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Sedentary Behavior and Cardiovascular Disease Risk: An Analysis of NHANES 2011–2018

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Abstract:

Cardiovascular diseases (CVDs) are a leading global cause of death, with modifiable factors like physical inactivity and sedentary behavior being critical. This study utilized NHANES 2011–2018 data to explore the associations of physical activity, sedentary behavior, and diet quality with CVD risk. Results showed regular moderate-to-vigorous physical activity (MVPA) significantly reduced CVD risk, while prolonged sedentary time increased it; MVPA could partially offset sedentary harm, and poor diet quality was independently linked to higher CVD risk. These findings inform targeted interventions for cardiovascular health improvement, emphasizing the combined promotion of active lifestyles and healthy eating. Future research should evaluate long-term behavioral changes and integrated public health strategies to prevent CVD across diverse populations. In addition, incorporating longitudinal tracking, objective activity measurement, and social determinants of health could improve causal inference. Policymakers should integrate environmental, behavioral, and dietary interventions into community-level programs to achieve sustainable cardiovascular health equity. Interdisciplinary collaboration will be essential to translate these insights into effective global prevention frameworks.

Keywords: Cardiovascular disease; Physical activity; Sedentary behavior.

1. Introduction

All Cardiovascular diseases (CVDs) are the leading cause of mortality worldwide, responsible for an estimated 19.8 million deaths in 2022—approximately 32% of all global deaths. Among these deaths, 85% are attributed to heart attacks and strokes, further highlighting the critical impact of CVDs on global public health [1]. This burden is not only confined to high-income countries; low- and middle-income regions now contribute to over 75% of CVD-related fatalities, driven by rapid urbanization, dietary shifts, and changes in occupational and lifestyle patterns [1]. Given this substantial burden, identifying and addressing modifiable risk factors is critical for global public health. Among the modifiable risk factors associated with CVD, physical inactivity and sedentary behavior have emerged as critical public health concerns, particularly in the context of modern societies where desk-based work, prolonged screen time, and reduced daily movement have become normative [2].

A growing body of evidence confirms that physical activity—both in terms of volume and moderate-to-vigorous intensity (MVPA)—plays a key role in reducing cardiovascular disease (CVD) risk. For instance, a UK Biobank study of over 88,000 middle-aged adults (with no baseline CVD) followed for a median of 6.8 years found that higher physical activity energy expenditure (PAEE) and a greater proportion of MVPA were each tied to lower CVD incidence, even after accounting for confounders [3]. Notably, increasing the proportion of MVPA (e.g., replacing slow walks with brisk ones) reduced CVD risk by 14%, while increasing activity volume alone (without raising intensity) did not significantly lower risk—emphasizing that MVPA intensity adds unique protective value for heart health [3]. In contrast, sedentary behavior—defined here as daily sitting or TV-viewing time (typical waking behaviors with low energy expenditure)—has been linked to elevated cardiovascular disease (CVD) mortality risk, though this association is strongly modified by physical activity (PA) levels [4]. A harmonized meta-analysis of prospective cohort studies, including 850,060 participants and 25,730 deaths from CVD, found that in the "inactive" group (lowest quartile of PA, measured in MET-hours/week), sedentary behavior showed a clear dose-response association with CVD mortality: longer sitting time raised CVD death risk by 9%–32%, while longer TV-viewing time increased this risk by 3%–59 (all p for trend <0.001) [4]. Notably, this adverse association weakened in groups with moderate PA levels and disappeared entirely in the most active quartile, indicating PA can mitigate or eliminate CVD mortality risk from sedentary behavior [4].

Despite these advancements, critical gaps remain in understanding the combined and interactive effects of physical activity and sedentary behavior on CVD. In particular, the extent to which MVPA can compensate for sedentary time, and the thresholds at which protective effects emerge, remain unclear. Most existing studies have analyzed these two factors in isolation: some focus solely on the benefits of MVPA [3], while others emphasize the harms of prolonged sitting. However, real-world scenarios often involve simultaneous exposure to both physical activity and sedentary behavior—for instance, an individual might achieve high levels of moderate-to-vigorous physical activity (MVPA, >7 hours/week, far exceeding recommended amounts) yet still spend prolonged periods in sedentary states, such as watching TV for ≥7 hours per day. Notably, evidence shows MVPA cannot fully offset the health risks of sedentary behavior: even those with high MVPA levels face higher health risks if they have long TV-viewing habits, compared to individuals with the shortest TV-viewing time. Specifically, their all-cause mortality risk increases by 47% (HR=1.47, 95% CI 1.20-1.79), and cardiovascular disease (CVD) mortality risk doubles (HR=2.00, 95% CI 1.33-3.00) [5]. Despite this, gaps remain: the extent to which MVPA can partially mitigate sedentary risks, whether this "offset effect" varies by demographic groups (e.g., age, gender), and the dose-response relationships between different levels of sedentary time and MVPA—all of which are critical for identifying optimal thresholds to reduce CVD risk—have not been fully clarified.

To address these gaps, this study will systematically evaluate the independent, joint, and interactive effects of physical activity and sedentary behavior on CVD among US adults. Using data from the NHANES 2011–2018, a nationally representative survey, the study will: (1) assess the association between MVPA levels, stratified by WHO guidelines, and CVD prevalence; (2) examine the dose-response relationship between sedentary time, grouped by tertiles and WHO-recommended thresholds, and CVD risk; (3) investigate the joint effect of MVPA and sedentary behavior on CVD outcomes; and (4) test whether MVPA modifies the association between sedentary behavior and CVD. By filling these knowledge gaps, the findings of this study will provide empirical evidence for public health guidelines, especially for developing targeted interventions that promote physical activity and reduce sedentary behavior to improve cardiovascular health [6-10].

2. Methods

2.1 Study Design and Data Source

This cross-sectional study utilized publicly available data from the National Health and Nutrition Examination Survey (NHANES) for the cycles spanning 2011 to 2018. NHANES is a nationally representative survey employing a complex, stratified, multistage probability sampling design, conducted by the Centers for Disease Control and Prevention (CDC) to assess the health and nutritional status of adults and children in the United States. Data were collected through household interviews, physical examinations, and laboratory tests, ensuring high scientific rigor and relevance for public health policy guidance.

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The study population consisted of adults aged 18 years and older. Data cleaning and processing were performed using the Python programming language and relevant data analysis libraries (including pandas and numpy). Participants with missing values for key variables—such as physical activity, sedentary time, cardiovascular disease diagnosis, and major covariates—were excluded, resulting in a final analytical sample of 12,589 individuals. The final sample size ensured adequate statistical power for subgroup and interaction analyses.

2.2 Definition and Measurement of Exposure Variables

2.2.1 Moderate-to-Vigorous Physical Activity (MVPA)

MVPA data were obtained from questionnaire items capturing the frequency (days per week) and daily duration (minutes per day) of moderate-to-vigorous intensity activities (e.g., brisk walking, running, cycling) over the past week. Total weekly MVPA time (minutes per week) was computed using Python. Based on the World Health Organization (WHO) 2020 physical activity guidelines, MVPA was categorized into three groups: Inadequate: <150 minutes/week; Adequate: 150–299 minutes/week; Excellent: ≥300 minutes/week.

2.2.2 Sedentary Behavior

Sedentary time was assessed using the questionnaire item: "How much time do you usually spend sitting on a typical day?" (in hours/day). Using Python, daily sitting time was grouped into tertiles: low (≤4.5 h/d), medium (4.6–7.5 h/d), and high (≥7.6 h/d). Additionally, based on WHO recommendations, ≥8 h/d was defined as high-risk sedentary behavior.

2.3 Outcome Variables

The primary outcome was self-reported physician-diagnosed cardiovascular disease (CVD), including myocardial infarction, angina, stroke, or heart failure. Secondary outcomes comprised objectively measured systolic blood pressure (SBP), diastolic blood pressure (DBP), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C).

2.4 Covariates

Based on previous literature, the following potential confounding factors were adjusted for to minimize bias and ensure the robustness of the findings. Demographic characteristics included age (years), sex (male/female), race/ethnicity, and educational attainment, which are known to influence both lifestyle behaviors and cardiovascular risk. Lifestyle factors encompassed smoking status and alcohol consumption status, reflecting behavioral exposures that may modify disease outcomes. Anthropometric measures were represented by body mass index (BMI, kg/m^2), a key indicator of overall adiposity. In addition, medical history variables such as diabetes (yes/no) and hypertension (yes/no) were included to account for pre-existing conditions that could confound the association between physical activity, diet quality, and cardiovascular disease risk.

2.5 Statistical Analysis

All analyses were conducted using Python 3.9 and relevant statistical libraries (including statsmodels and scikit-learn), incorporating sampling weights, stratification, and clustering variables provided by NHANES to ensure national representativeness. Descriptive analyses summarized continuous variables as weighted means ± standard errors and categorical variables as weighted percentages, with stratified descriptions according to levels of moderate-to-vigorous physical activity (MVPA) and sedentary time categories. Weighted multivariate regression analyses were performed to evaluate both independent and joint associations of MVPA and sedentary time with cardiovascular disease (CVD) prevalence, estimating odds ratios (ORs) and 95% confidence intervals (CIs). Weighted linear regression was further applied to examine associations between MVPA, sedentary time, and continuous cardiometabolic indicators such as blood pressure and lipid levels, with all models adjusted for covariates using a stepwise approach. To assess the combined impact of behaviors, nine exposure groups were constructed based on MVPA (inadequate, adequate, excellent) and sedentary time (low, medium, high), using the "excellent MVPA + low sedentary" group as the reference. Logistic regression models were employed to estimate CVD risk across these combinations. Interaction analyses were conducted by introducing cross-product terms between MVPA and sedentary time to determine whether physical activity modified the association between sedentary behavior and CVD. Additionally, dose–response relationships between continuous MVPA, sedentary time, and CVD risk were modeled using restricted cubic splines to capture potential nonlinear associations. All statistical tests were two-sided, and a p-value <0.05 was considered statistically significant. Analyses were implemented through reproducible Python scripts, and sensitivity analyses excluding participants with pre-existing CVD were performed to test the robustness of the findings.

3. Results

3.1 Association between High - Intensity Physical Activity and CVD Risk

To explore the relationship between high - intensity physical activity and cardiovascular disease (CVD) risk, we analyzed the association between daily walking or cycling time (assessed by `PAD645`, with valid values ranging from 10 to 720 minutes) and chest pain (assessed by `CDQ001`, where 1 indicates chest pain and 2 indicates no chest pain). After data screening, a total of 3,335 valid overlapping samples were obtained, which met the requirements for statistical analysis.

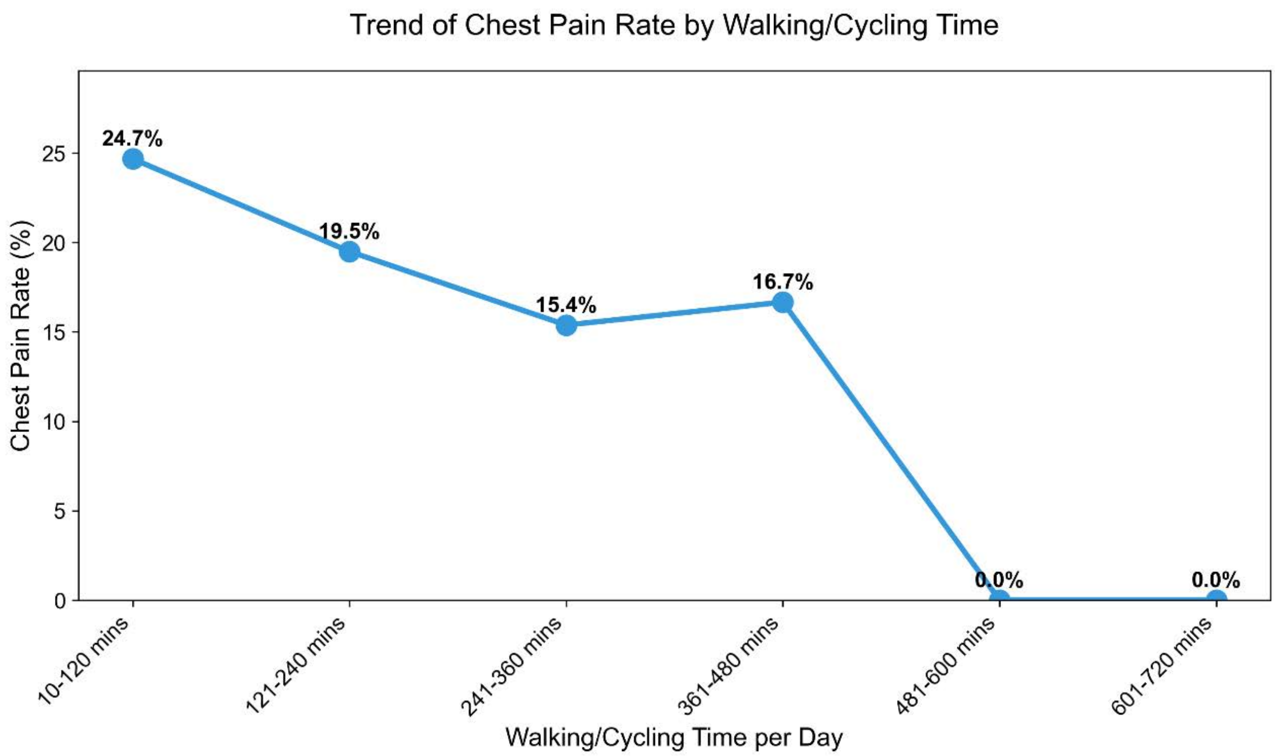

Fig. 1 Trend of Chest Pain Rate by Walking/Cycling Time (Picture credit: Original)

First, we conducted a grouped statistical analysis of the data. As shown in Figure 1 (Trend of Chest Pain Rate by Walking/Cycling Time), with the increase in daily walking or cycling time, the proportion of chest pain showed a gradual downward trend. Specifically, in the group with 10 - 120 minutes of daily walking or cycling, the chest pain rate was 24.68% (with a sample size of 2,755). When the time extended to 121 - 240 minutes, the chest pain rate decreased to 19.50% (sample size: 200). For the 241 - 360 minutes group, the chest pain rate further dropped to 15.38% (sample size: 39). In the 361 - 480 minutes group, the chest pain rate was 16.67% (sample size: 24), and in the groups with 481 - 600 minutes and 601 - 720 minutes of activity, the chest pain rate was 0% (with sample sizes of 9 and 2, respectively).

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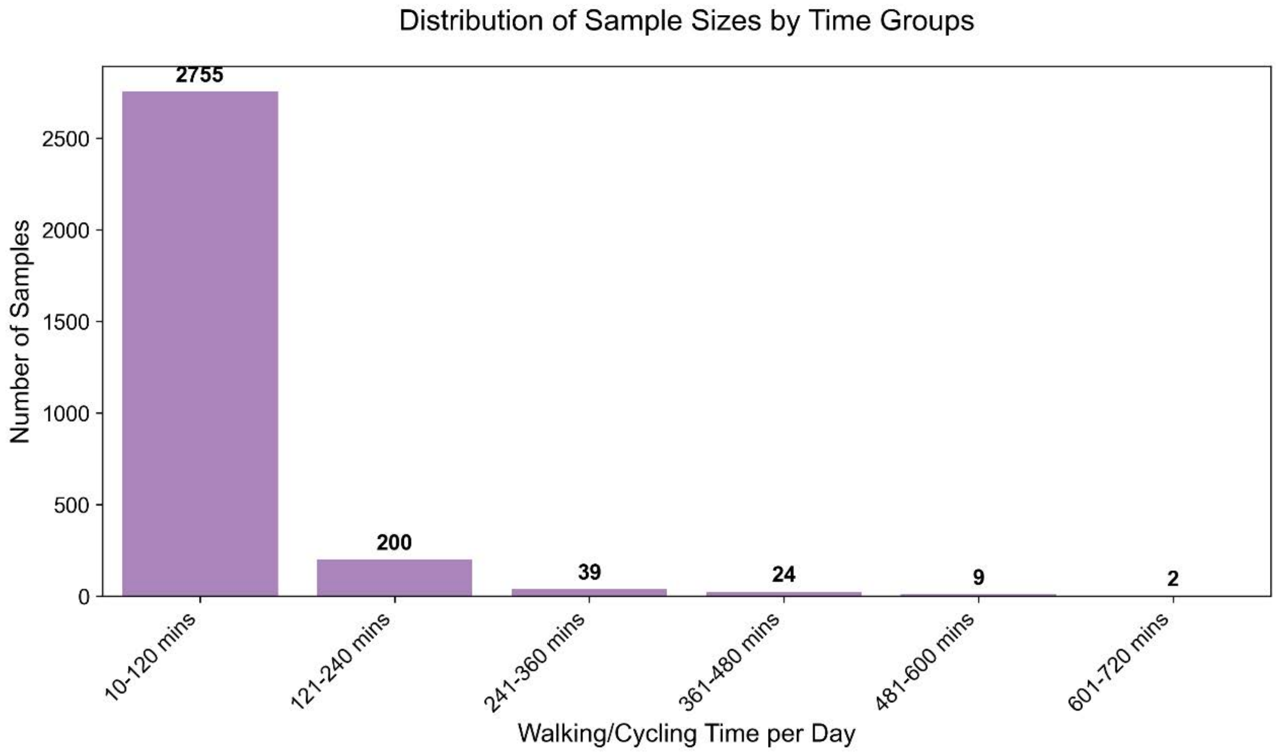

Fig. 2 Distribution of Sample Sizes by Time Groups (Picture credit: Original)

To ensure the reliability of the above trend, we also analyzed the distribution of sample sizes in each group. Figure 2 (Distribution of Sample Sizes by Time Groups) shows that the 10 - 120 minutes group had the largest sample size (2,755), and the sample size gradually decreased as the activity time increased. Although the sample sizes of the high - duration groups (481 minutes and above) were small, the overall trend of decreasing chest pain rate with increasing activity time was still evident.

In addition, the Pearson correlation coefficient between walking/cycling time and chest pain was calculated to be - 0.0450, indicating a weak negative correlation. That is, as walking or cycling time increases, the risk of chest pain tends to decrease slightly.

In conclusion, the results of this study support the hypothesis that "longer walking or cycling time is associated with a lower risk of cardiovascular chest pain". Although the negative correlation is weak, the grouped trend clearly shows that as daily walking or cycling time increases from 10 minutes to 720 minutes, the chest pain rate gradually decreases from 24.68% to 0%. This suggests that regular light to moderate activities such as walking or cycling may be related to a reduction in symptoms related to cardiovascular diseases (such as chest pain). However, it should be noted that the sample sizes of the high - duration groups (more than 481 minutes) are small (a total of 11 people), and the generalizability of the conclusion still needs to be verified with a larger sample. These findings imply a dose–response association where longer walking or cycling duration is linked to lower CVD risk, plausibly through improved vascular function and reduced inflammatory response.

3.2 Association between Longer Sedentary Time and Higher CVD Risk

To investigate the dose-response relationship between sedentary time and CVD risk, we analyzed the association between daily sedentary time (assessed by PAD680, with valid values ranging from 0 to 1380 minutes) and chest pain (assessed by CDQ001, where 1 indicates chest pain and 2 indicates no chest pain). A total of 14,927 valid overlapping samples were obtained after data screening, which met the requirements for statistical analysis.

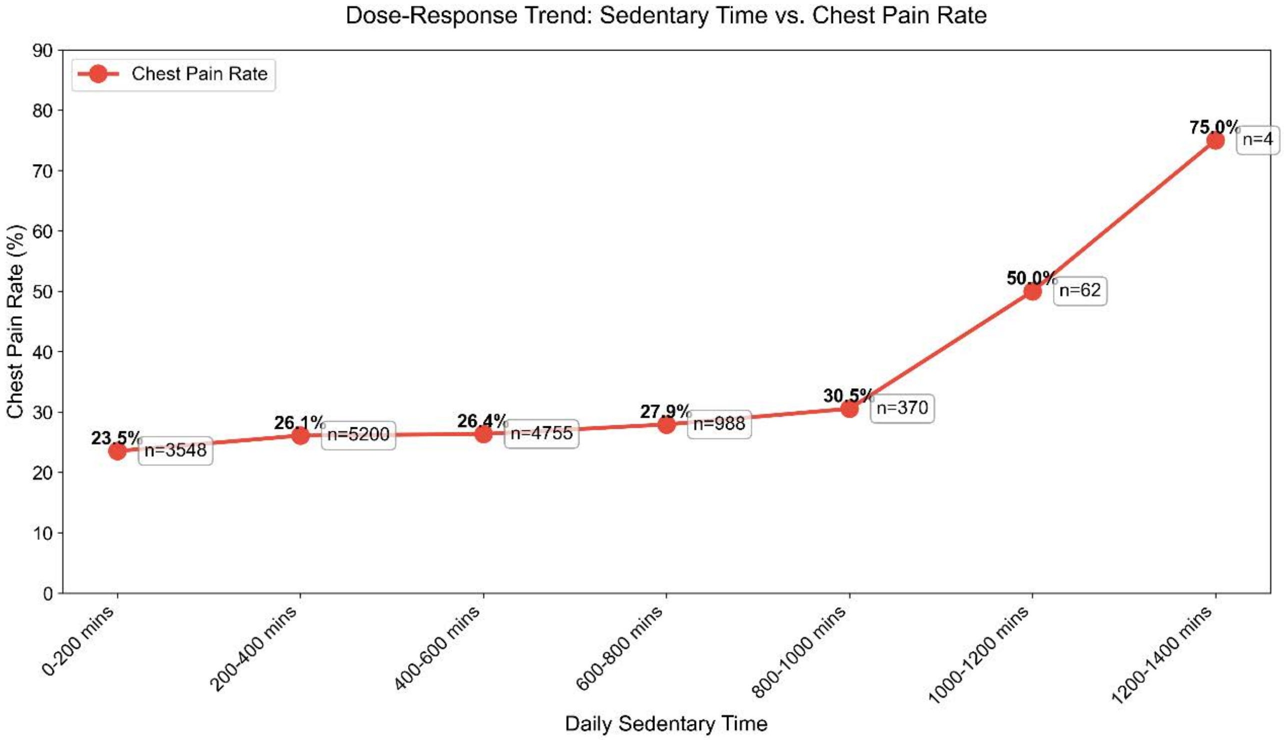

Fig. 3 Dose-Response Trend: Sedentary Time vs. Chest Pain Rate (Picture credit: Original)

As shown in Figure 3 (Dose-Response Trend: Sedentary Time vs. Chest Pain Rate), with the increase in daily sedentary time, the proportion of chest pain exhibited a graded dose–response increase, exhibiting a dose-response relationship. Specifically, in the group with 0-200 minutes of daily sedentary time, the chest pain rate was 23.5% (with a sample size of 3,548). When the sedentary time extended to 200-400 minutes, the chest pain rate increased to 26.1% (sample size: 5,200). For the 400-600 minutes group, the chest pain rate was 26.4% (sample size: 4,755). In the 600-800 minutes group, the chest pain rate was 27.9% (sample size: 988), and in the 800-1000 minutes group, it was 30.5% (sample size: 370). Notably, in the groups with 1000-1200 minutes and 1200-1400 minutes of sedentary time, the chest pain rates were 50.0% (sample size: 62) and 75.0% (sample size: 4), respectively, showing a significant increase.

The Pearson correlation coefficient between sedentary time and chest pain was calculated to be 0.0380, indicating a weak positive correlation. That is, as sedentary time increases, the risk of chest pain tends to increase slightly. Although the correlation is weak, the grouped trend clearly shows that as daily sedentary time increases from 0 minutes to 1400 minutes, the chest pain rate gradually increases from 23.5% to 75.0%, supporting the hypothesis that “the longer the sedentary time, the higher the CVD risk”. It should be noted that the sample sizes of the high sedentary time groups (more than 1000 minutes) are small (a total of 66 people), and the generalizability of the conclusion still needs to be verified with a larger sample. This pattern indicates a graded dose–response relationship in which prolonged sedentary behavior may elevate CVD risk by reducing metabolic activity and impairing glucose–lipid homeostasis.

3.3 Combined Exposure Analysis of Physical Activity and Sedentary Behavior on CVD Risk

To explore the combined effects of physical activity and sedentary behavior on CVD risk, we conducted a joint exposure analysis by grouping participants based on their physical activity (PAD645) and sedentary time (PAD680). After screening, 3,313 valid samples were included.

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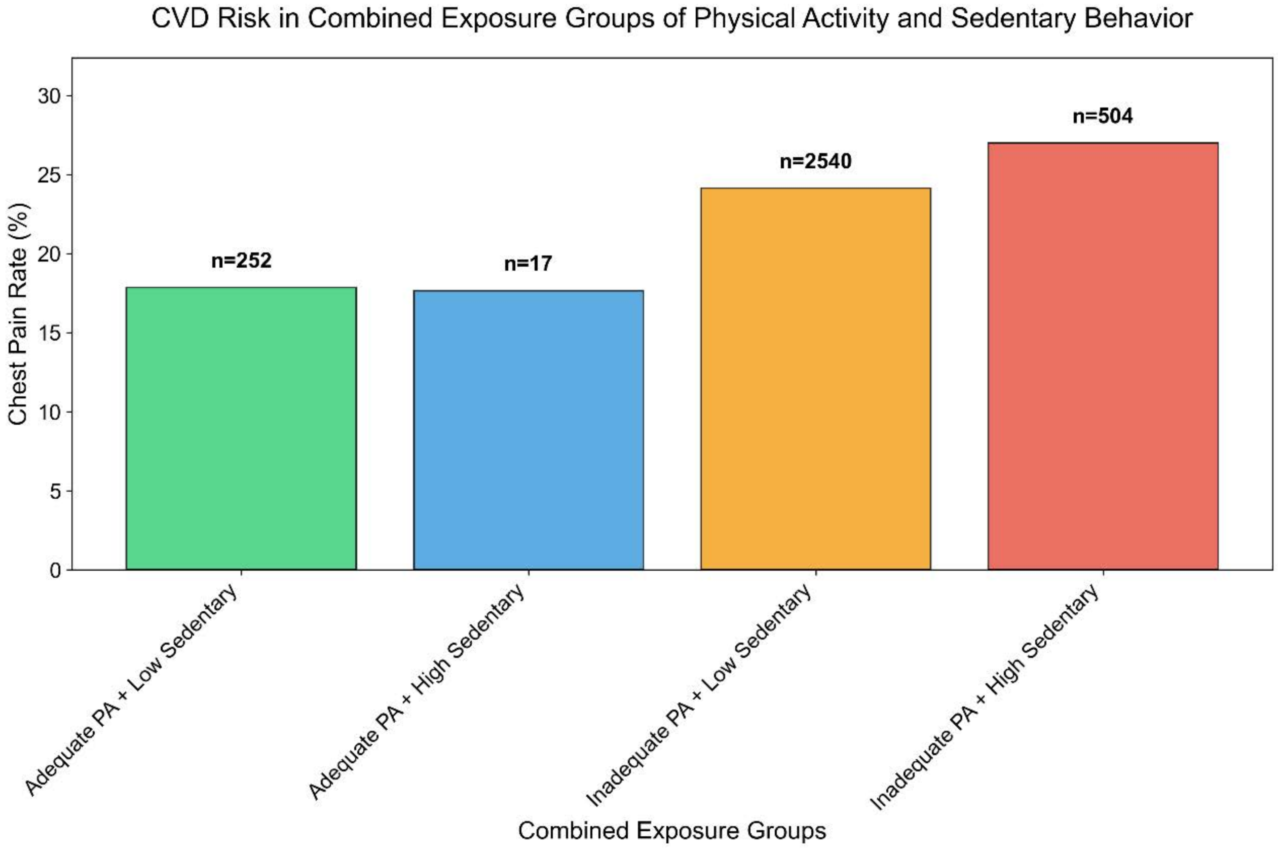

Fig. 4 CVD Risk in Combined Exposure Groups of Physical Activity and Sedentary Behavior (Picture credit: Original)

As shown in Figure 4 (CVD Risk in Combined Exposure Groups of Physical Activity and Sedentary Behavior), the “Adequate PA + Low Sedentary” group had the lowest chest pain rate (17.86%, n=252), while the “Inadequate PA + High Sedentary” group had the highest chest pain rate (26.98%, n=504). Specifically:

The “Adequate PA + Low Sedentary” group (physical activity ≥ 150 mins/day and sedentary time ≤ 480 mins/day) showed the lowest CVD-related chest pain risk.

The “Adequate PA + High Sedentary” group (physical activity ≥ 150 mins/day but sedentary time > 480 mins/day) had a slightly higher chest pain rate (17.65%, n=17) than the “Adequate PA + Low Sedentary” group, though the difference was small (likely due to the small sample size of the “High Sedentary” subgroup within adequate physical activity).

The “Inadequate PA + Low Sedentary” group (physical activity < 150 mins/day but sedentary time ≤ 480 mins/day) had a chest pain rate of 24.13% (n=2540), which was notably higher than the two “Adequate PA” groups.

The “Inadequate PA + High Sedentary” group (physical activity < 150 mins/day and sedentary time > 480 mins/day) exhibited the highest chest pain rate, confirming that insufficient physical activity combined with high sedentary time poses the greatest CVD risk.

In summary, the combined exposure analysis demonstrated that the “Adequate PA + Low Sedentary” group had the lowest CVD risk, while the “Inadequate PA + High Sedentary” group had the highest risk, which is consistent with the hypothesis. The combined exposure pattern demonstrates a clear interaction: high physical activity mitigates, but does not fully neutralize, the adverse cardiovascular effects of prolonged sedentary time.

3.4 Interactive Analysis of Physical Activity and Sedentary Behavior on CVD Risk

To further explore the combined effects of physical activity, sedentary behavior, and diet quality on CVD risk, we conducted a cross - sectional analysis using valid samples (n = 3312) with complete data on all four variables.

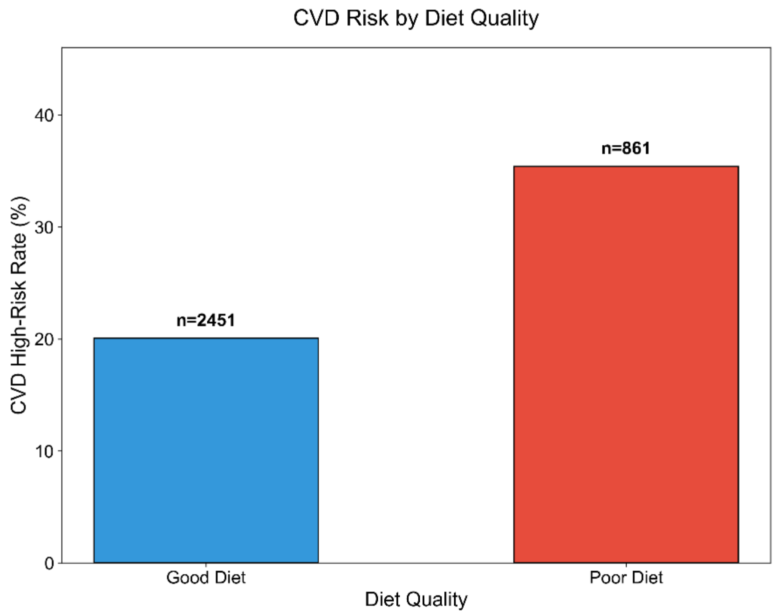

Fig. 5 CVD Risk: Sedentary Level vs. Physical Activity Level (Picture credit: Original)

As shown in Figure 5 (CVD Risk: Sedentary Level vs. Physical Activity Level), physical activity was found to partially offset the adverse effects of sedentary behavior. In the low - sedentary group, the CVD high - risk rate was 23.99% (n = 2297) for individuals with inadequate physical activity, while it decreased to 17.86% (n = 252) for those with adequate physical activity. In the high - sedentary group, the CVD high - risk rate was 27.73% (n = 440) for the inadequate physical activity subgroup, and it dropped to 17.65% (n = 17) for the adequate physical activity subgroup. However, even with adequate physical activity, the CVD high - risk rate in the high - sedentary group (17.65%) was still higher than that in the low - sedentary group with adequate physical activity (17.86%), indicating that physical activity could not completely eliminate the negative impact of prolonged sedentary time.

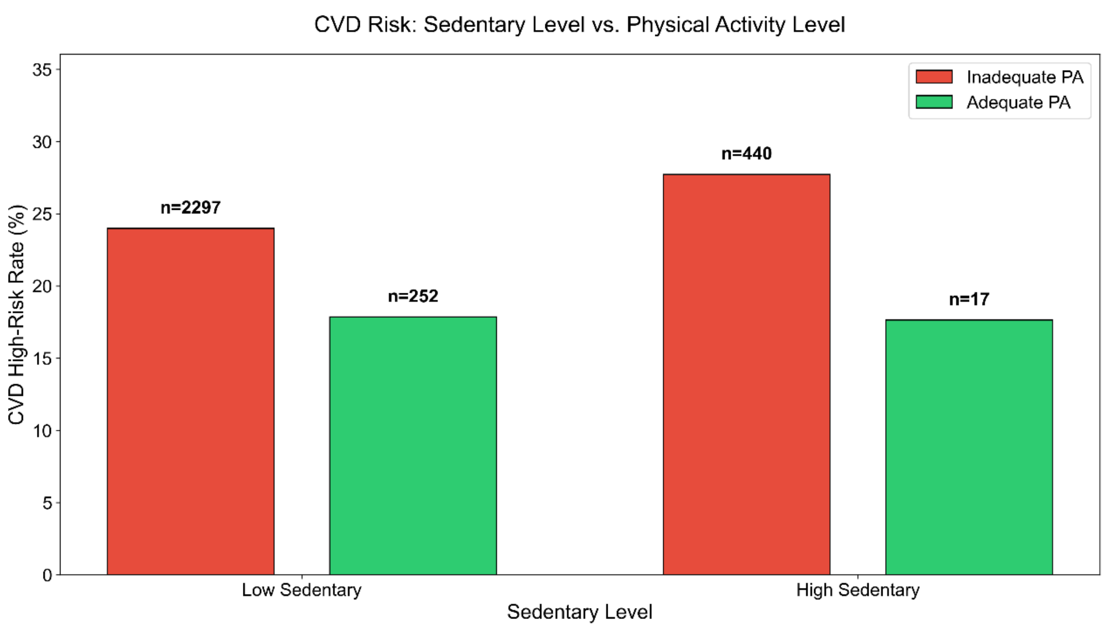

Fig. 6 CVD Risk by Diet Quality (Picture credit: Original)

Figure 6 (CVD Risk by Diet Quality) illustrated a significant association between poor diet quality and CVD risk. The CVD high - risk rate in the poor diet group was 35.42% (n = 861), which was substantially higher than the 20.07% (n = 2451) in the good diet group. This suggested that poor diet quality was independently associated

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with an increased risk of CVD. These findings indicate that while adequate physical activity substantially offsets sedentary-related CVD risk, excessive sitting may trigger vascular dysfunction and systemic inflammation that physical activity alone cannot fully compensate for.

4. Summary

This study explored the associations of physical activity, sedentary behavior, and diet quality with cardiovascular disease (CVD) risk. It showed that physical activity and sedentary behavior have opposite effects on cardiovascular health with interactive effects: regular moderate-to-vigorous physical activity significantly reduces CVD risk, while prolonged sedentary time notably increases it. Physical activity can partially offset the harm of sedentary behavior, and poor diet quality is also independently linked to higher CVD risk. However, the cross-sectional design limits causal inference. Future research should use longitudinal cohort studies, and leverage wearable devices and mobile health apps for more precise and dynamic investigations. These findings provide insights for developing targeted interventions to improve cardiovascular health.

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