the lme4 package [25]. Moreover, we included all-cause mortality as an outcome to provide a more comprehensive understanding of the overall impact. Statistical significance was defined as 95% CIs that do not include 1, or *P* values less than 0.05. All analyses were performed using R Software version 4.1.3 (The Foundation for Statistical Computing).

Results

Access to exercise opportunities and CVD mortality

In general, the southeastern region of the USA exhibited the highest proportion of counties characterized by limited access to exercise opportunities, elevated levels of physical inactivity, and increased cardiovascular disease (CVD) mortality rates. In contrast, the northeastern and northwestern regions showed higher access to exercise opportunities, lower levels of physical inactivity, and reduced CVD mortality rates (Fig. 1).

As shown in Table 1, the age-adjusted total CVD mortality rates (per 100,000 population) were highest in the 1st quartile (272.00 [95% CI, 229.80–319.62]) and lowest in the 4th quartile (210.70 [183.10–242.10]). Overall, the CVD mortality decreased from the 1st to 4th quartile across all sociodemographic subgroups, including age, sex, race, and urbanization ($P < 0.001$). The RRs for CVD mortality (highest value versus lowest value) slightly varied when stratified by urbanization, where people living in the large fringe metro had an 11% lower risk of CVD mortality in the 4th versus 1st access to exercise opportunities quartile (RR, 0.89 [0.84–0.94]) (Table 1). In the entire population, the environmental access to exercise opportunities were significantly associated with a reduced risk of CVD mortality (unadjusted RR, 0.66 [0.65–0.67]). After adjusting for various sociodemographic factors, the county-level metrics of access to exercise opportunities were significantly associated with a reduced risk of CVD mortality (RR, 0.93 [0.91–0.95]) (Fig. 2). The subgroup analyses results indicate consistent and robust outcomes, regardless of income disparities (Fig. S1) and sex distribution (Fig. S2). After accounting for potential clustering effects at the state level, the results remained largely unchanged (Fig. S3). This association was consistent for all-cause mortality, though the RR for all-cause mortality was much lower than that for CVD mortality (RR, 0.96 [0.94–0.97]) (Table S2).

As for specific types of CVD, the age-adjusted IHD mortality rates were highest in the 1st quartile (121.80 [98.40–154.10]) and lowest in the 4th quartile (85.70 [69.40–104.93]). Also, the age-adjusted AMI mortality rates were highest in the 1st quartile (73.40 [45.85–108.65]) and lowest in the 4th quartile (21.80 [17.10–29.10]). The mortality rates attributable to IHD, AMI, HF, and cerebrovascular disease decreased from the lowest to highest quartiles (Table 2). In the crude model (model 1), the RRs of IHD and AMI were 0.65 (0.64–0.67) and 0.35 (0.33–0.36) in the 4th versus 1st quartile of access to exercise opportunities, respectively. The RRs of HF and cerebrovascular diseases were 0.49 (0.47–0.51) and 0.70 (0.68–0.71), respectively. In the fully adjusted model (model 2), the RRs of IHD and AMI were 0.96 (0.93–0.99) and 0.80 (0.76–0.85), respectively (Fig. 2A). In model 2, the RRs of HF and cerebrovascular diseases were 0.88 (0.83–0.93) and 0.95 (0.93–0.98), respectively (Fig. 2A).

Physical inactivity and CVD mortality

As indicated in Table 3, the lowest age-adjusted total CVD mortality rates (per 100,000 population) were observed in the 1st quartile (197.40 [174.80–223.40]), while the highest rate was found in the 4th quartile (288.60 [250.10–332.60]). The CVD mortality rates increased from the 1st to 4th quartile across all categories, including age, sex, race, and urbanization ($P < 0.001$). The RRs for CVD mortality (highest value versus lowest value) varied slightly when stratified by sex, race, and urbanization. For example, the male (RR, 1.13 [1.11–1.15]) and female (RR, 1.20 [1.17–1.22]) in the 4th physical inactivity quartile had 1.13-fold and 1.20-fold higher CVD mortality than those in the 1st quartile, respectively. The White (RR, 1.20 [1.19–1.22]) adults in the 4th physical inactivity quartile had a significantly higher risk of CVD mortality than those in the 1st quartile. The small metro (RR, 1.25 [1.20–1.30]) had a 1.25-fold CVD mortality risk in the 4th versus 1st physical inactivity quartile (Table 3). In model 1, the RR of CVD mortality was 1.64 (1.62–1.66) in the 4th versus 1st quartile of physical inactivity, respectively. In model 2, the RR of CVD mortality was 1.16 (1.14–1.17) (Fig. 2B). The results also showed consistency when stratified by income disparities (Fig. S1) and sex distribution (Fig. S2). In sensitivity analyses, adjusting for clustering effects at the state level did not significantly alter the findings (Fig. S3). Similar association was observed for all-cause mortality; however, the RR when comparing the 4th quartile to the 1st quartile for all-cause mortality was notably lower than that for CVD mortality, with an RR of 1.05 (1.04, 1.06) (Table S2).

For specific types of CVD, the age-adjusted mortality rates revealed similar patterns. The IHD mortality rates were lowest in the 1st quartile at 197.40 (174.80–223.40) and highest in the 4th quartile at 288.60 (250.10–332.60). Similar trends were observed for AMI, HF, and cerebrovascular diseases, with mortality rates decreasing from the 4th quartile to the 1st quartile (Table 4). Higher RRs

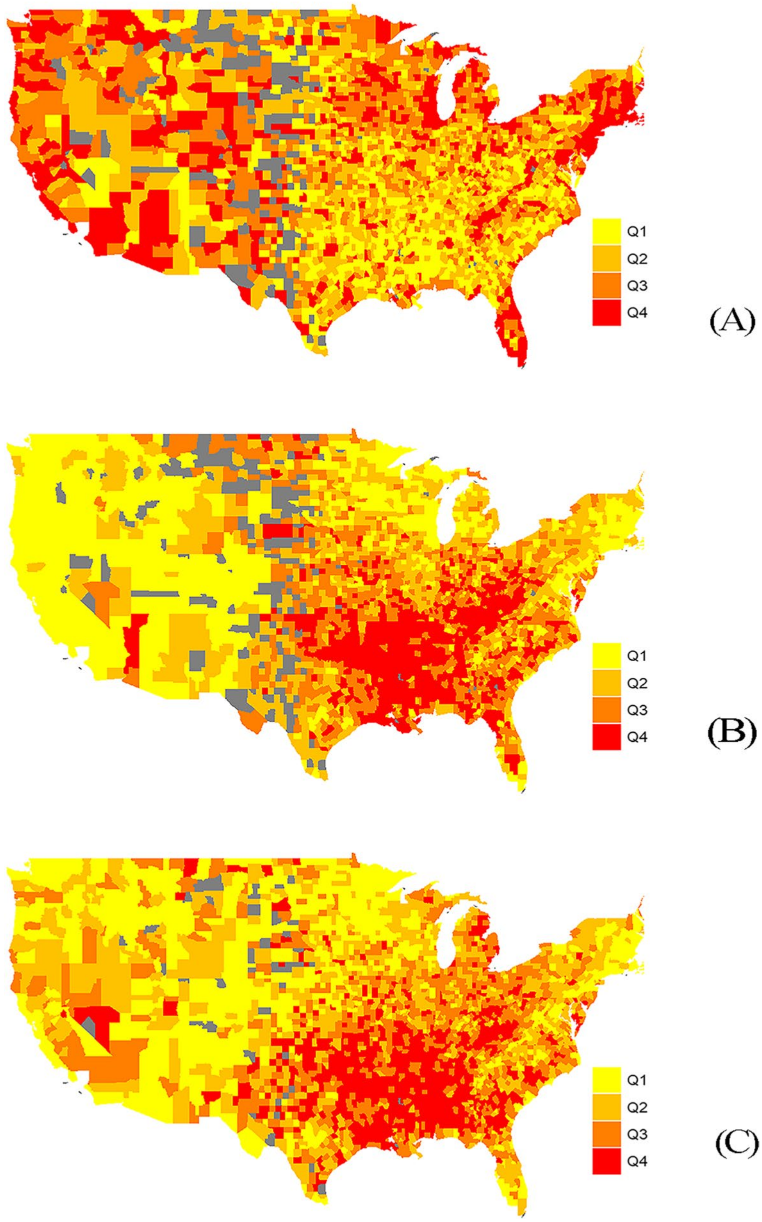

Fig. 1 The US county-level physical activity value and cardiovascular disease. **A** Counties by access to exercise opportunities index value; **B** counties by physical inactivity index value; **C** counties by age-adjusted cardiovascular disease mortality rates per 100,000 among adults. Q indicates quartile

were detected in the mortality of IHD and AMI. In the 4th quartile of physical inactivity, the mortality from IHD and AMI were increased by 35% (RR, 1.35 [1.31–1.38]) and 32% (RR, 1.32 [1.25–1.38]), respectively, compared to the 1st quartile (Fig. 2B).

Discussion

In this study, counties with greater access to physical activity opportunities had lower levels of CVD mortality. Specifically, counties in the highest quartile of access to physical activity opportunities were associated with a 20% lower rate of AMI mortality compared to counties in the lowest quartile. Counties with higher levels of physical inactivity were associated with increased rates of CVD mortality. Compared to counties in the 1st quartile of physical inactivity, those in the 4th quartile exhibited 35% and 32% higher mortality rates for IHD and AMI, respectively.

Previous studies on the association between access to environmental exercise opportunities and CVD are

Table 1 Age-adjusted mortality rates* for major cardiovascular disease stratified by access to exercise opportunities value quartiles in US counties, 2016–2020

Cardiovascular mortality	Access to exercise opportunities					
	Quartile 1	Quartile 2	Quartile 3	Quartile 4	*P* value	Rate ratio, quartile 4/1
Total	272.00 (229.80, 319.62)	250.60 (214.70, 294.90)	235.30 (203.10, 272.08)	210.70 (183.10, 242.10)	< 0.001	0.93 (0.91, 0.95)
By age						
45–64 y	283.00 (220.20, 355.00)	212.60 (167.00, 277.85)	180.60 (141.25, 232.10)	134.50 (102.25, 179.88)	< 0.001	0.95 (0.92, 0.98)
> 64 y	1649.10 (1418.90, 1906.80)	1565.00 (1361.60, 1799.45)	1493.40 (1315.10, 1688.20)	1365.50 (1207.95, 1545.30)	< 0.001	0.93 (0.92, 0.95)
By sex						
Male	340.15 (283.42, 408.15)	308.60 (263.70, 368.40)	287.25 (244.22, 345.50)	254.40 (211.50, 309.45)	< 0.001	0.95 (0.93, 0.97)
Female	233.30 (195.20, 280.55)	208.90 (178.10, 248.28)	195.30 (165.80, 231.33)	172.25 (144.00, 209.00)	< 0.001	0.93 (0.91, 0.96)
By race						
White	278.80 (223.50, 346.75)	254.40 (203.00, 313.70)	235.50 (189.80, 290.50)	208.40 (167.30, 257.90)	< 0.001	0.91 (0.90, 0.93)
American Indian or Alaska Native	230.30 (160.25, 341.48)	303.25 (207.55, 508.17)	202.90 (154.30, 265.90)	211.80 (127.35, 297.80)	0.015	0.86 (0.73, 1.01)
Black or African American	382.70 (301.80, 493.40)	344.25 (270.43, 444.53)	296.30 (237.70, 371.80)	258.60 (210.80, 328.90)	< 0.001	1.03 (0.97, 1.09)
By urbanization						
Large fringe metro	253.10 (217.47, 287.80)	228.80 (199.50, 255.20)	212.35 (186.12, 238.10)	186.70 (165.88, 217.10)	< 0.001	0.89 (0.84, 0.94)
Medium metro	253.90 (213.90, 295.10)	241.30 (212.52, 270.23)	227.15 (200.25, 247.30)	201.75 (183.38, 236.50)	< 0.001	0.99 (0.95, 1.04)
Small metro	263.80 (214.10, 301.60)	242.65 (210.28, 276.15)	228.40 (200.80, 262.90)	205.30 (180.80, 234.90)	< 0.001	0.97 (0.93, 1.01)
Noncore	283.70 (241.40, 335.08)	266.80 (222.90, 313.70)	244.00 (210.00, 290.00)	236.00 (202.00, 282.70)	< 0.001	0.94 (0.92, 0.96)

*Age-adjusted mortality rates are presented per 100,000 adults with 95% CIs. *P* values were derived using the generalized linear models. These models were employed to assess the association between access to exercise opportunities (independent variable) and group-specific CVD mortality (dependent variable)

limited. Similar to an earlier study which showed that increased neighborhood access to physical activity opportunities, measured within a 5-km radius of participants' homes, was associated with a reduced risk of incident CVD among 3595 older adults. Specifically, each standard deviation increase in walking destinations and physical activity facilities was associated with a 7% and 12% reduction in CVD risk, respectively [26]. In addition, previous research reported that greater environmental access to exercise opportunities can promote individual physical activity and reduce the prevalence of obesity. For example, a prior study found that increased enjoyment and engagement in physical education, as well as active transport to school, are associated with improved fitness levels and reduced BMI among adolescents in low-income communities [13]. Another study found that providing universal free access to leisure facilities, coupled with outreach and marketing activities, led to a 64% increase in attendance at swimming and gym sessions and higher participation in physical activity in a disadvantaged area in northwest England. The effects were pronounced among lower socioeconomic groups [14].

Physical activity can improve mental health and effectively reduce levels of psychosocial stress. Research indicates that the benefits of exercise in alleviating stress are amplified when exercise occurs in a social environment, such as group workouts, team sports, and interactive games [27]. When people have more access to exercise facilities, they are more likely to participate in physical activities such as aerobic exercise and strength training [28]. In addition, walking trails, bike paths, and outdoor fitness zones in communities not only increase physical activity levels but also encourage outdoor exposure, which has its own set of mental health benefits, such as reduced symptoms of depression and anxiety [29]. By increasing accessibility and opportunity for physical activity through environmental design, communities can

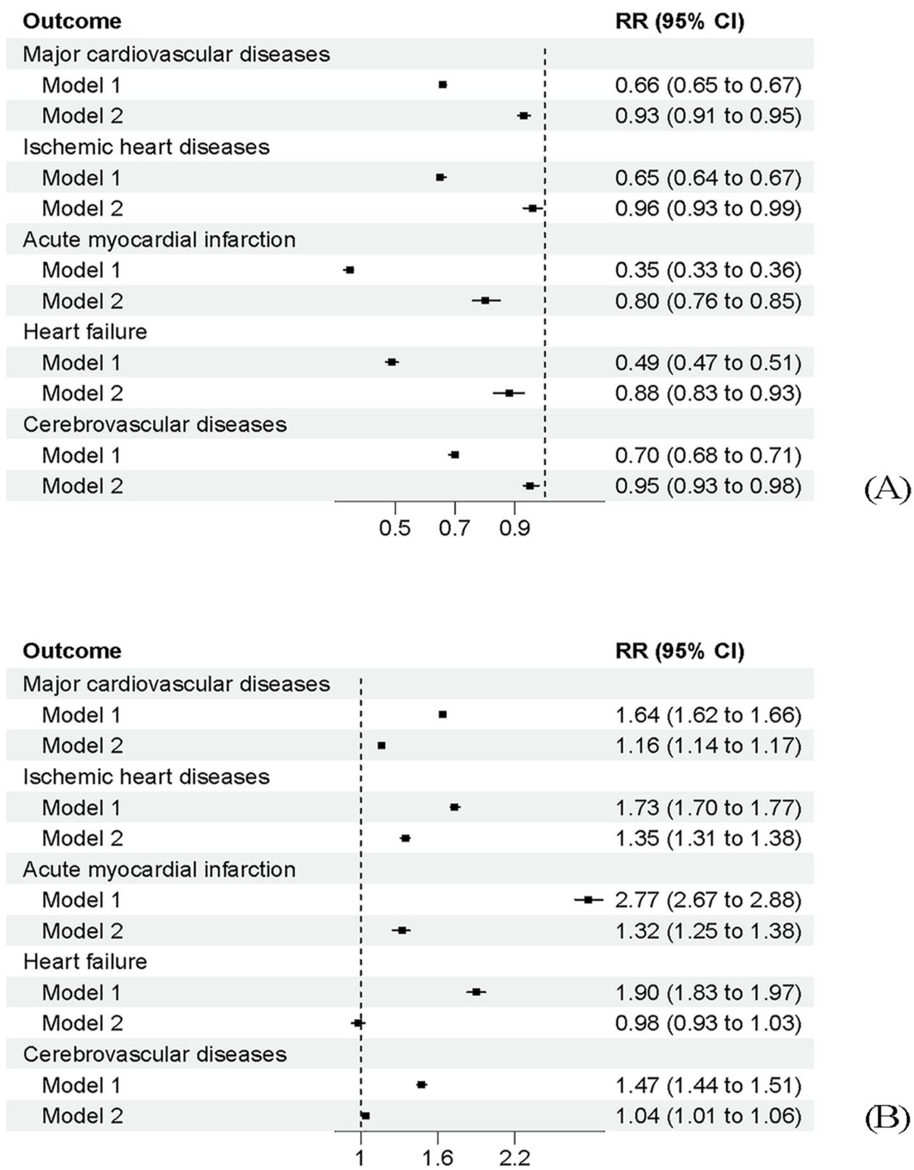

Fig. 2 Association of **A** access to exercise opportunities value and **B** physical inactivity value with age-adjusted mortality rates for specific cardiovascular disease, 4th (highest) value versus 1st (lowest) value. Model 1 was adjusted for year. Model 2 was additionally adjusted for percentage of female, percentage of Hispanic, percentage of rural population, percentage of population over the age of 65 years, percentage of uninsured population, ratio of population to primary care physician, household income inequality, adults smoking prevalence, obesity prevalence, and diabetes prevalence

foster healthier lifestyles and mitigate the negative impact of psychosocial stress on cardiovascular health [30].

With more access to exercise opportunities, the cardiovascular protective effects were slightly higher among people living in large fringe metro areas. According to a previous study [31], the quality of parks is associated with higher levels of park utilization and increased moderate to vigorous physical activity. Furthermore, large cities may often possess a greater number of high-quality parks and a more diverse range of fitness facilities, contributing to elevated levels of physical activity among their residents [31]. Large cities may also excel in creating a physical and social environment that promotes physical activity through urban environments design strategies such as increasing net residential density, public transport density, and park density, thereby enhancing active transportation and walkability [32, 33]. While it highlights the benefits of urban access to facilities and infrastructure, it is important to acknowledge that we cannot rule out other factors, such as socioeconomic disparities

Table 2 Age-adjusted mortality rates* for major and specific cardiovascular diseases (CVD) stratified by access to exercise opportunities value quartiles

Cardiovascular mortality	Access to exercise opportunities				
	Quartile 1	Quartile 2	Quartile 3	Quartile 4	*P* value
Major CVD	272.00 (229.80, 319.62)	250.60 (214.70, 294.90)	235.30 (203.10, 272.08)	210.70 (183.10, 242.10)	< 0.001
Ischemic heart diseases	121.80 (98.40, 154.10)	107.00 (87.80, 133.50)	100.10 (80.50, 124.20)	85.70 (69.40, 104.93)	< 0.001
Acute myocardial infarction	73.40 (45.85, 108.65)	45.25 (31.10, 72.73)	32.80 (23.33, 51.70)	21.80 (17.10, 29.10)	< 0.001
Heart failure	40.30 (28.78, 56.23)	29.70 (22.10, 39.95)	25.00 (18.60, 33.23)	19.90 (14.57, 25.70)	< 0.001
Cerebrovascular diseases	49.10 (40.58, 58.70)	43.15 (36.10, 52.00)	39.90 (34.10, 46.80)	36.00 (30.30, 42.48)	< 0.001

*Age-adjusted mortality rates are presented per 100,000 adults with 95% CIs. The *P* values were calculated using generalized linear models. These models were employed to assess the association between access to exercise opportunities (independent variable) and CVD mortality (dependent variable)

Table 3 Age-adjusted mortality rates* for major cardiovascular disease stratified by physical inactivity value quartiles in US counties, 2016–2020

Age adjusted rate	Physical inactivity					
	Quartile 1	Quartile 2	Quartile 3	Quartile 4	*P* value	Rate ratio, quartile 4/1
Total	197.40 (174.80, 223.40)	229.70 (203.90, 260.35)	254.30 (221.75, 291.83)	288.60 (250.10, 332.60)	< 0.001	1.16 (1.14, 1.17)
By age						
45–64 y	120.80 (96.77, 153.20)	174.45 (142.67, 213.35)	221.30 (182.20, 280.70)	290.20 (235.40, 363.40)	< 0.001	1.15 (1.12, 1.18)
≥ 65 y	1312.00 (1165.70, 1472.90)	1467.10 (1306.00, 1641.70)	1573.15 (1384.20, 1778.88)	1713.50 (1504.05, 1954.90)	< 0.001	1.14 (1.12, 1.15)
By sex						
Male	238.10 (205.40, 280.02)	281.60 (245.60, 328.28)	318.50 (275.10, 374.60)	358.90 (305.60, 427.70)	< 0.001	1.13 (1.11, 1.15)
Female	163.00 (139.20, 192.70)	191.00 (164.85, 221.75)	213.40 (184.85, 251.65)	245.60 (208.10, 291.83)	< 0.001	1.20 (1.17, 1.22)
By race						
White	198.60 (160.20, 241.95)	232.30 (186.10, 283.10)	257.10 (206.70, 316.92)	290.65 (234.85, 357.70)	< 0.001	1.20 (1.19, 1.22)
Black or African American	253.80 (207.10, 318.20)	291.30 (231.17, 373.83)	338.10 (268.82, 428.05)	386.50 (302.10, 508.90)	< 0.001	0.96 (0.92, 1.00)
By urbanization						
Large fringe metro	176.65 (160.40, 199.30)	210.60 (193.70, 228.85)	234.35 (211.25, 258.55)	256.90 (228.02, 291.55)	< 0.001	1.14 (1.09, 1.19)
Medium metro	194.10 (176.67, 213.90)	226.75 (201.70, 248.40)	242.85 (214.93, 270.45)	266.30 (239.50, 314.70)	< 0.001	1.20 (1.15, 1.24)
Small metro	191.65 (172.73, 217.57)	217.90 (195.67, 243.28)	256.10 (220.10, 281.90)	277.20 (246.03, 313.27)	< 0.001	1.25 (1.20, 1.30)
Noncore	220.50 (187.38, 252.12)	241.25 (210.72, 281.62)	264.55 (229.57, 308.18)	04.20 (260.57, 351.30)	< 0.001	1.16 (1.14, 1.19)

*Age-adjusted mortality rates are presented per 100,000 adults with 95% CIs. *P* values were derived using the generalized linear models. These models were employed to assess the association between physical inactivity (independent variable) and group-specific CVD mortality (dependent variable)

and healthcare access, that may also influence these outcomes. When compared to rural areas, urban areas typically enjoy advantages in terms of healthcare services and infrastructure, which may synergistically enhance cardiovascular protection in conjunction with access to physical opportunities [32]. By focusing on access to physical activity opportunities at the community level, our study provides valuable insights into potential policy interventions aimed at reducing CVD risk on a population scale. Therefore, building on our findings, cities should prioritize investment in community infrastructure such as parks and recreational areas. Supporting worksite

Table 4 Age-adjusted mortality rates* for specific cardiovascular diseases stratified by physical inactivity value quartiles

Age adjusted rate	Physical inactivity				
	Quartile 1	**Quartile 2**	**Quartile 3**	**Quartile 4**	***P* value**
Major cardiovascular diseases	197.40 (174.80, 223.40)	229.70 (203.90, 260.35)	254.30 (221.75, 291.83)	288.60 (250.10, 332.60)	< 0.001
Ischemic heart diseases	79.80 (66.10, 96.80)	98.20 (81.77, 117.53)	110.60 (91.50, 135.50)	127.00 (101.30, 158.10)	< 0.001
Acute myocardial infarction	21.70 (16.70, 29.70)	31.00 (23.08, 47.92)	43.00 (29.90, 68.10)	70.25 (42.65, 104.18)	< 0.001
Heart failure	19.70 (14.60, 25.58)	24.50 (18.50, 32.20)	29.00 (21.60, 39.30)	37.90 (26.30, 55.00)	< 0.001
Cerebrovascular diseases	35.30 (30.20, 40.80)	39.15 (33.30, 45.80)	44.00 (37.20, 52.20)	49.45 (41.80, 58.90)	< 0.001

*Age-adjusted mortality rates are presented per 100,000 adults with 95% CIs. The *P* values were calculated using generalized linear models. These models were employed to assess the association between physical inactivity (independent variable) and CVD mortality (dependent variable)

wellness programs and implementing targeted physical activity initiatives can further promote active lifestyles. Enacting policy changes to create walkable neighborhoods and increasing access to exercise facilities, especially for low-income populations, are also crucial steps in fostering healthier urban environments [34–36].

In the current study, there were significant changes in RR for different CVD outcomes following multivariable adjustment, particularly for AMI. This finding likely arises from the specific sensitivity of AMI to the covariates included in our adjustment model, such as smoking prevalence, obesity, and diabetes. These covariates are established risk factors for AMI and may directly influence its risk more significantly compared to other CVD outcomes [37]. The differential effects highlight the need to carefully consider the distinct risk profiles associated with each CVD outcome when interpreting the impact of confounding factors. In addition, while environmental access to exercise opportunities may affect CVD outcomes, its impact on all-cause mortality is less pronounced. Exercise and inactivity are strongly associated with CVD. While their impact on deaths from other causes, such as cancer, accidents, or infections, might be less significant, further research is needed to fully understand these relationships [38, 39]. Nevertheless, our findings underscore the importance of comprehensive multivariable adjustment to capture the nuanced interplay of factors affecting each CVD outcome. Further research could explore the mediating roles of these factors to enhance our understanding of their influence on CVD risk, particularly in relation to specific conditions like AMI.

In addition, future studies could explore several approaches to deepen the understanding and enhancement of the relationship between physical activity opportunities and cardiovascular health. First, conducting longitudinal studies would be beneficial to assess the causal impact of changes in access to physical activity opportunities on CVD mortality. Furthermore, research should focus on customizing interventions to reduce disparities across different socioeconomic and racial/ethnic groups, ensuring that all community segments benefit equally [40]. Public policy and urban planning studies could also assess the effectiveness of specific policies and urban design strategies that prioritize physical activity infrastructure [41]. Through these avenues, we can better leverage physical activity opportunities to improve cardiovascular health and guide evidence-based policy-making.

Our research conducted a nationwide study in the USA to assess the association between access to exercise opportunities, physical inactivity, and cardiovascular mortality. By leveraging a large and representative sample from the US population, this study enhances the generalizability of its findings across diverse demographic and geographic contexts. It also provides a framework for understanding national trends, thereby offering valuable insights for policymakers and public health initiatives. Nevertheless, some limitations should be addressed. First, the measure of access to exercise opportunities is still limited because it excludes places like sidewalks, malls, and school gyms. Access can also be restricted by factors like park entry points, busy streets, and usage fees. The measure of physical inactivity ignores physical activity from jobs, potentially mislabeling low-income communities as “inactive” and reinforcing stereotypes. Second, as our analysis relied on aggregated county-level data and employed GLMs to estimate effect sizes based on rates rather than event timing, we did not incorporate competing risks models to account for CVD mortality. Furthermore, the ecological design of our study could lead to the ecological fallacy, limiting our ability to establish causal relationships between exercise opportunity access, physical inactivity, and CVD mortality. Consequently, we are not able to determine whether limited access to exercise opportunities causes higher CVD mortality or if areas with high CVD rates invest less in exercise infrastructure due to other existing health challenges. Finally, our analysis was conducted at the county level, which precluded adjustments for individual-level variations and clinical risk factors like medication use. Our estimates may provide a broader population-level perspective regarding CVD mortality. Future research may incorporate longitudinal designs and individual-level data to explore potential mediation pathways and establish causal relationships more robustly.

Conclusions

In conclusion, our findings emphasized the importance of county-level access to exercise opportunities and physical activity in realizing significant cardiovascular health benefits. To effectively promote CVD prevention, it is essential to establish environments that promote physical activity participation and remove barriers to exercise among residents. Future research and public health strategies should focus on removing barriers to exercise by investing in safe and accessible recreational spaces, implementing targeted community-based programs, and refining urban planning policies to support active lifestyles among all residents.

Abbreviations

CVD	Cardiovascular disease
AMI	Acute myocardial infarction
IHD	Ischemic heart disease
HF	Heart failure
RR	Rate ratio
CIs	Confidence intervals
NO	Nitric oxide
CDC	Centers for Disease Control and Prevention
WONDER	Wide-Ranging Online Data for Epidemiological Research
ICD- 10	International Classification of Diseases 10th Revision

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-04060-8.

Additional file 1: Table S1. Data source for variables included in this study. Table S2. Rate ratios* for the association of access to exercise opportunities value and physical inactivity value with all-cause age-adjusted mortality rates. Fig. S1. Association ofaccess to exercise opportunities value andphysical inactivity value with age-adjusted mortality rates for specific cardiovascular disease, 4 thvalue versus 1 stvalue, stratified by household income. Fig. S2. Association ofaccess to exercise opportunities value andphysical inactivity value with age-adjusted mortality rates for specific cardiovascular disease, 4 thvalue versus 1 stvalue, stratified by household income. Fig. S3. Sensitivity analysis of the association between access to exercise opportunity, physical inactivity, and age-adjusted cardiovascular disease mortality rates: a state-level clustering-adjusted comparison of highest versus lowest quartile values.

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Authors' contributions

XW: conceptualization, data curation, formal analysis, and writing−original draft preparation. YG: data curation, formal analysis, and writing−reviewing and editing. YW: writing−reviewing and editing. YQ, TC: data curation and writing−reviewing and editing. PH, KZ, SL, YQ, ZL, XD, JS, SZ, XD, SL, XL: writing−reviewing and editing. ZD, YH: conceptualization, supervision, writing−reviewing and editing. WZ: conceptualization, methodology, and writing−reviewing and editing. All authors contributed to the article and approved the submitted version.

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Data availability

The datasets can be found in online repositories. At: https://wonder.cdc.gov/Deaths-by-Underlying-Cause.html and https://www.countyhealthrankings.org/explore-health-rankings/rankings-data-documentation/national-data-documentation-2010-2019

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

The authors declare no competing interests.

Competing interests

The authors declare no competing interests.

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