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Research article

Association between the recommended volume of leisure-time physical activity and erectile dysfunction: A cross-sectional analysis of the national health and nutrition examination survey, 2001–2004

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A R T I C L E I N F O

Keywords:
Physical activity
Erectile dysfunction
Smoking
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A B S T R A C T

Objective: Physical activity-related interventions alleviate the severity of erectile dysfunction (ED), but it is unknown whether the recommended volume of physical activity (PA) or a higher level of physical activity reduces the likelihood of ED in adult males. We aimed to evaluate the association between the recommended volume of PA and ED among US male adults.
Design: A nationally representative cross-sectional survey.
Setting: National Health and Nutrition Examination Survey 2001–2004.
Participants: A total of 2509 men aged ≥20 years were enrolled.
Primary and secondary outcome measures: ED and PA were assessed by a standardised self-report questionnaire. Weighted logistic regression analysis and spline fitting were used to assess the relationship between PA volume and the odds of ED.
Results: Among 2509 US adult males, the mean (standard error) age was 43.7 (0.46) years. A total of 61.1 % of men reached the recommended volume of aerobic PA. Compared with participants not meeting the PA guidelines, individuals who had recommended aerobic activities demonstrated a 34 % reduction in the odds of having ED (OR 0.66, 95 % CI 0.48–0.90; p = 0.011). Notably, according to the restricted cubic spline, we revealed a dose−response pattern between PA volume and reduced odds of ED, even when exceeding the recommended PA levels. When compared to males with moderate-equivalent PA of less than 150 min/week, the odds of ED in those with moderate-equivalent PA levels of 150–300 min/week and >300 min/week decreased by 22 % and 39 %, respectively. Compared with participants who did not meet the PA guidelines, the multivariable-adjusted ORs (95 % CIs) of ED associated with adequate PA volumes were 0.37 (0.22–0.61) among non-smokers and 0.85 (0.57–1.25) among current smokers (*p* for interaction = 0.023).
Conclusions and Relevance: Our findings supported the benefit of meeting the guideline-recommended PA equivalents or higher volumes for ED prevention. However, PA-related benefit might be significantly diminished by smoking.

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1. Introduction

Erectile dysfunction (ED) is defined as the persistent inability to achieve or maintain penile erection sufficient to perform satisfying sexual intercourse [1–4]. ED is a multifactorial medical disorder that has been linked to numerous etiologies, including organic (for example, caused by cavernosal injury, drug use, or hormonal imbalance) or psychogenic in origin, or a combination of both organic and psychogenic factors [5,6]. Epidemiological studies have demonstrated numerous risk factors for ED, such as age, diabetes, depression, hypertension and smoking, but less so for protective factors [7–9].

Physical exercise, aerobic exercise, resistance exercise, and pelvic floor muscle-specific exercise intervention are considered promising adjunct treatments for ED [10]. However, some results are inconsistent and inconclusive [11]. For example, a pooled analysis recently reported no significant efficacy of pelvic floor muscle-specific exercises in improving erectile function [12]. In most instances, treatment is not cause specific [13]. It involves a trial-and-error approach that depends on cost, invasiveness, efficacy, and safety, in addition to both patient and partner satisfaction. Not all men respond well to medication or other available treatments, meaning that physicians are always looking for safe alternative methods for treating ED [14]. Regular physical activity (PA) is a low-cost option that can reduce the severity of erectile dysfunction [10]. Lifestyle factors commonly associated with ED, such as smoking, alcohol consumption, obesity, and limited PA, can significantly improve erectile function as well as testosterone levels [15]. Moreover, numerous studies have provided compelling evidence that PA and exercise interventions improve patients' reported ED, particularly aerobic exercise with moderate-to-vigorous intensity [15]. According to the World Health Organisation 2020 guidelines, all adults should perform 150–300 min/week of moderate-intensity, 75–150 min/week of vigorous-intensity PA, or an equivalent combination of moderate-intensity and vigorous-intensity aerobic PA [16,17].

To our knowledge, the specific benefits for ED prevention when meeting the volumes of PA recommended by the latest WHO PA guidelines has not been investigated. Moreover, the benefits of PA volumes beyond the recommendation is also unknown. Given the protective effect of PA on general health and the updating of new PA guidelines, we determined the association between the recommended amount of PA according to the 2020 guidelines and the odds of erectile dysfunction using a sample from the US National Health and Nutrition Examination Survey.

2. Methods

2.1. Study population

This cross-sectional analysis was based on data from the National Health and Nutrition Examination Survey (NHANES) 2001–2004 survey cycles. The NHANES used a nationally representative sample of the civilian, non-institutionalised population in the United States, with a stratified and multistage probability-sampling design to assess health and nutritional status [18]. The continuous NHANES database has collected information on the health and nutrition of the U.S. population since 1999, with a biennial cycle as an independent subset. This study was a secondary analysis of publicly available NHANES data. The protocols and procedures of the NHANES were approved by the Research Ethics Review Board of the Centers of Disease Control and Prevention of the United States (Protocol #98–12). All participants provided written informed consent before any data were collected. Detailed information and datasets can be found in this study (https://www.cdc.gov/nchs/index.htm) [19,20].

The data regarding ED were collected only from the NHANES 2001–2002 and 2003–2004 cycles. Among the 21161 participants in the NHANES 2001–2004, we excluded those aged <20 years (n = 10709), female adults (n = 5498), male adults without available data regarding PA (n = 2040) and ED (n = 359), male adults who received testosterone therapy (n = 10), and men with a history of prostate cancer because the medication may be a potential cause of ED (n = 46). Finally, the analysis included 2509 male participants 20 years or older who responded to the ED and PA questionnaires (Fig. 1).

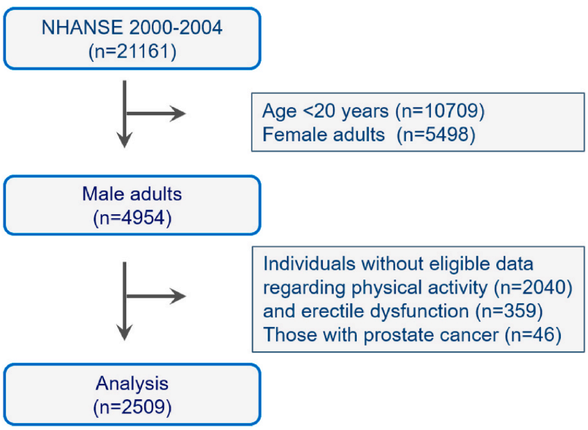

Fig. 1. Study flowchart.

2.2. Patient and public involvement

No participants were involved in the development of the research question or design of the study.

2.3. Study exposure: physical activity

All participants responded to questionnaires providing details of their daily PA during the past month based on the Global PA Questionnaire. The detailed questionnaire assessed leisure-time PA and included questions to assess intensity (vigorous or moderate), which was created by the World Health Organisation (WHO) per week, and duration (minutes) in a typical week. Minutes of vigorous PA were doubled and added to minutes of moderate PA as validated. According to the World Health Organisation 2020 guidelines on PA and sedentary behaviours, adults were recommended to undertake 150–300 min of moderate-intensity, 75–150 min of vigorous-intensity PA, or an equivalent combination of moderate- and vigorous-intensity aerobic PA per week. We categorised the intensity of PA as insufficient (less than 150 min) or sufficient (≥150 min, meeting the leisure-time PA guidelines) in the primary analysis. We further divided participants with sufficient activity into 150–300 min and >300 min of equivalent moderate-intensity activity to assess the potential benefits of more PA than recommended.

2.4. Study outcome: erectile dysfunction

To identify ED, male participants aged 20 years or older were asked the following question in a private room using a self-paced audio computer-assisted self-interview system previously validated in large national epidemiologic surveys to investigate the prevalence of ED [21,22]. ED could be extracted from the standardised questionnaire: “Many men experience problems with sexual intercourse. How would you describe your ability to get and keep an erection adequate for satisfactory intercourse?” Response options were available as “always or almost always able,” “usually able,” “sometimes able,” and “never able to get and keep an erection?” Participants who reported that they were “sometimes able” or “never able” to get and keep an erection adequate for satisfactory intercourse were categorised as having ED, as previously reported [23]. The details are available at https://wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx.

2.5. Other variables

Demographic and lifestyle factors, including age, race/ethnicity, family income ratio, education, marital status, smoking status, alcohol intake, and disease history (cardiovascular disease, diabetes, hypertension, and cancer), were self-reported during personal interviews via standardised questionnaires [24]. Physical examination was performed according to standardised protocols and processes at a mobile examination center. Body mass index (BMI) was calculated as weight (kilograms) divided by height (meters) squared [12]. Three consecutive blood pressure readings were acquired following a period of quiet rest in a seated position for 5 min. The average systolic blood pressure and diastolic blood pressure are presented as the means of three measurements. The detection of biosamples was conducted in special central laboratories with validated methods. Triglycerides (TG), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), glycosylated c (HbA1c), and creatinine were detected in each survey cycle. The Chronic Kidney Disease Epidemiology Collaboration method was applied to calculate the estimated glomerular filtration rate (eGFR). Diabetes mellitus was defined as a self-reported or HbA1c level ≥6.5 %. Total cholesterol (TC) and high-density lipoprotein cholesterol (HDL-C) were measured to calculate the TC/HDL-C ratio.

2.6. Statistical analysis

Assuming a sample ratio of 1:1 for inadequate to adequate exercise levels and a prevalence of ED between high and low PA levels of 15 % and 11 %, respectively, a statistical power of 0.9 would be attained among approximately 2300 participants at the 0.05 level of significance [25]. According to the analytical guidelines, sampling weights, the masked variance of the primary sampling unit, and strata were utilised to account for the complex study design, such as the selective bias, nonresponse, and oversampling of certain subpopulations, to achieve nationally representative estimates of the total US population. Categorical and continuous variables are presented as weighted means (standard errors, SEs) and proportions after adjustment for the complex NHANES sampling design. Odds ratios (ORs) and 95 % confidence intervals (CIs) were calculated by using crude and weighted logistic regression models for the relationship between the intensity of PA and ED odds, with a PA less than 150 min as a reference. Two logistic regression models adjusted for conventional risk factors were applied. Model 1 was adjusted for age. Model 2 was fully adjusted for age, race/ethnicity, poverty-to-income ratio (PIR), education, marital status, smoking status, alcohol intake, BMI, hypertension status, TC/HDL ratio, eGFR, cardiovascular disease status, and diabetes status [2,13]. We used a restricted cubic spline based on logistic regression to assess the nonlinear relationship between the intensity of PA (min) and ED odds after adjustment for age.

In stratified analyses, the associations between the intensity of PA (min) and the odds of ED were analysed in subgroups by binary age (<65 and ≥65 years), race (white and other), marital status (married and other), BMI (<30 and ≥ 30 kg/m2), current smoking status (no/yes), eGFR (≥60 and < 60 mL/min per 1.73 m^2), cardiovascular disease status (no/yes), and diabetes status (no/yes) with full adjustment (Model 2) except for stratification factors. The survey-weighted Wald test was applied to assess the statistical significance of the interaction terms. Additionally, we further divided participants with sufficient activity into 150–300 min and >300 min of equivalent moderate-intensity to assess the potential benefits of more PA than recommended. A two-sided p value less than 0.05

was considered to indicate statistical significance using STATA version 12.0 (College Station, TX).

3. Results

3.1. Baseline characteristics

We included and analysed 2509 male adults who completed the questionnaires on PA and erectile function, with a mean age of 43.7 years, comprising 6.1 % Mexican-Americans, 8.9 % non-Hispanic Black, 76.8 % non-Hispanic white and 8.2 % other races/ethnicities. Overall, 61.1 % of adults had ≥150 min/week of moderate-intensity PA, ≥75 min/week of vigorous-intensity PA, or the equivalent combination of moderate-intensity and vigorous-intensity aerobic PA, as recommended by 2020 guidelines (Table 1). The weighted median volumes of moderate and vigorous PAs were 104.7 min/week and 41.9 min/week, respectively (Fig. 2).

Compared with male individuals who did not meet the recommendations, those who met the recommendations were more likely to have a higher family income, more likely to have a high school education, more likely to never smoke, and less likely to have a chronic disease. (Table 1).

3.2. Associations of recommended physical activity with odds of erectile dysfunction

The weighted prevalence of ED among US men aged ≥20 years was 15.8 %. Compared to those in the inadequate PA group, men who met the recommended PA were less likely to have ED (14.4 % versus 18.2 %, p = 0.04).

The association of recommended PA volumes with the odds of ED was further investigated by weighted logistic regression analysis (Fig. 2). According to the unadjusted model, participants with adequate PA had significantly lower likelihood of ED (OR 0.76, 95 % CI

Table 1
Characteristics of males in the NHANES 1999–2004 according to physical activity guidelines for Americans.

Volume of physical activity	<150 min (n = 1002)	≥150 min (n = 1507)	p value
Age, years	43.8 ± 0.72	43.6 ± 0.52	0.798
20–45 years	58.5	54.4	
45–65 years	30.7	32.6	
≥65 years	10.8	13.0	
Race/ethnicity, %			0.173
Non-Hispanic White	74.87	77.76	
Non-Hispanic Black	9.39	8.67	
Hispanic-Mexican	7.29	5.55	
Other	8.46	8.03	
Poverty to income ratio	3.2 ± 0.07	3.5 ± 0.06	0.004
Marital status, %			0.556
Married	61.66	61.77	
Never married	26.29	27.81	
Other	12.06	10.42	
Education, %			0.011
Less than high school	16.22	9.82	
High school	23.59	25.38	
More than high school	60.20	64.80	
Smoking status, %			<0.001
Never smoking	41.24	50.79	
Former smoker	29.55	28.37	
Current smoker	29.21	20.84	
BMI, kg/m2	28.0 ± 0.24	27.9 ± 0.15	0.538
CVD, %	9.63	6.27	0.017
Hypertension, %	35.02	29.31	0.025
Diabetes, %	7.49	6.07	0.227
Cancer, %	9.09	7.38	0.213
Dyslipidemia, %	48.70	43.42	0.059
CKD, %	5.18	3.57	0.015
Alcohol consumption, g/day	7.7 ± 0.52	6.6 ± 0.39	0.077
TC/HDL-C ratio	1.8 ± 0.12	1.7 ± 0.09	0.446
eGFR, mL/min per1.73 m^2	94.0 ± 0.89	93.6 ± 0.66	0.656
Systolic BP, mmHg	123.4 ± 0.71	122.6 ± 0.52	0.231
Diastolic BP, mmHg	73.4 ± 0.47	72.8 ± 0.26	0.213
C-reactive protein, mg/dL	0.33 ± 0.02	0.28 ± 0.02	0.150

We categorised the intensity of physical activity as insufficient (less than 150 min of moderate intensity) and sufficient (≥150 min, meeting the leisure-time physical activity guidelines). Minutes of vigorous physical activity were doubled and added to minutes of moderate equivalent. All variables are shown as the weighted mean ± standard error or proportion (%) and were analysed by chi-square tests and Student's *t*-test, respectively. The observed numbers for participants were unweighted.
BMI, body mass index; BP, blood pressure; HDL-C, high-density lipoprotein cholesterol; eGFR, estimated glomerular filtration rate; CVD, cardiovascular disease.

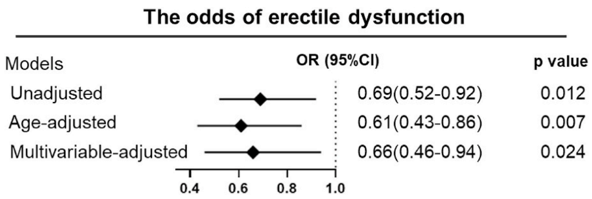

Fig. 2. The potential benefits of meeting the recommended volumes of aerobic physical activity for reducing the odds of erectile dysfunction. OR (95 % CI) was estimated by logistics regression analysis and was presented as the odds of erectile dysfunction meeting the recommended volume of physical activity (150 min/week or more) compared to that of males with inadequate physical activity (less than 150 min/week). The volume of physical activity was calculated as the equivalent combination of moderate- and vigorous-intensity aerobic physical activity per week. Multivariable logistics analysis was adjusted for age (year, continuous), race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic-Mexican and other), poverty-to-income ratio/poverty-to-income ratio (<1.3, 1.3–3.5, or ≥3.5), education (less than high school, high school graduate, or more than high school), marital status (married, never married, or other), smoking (never, ever, or current), alcohol intakes (g/d, continuous), BMI(normal, overweight, and obesity), hypertension (no/yes), TC/HDL ratio (continuous), eGFR (mL/min per 1.73 m^2, continuous), cardiovascular disease (no/yes), and diabetes (no/yes).

0.59–0.97; p = 0.03). According to the age-adjusted model, the odds of having ED substantially decreased by 39 % for men who met the PA guidelines compared with those who did not (OR 0.61, 95 % CI 0.44–0.84; p = 0.03). After additionally adjusting for the poverty-to-income ratio, education, marital status, smoking status, alcohol intake, BMI, hypertension status, TC/HDL ratio, eGFR, cardiovascular disease status, and diabetes status, compared with those of participants who did not meet the PA guidelines, the odds of having ED were found to be lower for those who engaged in the recommended aerobic activity (OR 0.66 95 % CI 0.48–0.90; p = 0.011).

Consistently, the association still complied with a dose−response pattern, with a 3 % decrease in the odds of having moderate ED per 50 min increase in the equivalent PA (OR 0.97 95 % CI 0.96–0.99, p < 0.001). In multiple restricted cubic spline fitting, a linear trend between PA and odds of ED was also noted (Fig. 3).

3.3. Stratification and additional analyses

According to the stratified analyses, the association between the recommended PA and a lower likelihood of experiencing ED was largely consistent in most subgroups (Fig. 4). Notably, a significant interaction effect on ED was observed between PA and current smoking (p for interaction = 0.023). Compared with participants who did not meet the PA guidelines, the multivariable-adjusted ORs of ED for adequate PA were 0.37 (0.22–0.61) among adults without current smoking versus 0.85 (0.57–1.25) among current smokers. Current smoking may weaken the benefits of recommended PAs to prevent ED.

For sensitivity analysis, we further divided participants with sufficient activity into 150–300 min and >300 min of equivalent moderate-intensity PA to assess the potential benefits of more PA than recommended (**Supplementary Table 1**). Interestingly, compared with participants with inadequate PA (<150 min/week, moderate equivalent intensity), those who had more PA than recommended (>300 min/week, moderate equivalent intensity) had the lowest odds of experiencing ED. The multivariable-adjusted ORs (95 % CI) in the <150 min/week, 150–300 min/week and >300 min/week groups were 1.00 (reference), 0.78 (0.47–1.28), and 0.61 (0.43–0.85), respectively (p for trend = 0.005).

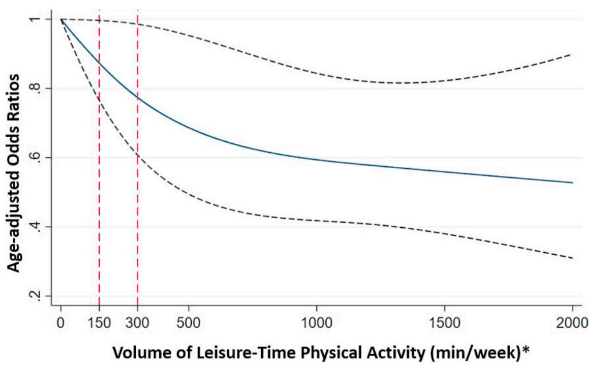

Fig. 3. Restricted cubic spline curve showing the association between volumes of physical activity and the likelihood of erectile dysfunction. * The equivalent combination of moderate- and vigorous-intensity aerobic physical activity per week. The restricted cubic spline shows the relationship between the volume of PA (min) and the odds of erectile dysfunction. The knots include the 5th, 27.5th, 50th, 72.5th, and 95th percentiles. The OR (95 % CI) was estimated with logistics regression analysis after adjustment for age. The solid and dashed lines represent point estimates and 95 % CIs, respectively. Compared with participants with recommended physical activity (150–300 min/week of moderate equivalent-intensity activity), males who had more physical activity than recommended (more than 300 min/week of moderate equivalent-intensity activity) still had incremental benefits for reducing the odds of erectile dysfunction.

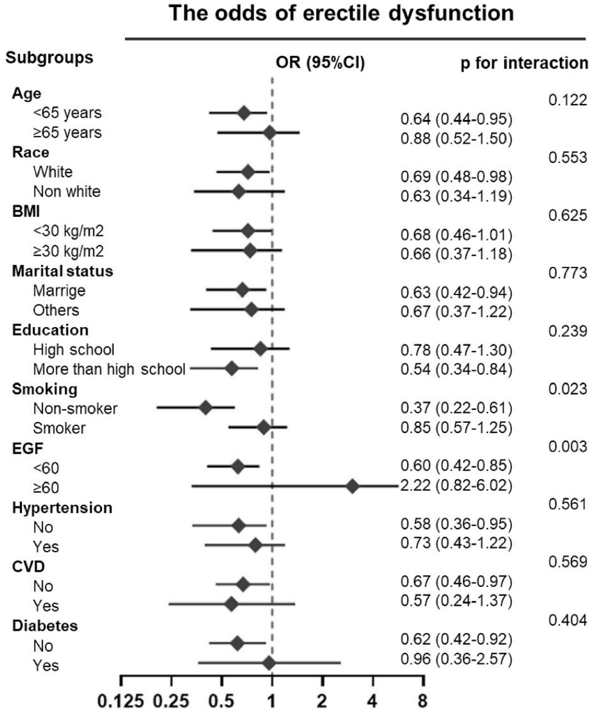

Fig. 4. Stratification analysis for the association between physical activity volumes and erectile dysfunction. HR (95 % CI) was estimated with weighted logistics regression adjusted for the multivariable model except for the corresponding subgroup factors. A p value < 0.05 represents a significance for the interaction of stratification factors for the association of meeting PA guidelines with mortality.

4. Discussion

In this nationally representative sample of US males, we demonstrated that compared with PA levels <150 min/week as moderate activity, PA volumes meeting or beyond the current recommendations were significantly associated with decreased odds of ED after fully adjusting for potential confounders [26,27]. The benefits of sufficient PA volumes were especially significant in males without smoking [28,29]. Our findings highlight the benefits of guideline-recommended weekly physical activity equivalents for ED prevention; however, this benefit was significantly offset by smoking.

PA is a low-cost strategy for alleviating the severity of ED. Previous studies have reported the therapeutic effects of exercise interventions on ED [27,30,31]. In several recent studies, PA has been identified as an important clinical strategy for preventing and treating ED [11,13,32]. A recent pooled analysis of 7 exercise intervention studies demonstrated that aerobic exercise and PA with moderate-to-vigorous intensity significantly improved self-reported ED [13]. However, the risk of bias in those trials seemed to be moderate to high, which may have limited the strength of the study. A recently published cross-sectional study with 20,789 Brazilian men suggested that low or high PA levels were related to an approximately 20 % reduction in the risk of ED [33]. However, the specific benefit of a guideline-recommended volume of PA with moderate-to-vigorous intensity or more has not been reported. Our study was in line with previous studies supporting the benefits of PA for ED, but our findings further add new evidence that the current PA guidelines for optimal effect for ED prevention may need to be validated. Compared to those of male adults with insufficient PA, the odds of ED decreased by one-third for participants who had recommended aerobic activities. Furthermore, compared to individuals with insufficient physical activity, those who exceeded recommended physical activity levels had a lower likelihood of having ED. Notably, among those who reported more than 300 min/week of moderate PA, additional benefits of reducing the risk of ED were observed. Inflammation, chronic kidney disease, and blood pressure may damage the endothelium and are potential risk factors for ED [34,35]. Furthermore, PA can impact hormone levels, such as testosterone, which can strengthen endothelial function and positive body image and decrease stress and anxiety. Testosterone replacement could be a therapy for the management of ED [36]. It has been reported that hyperestrogenism is associated with the severity of erectile dysfunction, and physical training could bring positive effects on hyperestrogenic animals [37,38]. However, our conclusions were unlikely to be influenced by androgen therapy because adult males who reported the use of testosterone replacement therapy were excluded from the ED questionnaire. PA showed the largest effect sizes in terms of efficacy for preventing ED.

Penile erection is a hemodynamic process involving increased arterial inflow and restricted venous outflow. Activation of parasympathetic nerves in response to sexual stimulation leads to vasodilation of the cavernous and helicinal arteries and relaxation of smooth muscle cells in the corpora cavernosa. Multiple central transmitters are involved in erectile control, including dopamine, acetylcholine, nitric oxide (NO), and peptides such as adrenocorticotropin and oxytocin6 [39]. NO, released locally from endothelial cells and parasympathetic nerve terminals, is considered the most important factor for the relaxation of penile vessels and the corpora cavernosa [40]. This intricate process entails the orchestration of multiple regulatory systems, encompassing psychological, neurological, endocrinological, and vascular factors. Disruption of any of these systems, either individually or in combination, has the potential to induce ED [41–43]. Vascular shear stress in response to PA leads to increases in NO from endothelial NO synthase (eNOS) [44]. NO can induce vasodilation immediately to match blood flow to metabolic demands or be metabolised into nitrite and nitrosothiols. Repeated exercise results in elevated steady-state levels of these metabolites that increase NO bioavailability and cardioprotective effects [10,45].

Erectile function is a hemodynamic process governed by multiple regulatory systems, notably cardiovascular diseases, endothelial nitric oxide (NO), testosterone, hyperestrogenism and psychological factors. Endothelial dysfunction is the critical pathophysiological change associated with ED and thus is considered an early sign of cardiovascular disease [27]. Using atherosclerotic cardiovascular disease as a diagnostic tool is effective in identifying patients with arteriogenic erectile dysfunction [46]. The cardiovascular benefits of PA have long been well documented [28]. In this study, we further demonstrated that PA volumes meeting the current recommendations were significantly associated with decreased odds of ED. Even the volumes pf PA more than the recommendations provide additional benefits for ED prevention. Interestingly, we found that smoking counteracts the potential benefit of meeting the recommended volume of PA in reducing the risk of erectile dysfunction. Smoking is a widely recognised hazardous behaviours closely linked to ED. Our results align with the findings of Jones et al. underscoring the positive relationship between smoking and ED [47]. In fact, smoking is an established cause of endothelial damage. Accumulated evidence suggest that tobacco smoking plays a pivotal role in vessel endothelial dysfunction, which contributes to the formation and worsening of ED [48–50]. Previous studies have also reported an association between smoking and an increased risk of ED [33]. Our study highlights the equal importance of smoking cessation when promoting guidance-recommended PA to reduce erectile dysfunction risk in adult males.

4.1. Strengths and limitations

In terms of strengths, the NHANES study was a national sampling dataset that favoured repeatability and generalizability. We adjusted for a variety of potential confounders, and the relationship between the volume of PA and ED volume remained significant. While the literature has acknowledged the general positive impact of physical exercise on sexual health, our research further dissects the intricacies of this association. Our study introduces a comparative dimension by juxtaposing the influence of smoking and cardiovascular diseases on erectile function [51].

Our study has several limitations. First, unmeasured residual confounders, such as the presence of penile or perineal trauma and the use of medications influencing ED, cannot be completely ruled out. Second, the causality of this link between PA and the odds of ED could not be determined because of the observational nature of this study. Further population-based interventional studies confirming the benefits of meeting PA at the recommended levels are highly desirable. However, prior studies have demonstrated that endothelial dysfunction is the key pathological characteristic of ED, which can be improved by exercise. Third, the participants enrolled in this study were US civilians, so the results need to be extrapolated to other populations for further verification. Fourth, the characteristics of ED and PA in the NHANES were investigated nearly twenty years ago. However, the information was collected by using standardised questionnaires. In particular, the study protocols used to determine the intensity and duration of PA in 2001–2004 were consistent with recent criteria [52].

5. Conclusions

Our findings support that compared with below a threshold of recommended PA (<150 min/week as moderate activity), an adequate volume of PA was significantly associated with decreased odds of ED after fully adjusting for potential confounders. A greater volumes of PA than the guideline recommendation may further decrease the odds of ED. However, this benefit was significantly offset by smoking. Our findings highlight the importance of joint management of adequate PA recommended by guidelines and quitting smoking for ED prevention.

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Ethics approval statement

The protocols and procedures of the NHANES were agreed by the Research Ethics Review Board of the Centers of Disease Control and Prevention of the United States (Protocol #98–12). All participants had written the informed consent before any data collection.

Ethics and dissemination

This study was conducted in accordance with the Declaration of Helsinki. The protocols of the NHANES were approved by the National Center for Health Statistics ethics review board. All participants provided informed consent.

Data availability statement

The data associated with our study has been deposited into a publicly available repository the National Health and Nutrition Examination Survey (NHANES). NHANES were agreed by the Research Ethics Review Board of the Centers of Disease Control and Prevention of the United States (Protocol #98–12). All participants had written the informed consent before any data collection. Detailed information and datasets can be accessed to reproduce this study (https://www.cdc.gov/nchs/index.htm).

CRediT authorship contribution statement

Mingming Zhang: Writing – review & editing, Writing – original draft, Data curation. **Zichun Wang:** Formal analysis, Data curation. **Wanpeng Liu:** Methodology. **Minglei Wang:** Writing – original draft. **Huaying Wu:** Writing – original draft. **Ruihua An:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e32884.

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