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Comparative study on the association between types of physical activity, physical activity levels, and the incidence of osteoarthritis in adults: the NHANES 2007–2020

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It is known that physical activity is beneficial for the prevention of osteoarthritis (OA), but specific discussions on which types and levels of physical activity are more effective in reducing the incidence of OA are restricted. This study is aimed at exploring the correlation concerning the types of physical activity, levels of physical activity, and the incidence of OA by assessing the participation in five typical forms of physical activity (vigorous work activity, vigorous recreational activity, moderate work activity, moderate recreational activity, and walking or bicycling). Cross-sectional study was conducted. Self-reported data on specific types of physical activity were obtained from individuals in the National Health and Nutrition Examination Survey (NHANES) from 2007 to 2020 with the use of the Physical Activity Questionnaire (PAQ). The incidence of OA was assessed through the "Health Conditions" questionnaire section of NHANES. Weighted logistic regression analysis was employed to study the correlation between physical activity types and levels, and the incidence of OA. Different kinds of physical activity and physical activity levels have varying impacts on the incidence of OA. Among the types of physical activity, vigorous recreational activity and moderate recreational activity are found to have a preventive effect on OA. In terms of physical activity levels, low physical activity levels of moderate work activity are associated with an increased risk of OA, while moderate physical activity levels are confirmed to have a protective effect against OA in the age groups of 20–44 and 45–64. However, gender-stratified analyses reveal that both low and moderate physical activity levels provide protection against OA in males, with moderate physical activity levels showing a more significant protective effect.

Keywords Osteoarthritis, Physical activity, Epidemiology, NHANES

Abbreviations

BMI	Body mass index
CI	Confidence interval
MET	Metabolic equivalent
NHANES	National Health and Nutrition Examination Survey
OR	Odds ratio
PAQ	Physical Activity Questionnaire

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Osteoarthritis (OA) refers to one of the most common joint diseases worldwide, influencing around 10% of men and 18% of women over 60 years of age[1]. it can occur in both large and small joints throughout the body, with the primary manifestations including morning stiffness, pain, deformity and joint activity limitations, and in severe cases, it can lead to joint instability or limb disability, seriously impacting quality of life[2].

Epidemiological studies have indicated that physical activity is closely related to OA[3]. Based on different activity types, physical activity types can be categorized into occupational activity, recreational activity, and transportation activity. Additionally, different physical activity levels can be calculated based on various factors such as activity intensity, frequency, duration, and type. Most previous studies consistently revealed that physical activity can lower the risk of developing OA in joints. However, during physical activity, the load on the joints of the human body increases, and different types of physical activity impose varying loads on the knees [4,5]. The study found that when examining overall physical activity, the risk of OA did not increase[6]. One cohort study suggested that all kinds of physical activity are protective against knee OA[7–9]. However, in a recent study from a university, it was found that low-to-moderate physical intensity of activity is protective for OA[10], while high-intensity physical intensity of activity provides no protection against OA[11].

While many studies indicate that an active lifestyle can reduce the risk of OA, several studies have found that leisure physical activity and occupational physical activity have different effects on OA [12–14]. Additionally, there is no definitive evidence supporting recommendations regarding physical activity types and levels. As a result, according to the National Health and Nutrition Examination Survey (NHANES) data in the USA, this study aims to explore the relationships between physical activity types (vigorous work activity, vigorous recreational activity, moderate work activity, moderate recreational activity, walking or bicycling) and levels (non, low, medium, high) and the risk of OA. Clarifying the association between specific physical activity types and levels and OA risk will provide insights and thus guide more targeted physical activity recommendations for OA prevention and management. The findings are conducive to informing and optimizing public health strategies to reduce the personal and socioeconomic burden of OA.

Materials and methods

Study population

National Health and Nutrition Examination Survey (NHANE), a nationally representative cross-sectional survey conducted by the Centers for Disease Control and Prevention in the United States, employs a stratified, multi-stage random sampling method. The data analyzed in this study span the years 2007–2008, 2009–2010, 2011–2012, 2013–2014, 2015–2016, 2017–2018, and the ongoing period of 2017–2020.Among the 56,171 participants in NHANES from 2007 to 2020, rigorous assessments were conducted to ensure the integrity, consistency, and logical coherence of physical activity data. In this present study, a meticulous examination of the dataset led to the exclusion of individuals with missing, refused, or unknown information regarding physical activity, sedentary time, and durations exceeding 24 h (n = 24,376). Additionally, participants lacking, refusing, or with unknown covariate information (n = 8894). Ultimately, 22,901 participants remained with no missing or confounding information regarding key outcomes, exposures, or variables (Fig. 1).

Diagnosis of OA

OA diagnosis data was from the "Medical Conditions" questionnaire section of the NHANES. First of all, participants were asked if doctor ever said they had arthritis. If they answered "yes," they would be further asked to identify "which type of arthritis was it" (The arthritis was classified as OA, rheumatoid arthritis, psoriatic arthritis, and others based on NHANES questionnaire data).

Assessment of types of physical activity and levels of physical activity

The Global Physical Activity Questionnaire was used to collect respondent-level weekly physical activity information[15]. Physical activity levels were examined for three categories of physical activity participation: vigorous work activity/vigorous recreational activities, moderate work activity/moderate recreational activities, and walk/bicycle information. Vigorous work activity was defined as typical activity that induced significant increases in breathing or heart rate for at least 10 min continuously, such as hauling or lifting heavy weights, excavating, or building work. Vigorous recreational activities were characterized as high-intensity sports, fitness activities, or leisure activities that generate significant increases in respiration or heart rate, such as jogging or basketball. Moderate work activity was defined as any activity that induces minor increases in breathing or heart rate, such as brisk walking or carrying light burdens for at least 10 min continuously. Moderate leisure activities were defined as those that generate a slight rise in breathing or heart rate for at least 10 min continuously, such as brisk walking, biking, swimming, or volleyball. Walking or use of a bicycle was defined as a transportation to school/work or for shopping for at least 10 min continuously to get to and from places.

According to the World Health Organization (WHO) Analytical Guidelines, physical activity (PA) is converted into metabolic equivalent minutes (MET-min) per week for moderate to vigorous PA[16]. MET values vary by the type of exercise, and NHANES provides recommended MET values for each PA. PA is calculated based on the MET values, weekly frequency, and duration of each PA using the formula: PA (MET-min/week) = MET × weekly frequency × duration[17]. A PA value of 0 indicates participants who are not engaged in any PA. Finally, the participants were classified into different groups based on their PA level. The groups were defined as NPA: Non-physical activity (0 MET-min/week), Low PA(LPA) (Q_1), Medium PA (MPA) (Q_2) and High PA (HPA) (Q_3)[18].

Assessment of covariates

The following information was gathered using a household structured questionnaire: age (20–44, 45–64, ≥ 65 years), gender (male and female), race (Mexican American, Other Hispanic, Non-Hispanic white,

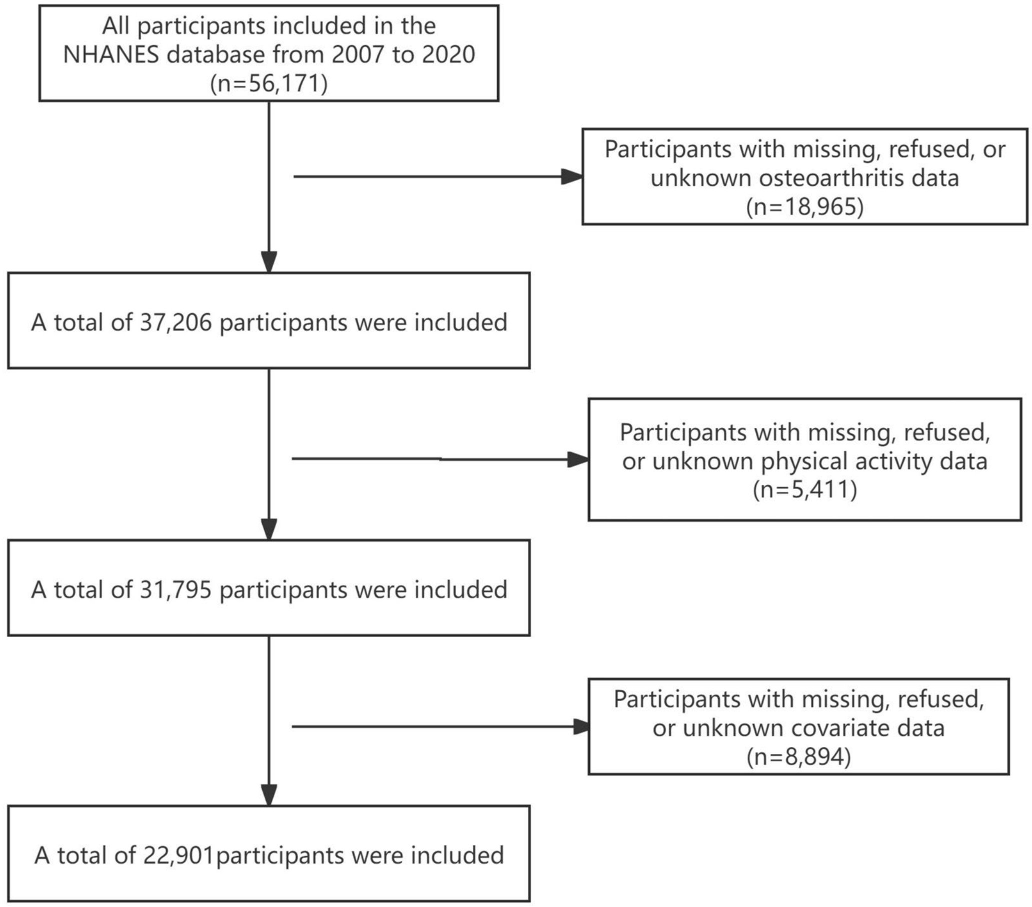

Fig. 1. Patient Enrollment Process Flowchart.

Non-Hispanic black and Other race), level of education (less than high school, high school, more than high school), Examination data included BMI (kg/m^2). Laboratory data covered blood urea nitrogen (BUN, mmol/L)[19], total calcium (Ca, mmol/L)[20], phosphorus (P, mmol/L)[21], triglycerides (TG, mmol/L)[22], uric acid (UA, μmol/L)[23], and total cholesterol (TC, mmol/L)[24]. As a final point, questionnaire data included information on smoking behavior (Yes/No)[25], alcohol consumption (Yes/No)[26], hypertension (Yes/No)[27], and diabetes (Yes/No)[28].

Statistical analysis
We used weighted samples and considered stratification and clustering in the design to generate nationally representative estimates for the US population. The NHANES cycles and weights were constructed according to the guidelines for continuous NHANES analysis[29]. The participants' baseline characteristics were classified based on their physical activity level and OA status. A descriptive statistical analysis was performed on basic demographic information (age, gender, race, level of education), physical activity types (vigorous work activity, vigorous recreational activities, moderate work activity, moderate recreational activities, walk or bicycle, physical activity levels), body measurements (BMI), and diseases (hypertension, diabetes).Laboratory data included blood urea nitrogen, total calcium, phosphorus, triglycerides, uric acid, and total cholesterol. The categorical variables were reported in frequency (%), with the chi-square test for unordered categorical variables and the chi-square trend test for ordered multi-categorical variables.

STATA version 17.0 was used for statistical analysis (Stata Corp LP, College Station, TX, USA). R version 4.2.3 was used to create the forest graphs. A p-value under 0.05 was considered statistically significant.

Result
Among the 22,901 participants (41.5% male, 58.4% female), the overall prevalence of OA was 11.8%. Table 1 shows the baseline characteristics of the participants stratified by OA status. In general, OA was more common in middle-aged (45–64 years) and elderly (≥65 years) individuals, females and non-Hispanic whites. Higher education levels of above high school, BMI ≥ 25 kg/m^2, heavy smoking, hypertension diagnosis and diabetes diagnosis were related to higher risk of OA. Compared to vigorous work activity and moderate work activity, OA prevalence was lower in those engaging in vigorous recreational activity and moderate recreational activity (Table 1). Females and participants with higher BMI were more likely to perform non-physical activity, and had higher risks of OA, hypertension or diabetes. Participants who received education higher than high school

Characteristic	Non-OA(n = 20,196)	OA (n = 2705)	*p*-Value
Age(years)			
20–44	7250(97.2)	206(2.8)	< 0.001
45–64	7331(87.5)	1049(12.5)	
≥65	5615(79.5)	1450(20.5)	
Gender			
Male	8669(91.2)	837(8.8)	< 0.001
Female	11,527(86.1)	1868(13.9)	
Race			
Mexican American	3317(92.6)	250(7.4)	< 0.001
Other Hispanic	2298(91.4)	216(8.6)	
Non-Hispanic white	7162(83.4)	1427(16.6)	
Non-Hispanic black	4810(89.4)	568(10.6)	
Other races	2809(92.0)	244(8.0)	
Level of education			
< High school	5911(89.8)	671(10.2)	< 0.001
High school	4811(88.5)	626(11.5)	
> High school	9474(89.1)	1408(12.9)	
BMI status(kg/m^2)			
< 25	5742(90.9)	551(9.1)	< 0.001
≥25	14,724(87.2)	2154(12.8)	
Smoking status			< 0.001
No	8681(86.1)	1399(13.9)	
Yes	11,515(89.8)	1306(10.2)	
Alcohol consumption			
Non-drinker	2939(89.1)	359(10.9)	< 0.001
< 2 alcohol drinks	4293(85.2)	746(14.8)	
≥2 alcohol drinks	6902(90.8)	701(9.2)	
Unspecified	6062(87.1)	899(12.9)	
Hypertension			
Yes	7918(81.6)	1789(18.4)	< 0.001
NO	12,278(93.1)	916(6.9)	
Diabetes			
Yes	3201(81.2)	743(18.8)	< 0.001
NO	16,481(89.9)	1858(10.1)	
Unspecified	514(83.2)	104(16.8)	
Vigorous work activity[a]			
Yes	19,504(88.0)	2656(12.0)	< 0.001
NO	692(93.4)	49(6.6)	
Moderate work activity[b]			
Yes	17,540(88.4)	2305(11.6)	0.019
NO	2656(86.9)	400(13.1)	
Walk or bicycle[c]			
Yes	17,574(87.8)	2453(12.2)	< 0.001
NO	2622(91.2)	252(8.8)	
Vigorous recreational activity[d]			
Yes	19,149(87.8)	2657(12.2)	< 0.001
NO	1047(95.6)	48(4.4)	
Moderate recreational activity[e]			
Yes	16,393(87.9)	2253(12.1)	0.008
NO	3803(89.4)	452(10.6)	
Physical activity levels (met-h/week)			
0	9413(86.2)	1509(13.8)	< 0.001
Q_1 (1.4–17.1)	4265(89.3)	510(10.7)	
Q_2 (17.7–42.9)	5335(90.7)	616(9.3)	
Q_3(45–1080)	2686(88.2)	251(11.8)	
Laboratory indices			
Continued			

Characteristic	Non-OA(n = 20,196)	OA (n = 2705)	*p*-Value
Blood urea nitrogen (mmol/L)	4.93 ± 0.018	5.80 ± 0.058	< 0.001
Total calcium (mmol/L)	2.34 ± 0.001	2.34 ± 0.003	0.001
Phosphorus (mmol/L)	1.20 ± 0.002	1.22 ± 0.005	0.025
Triglycerides (mmol/L)	1.76 ± 0.013	1.83 ± 0.034	0.017
Uric acid (μmol/L)	319.78 ± 0.797	323.79 ± 2.26	< 0.001
Total cholesterol (mmol/L)	5.28 ± 0.014	5.26 ± 0.039	< 0.001

Table 1. Baseline characteristics of the research population with and without OA. n: sample size; BMI, body mass index (calculated as weight in kilograms divided by height in square meters); MET, metabolic equivalent. [a]Vigorous work activity: typical activity that induced signification increases in breathing or heart rate for at least 10 min continuously. [b]Moderate work activity: any activity that induces minor increases in breathing or heart rate. [c]walk or use a bicycle for at least 10 min continuously to get to and from places. [d]Vigorous recreational activities: high-intensity sports, fitness activities, or leisure activities that generate signification increases in respiration or heart rate. [e]Moderate recreational activities: any activity that generates a slight rise in breathing or heart rate for at least 10 min continuously. Continuous variables were presented by mean ± Standard error (SE), and categorical variables were presented with numbers and percentages.

tended to have low physical activity level. Those with lower BMI and non-whites were more likely to have medium physical activity level. Younger individuals (20–44 years) and males were more inclined to have high physical activity level, and experienced lower risks of OA, hypertension, and diabetes (Table 2).

Figure 2 shows the relationship between different types of physical activity and risk of OA. The three models were defined as follows: Model 1 had no covariates adjusted; Model 2 adjusted for gender and age; Model 3 further adjusted for a comprehensive set of variables including age, gender, race, level of education, BMI, smoking status, alcohol consumption, hypertension, diabetes, blood urea nitrogen, total calcium, phosphorus, triglycerides, uric acid, and total cholesterol. We found that all types of physical activity in this study were associated with OA. In Model 1, moderate work activity was a risk factor (OR: 1.20, 95% CI: 1.20–1.40), while vigorous work activity, vigorous recreational activity and walking or bicycling were protective factors. Additionally, in particular, there was the strongest statistically significant inverse relationship between vigorous recreational activity and OA risk (OR: 0.31, 95% CI: 0.21–0.48). In Model 3 after controlling for age, gender, race, education level, BMI, smoking status, alcohol consumption, hypertension, diabetes, as well as laboratory data (blood urea nitrogen, total calcium, phosphorus, triglycerides, uric acid, total cholesterol) (in the fully adjusted model) high-intensity recreational activity (OR: 0.61, 95% CI: 0.41–0.92) and moderate-intensity recreational activity (OR: 0.79, 95% CI: 0.68–0.92) were both protective factors against OA, reducing the risk by 39% and 21%, respectively. High-intensity recreational activity showed the strongest protective effect against OA.

Figure 3 illustrates that in Model 1, as the physical activity level increases, the risk of OA gradually decreases. Compared to the population who does not conduct physical activity, the risk of OA decreased by 25% (OR: 0.75, 95% CI: 0.65–0.87), 36% (OR: 0.64 95% CI: 0.54–0.76) 和32% (OR: 0.68 95% CI: 0.58–0.81) for low, medium, and high physical activity level, respectively. In Model 3, among all levels of physical activity, individuals with medium physical activity level showed the strongest protective factor against OA (OR: 0.72, 95% CI: 0.60–0.87). The dose–response relationship between total physical activity level and the risk of OA varied with age and gender. Regardless of the physical activity level, no significant correlation was found with the risk of OA in age groups of ≥ 65 years (Additional file S1C). Medium physical activity, however, demonstrated preventive benefits against OA in the age groups of 20–44 years and 45–64 years and (OR:0.46, 95% CI:0.26–0.81, OR:0.73, 95% CI:0.54–0.99), reducing the risk of OA (Additional files S1A and B). In gender-stratified analyses, medium physical activity level was the strongest protective factor against OA in males (OR:0.70,95% CI:0.52–0.95), while no significant correlation was found with the risk of OA in females (Additional files S2A and B).

As displayed in Figs. 4A–C, across five different types of physical activity, namely vigorous work activity, vigorous recreational activity, moderate work activity, moderate recreational activity, and walking or bicycling, the impact of three physical activity levels on the risk of OA varies compared to non-physical activity. Individuals engaged in vigorous work activity with different levels of physical activity shows no significant relationship to OA risk (Fig. 4A). In addition, for vigorous recreational activity type, participating in vigorous recreational activities at a medium physical activity level reduces the incidence of OA by 59% (OR: 0.41, 95% CI: 0.17 -0.95) (Fig. 4A). In the moderate work activity type, low physical activity level is positively related to OA, raising the risk by 29%, respectively (OR:1.29, 95% CI: 1.01 -1.66). In moderate recreational activity type, a high physical activity level lowers the risk of OA by 29% (OR: 0.71, 95% CI: 0.55–0.91) (Fig. 4B). Regarding walking or bicycling related to transportation, there is no significant association between different levels of physical activity and the risk of OA (Fig. 4C).

Discussion

In this nationally representative study, vigorous recreational activities and moderate recreational activities serve as protective factors against OA, with vigorous recreational activities showing the greatest protective effect. Subdividing weekly metabolic equivalents revealed that engaging in weekly exercise at a medium physical activity level reduces the risk of OA, although this does not apply to all kinds of physical activities, including work-related activities and vigorous recreational activity. After categorizing different physical activity types, it was found that

Characteristic	Physical Activity Levels (met-h/week)				*p*-Value
	Q0(n = 10,922)	Q1(n = 4775)	Q2(n = 3441)	Q3(n = 3763)	
Age(years)					
20–44	3013(27.6)	1732(36.3)	1197(34.8)	1514(40.2)	< 0.001
45–64	3935(36.0)	1800(37.7)	1293(37.6)	1352(35.9)	
≥ 65	3974(36.4)	1243(26.0)	951(27.6)	897(23.8)	
Gender					
Male	4254(38.9)	1925(40.3)	1476(42.9)	1851(49.2)	< 0.001
Female	6668(61.1)	2850(59.7)	1965(57.1)	1912(50.8)	
Race					
Mexican American	1706(15.6)	629(13.2)	426(12.4)	606(16.1)	< 0.001
Other Hispanic	1266(11.6)	450(9.4)	367(10.7)	431(11.5)	
Non-Hispanic white	3998(36.6)	1779(37.3)	1350(39.2)	1462(38.9)	
Non-Hispanic black	2651(24.3)	1139(23.9)	740(21.5)	848(22.5)	
Other races	1301(11.9)	778(16.3)	558(16.2)	416(11.1)	
Level of education					
< High school	3545(32.5)	1103(23.1)	773(22.5)	1161(30.9)	< 0.001
High school	2680(24.5)	1067(22.3)	712(20.7)	978(26.0)	
> High school	4697(43.0)	2605(54.6)	1956(56.8)	1624(43.2)	
BMI status(kg/m^2)					
< 25	2636(24.1)	1284(26.9)	1065(31.0)	1038(27.6)	< 0.001
≥ 25	8286(75.9)	3491(73.1)	2376(69.0)	2725(72.4)	
Smoking status					
No	4834(44.3)	1973(41.3)	1434(41.7)	1839(48.9)	< 0.001
Yes	6088(55.7)	2802(58.7)	2007(58.3)	1924(51.1)	
Alcohol consumption					
Non-drinker	1729(15.8)	643(13.5)	455(13.2)	471(12.5)	< 0.001
< 2 alcohol drinks	2266(20.7)	1152(24.1)	865(25.1)	756(20.1)	
≥ 2 alcohol drinks	3249(29.7)	1641(34.4)	1225(35.6)	1488(39.5)	
Unspecified	3678(33.7)	1339(28.0)	896(26.0)	1048(27.9)	
OA					
No	9413(86.2)	4265(89.3)	3121(90.7)	3397(90.3)	< 0.001
Yes	1509(13.8)	510(10.7)	320(9.3)	366(9.7)	
Hypertension					
NO	5176(47.4)	1886(39.5)	1341(39.0)	1304(34.7)	< 0.001
Yes	5746(52.6)	2889(60.5)	2100(61.0)	2459(65.3)	
Diabetes					
NO	2231(20.4)	738(15.5)	464(13.5)	511(13.6)	< 0.001
Yes	8394(76.9)	3901(81.7)	2870(83.4)	3174(84.3)	
Unspecified	297(2.7)	136(2.8)	107(3.1)	78(2.1)	
Laboratory indices					
Blood urea nitrogen (mmol/L)	5.22 ± 0.028	4.89 ± 0.034	4.98 ± 0.041	4.86 ± 0.039	< 0.001
Total calcium (mmol/L)	2.34 ± 0.001	2.34 ± 0.002	2.35 ± 0.002	2.34 ± 0.002	< 0.001
Phosphorus (mmol/L)	1.2 ± 0.002	1.2 ± 0.003	1.2 ± 0.004	1.2 ± 0.004	< 0.001
Triglycerides (mmol/L)	1.83 ± 0.019	1.77 ± 0.024	1.69 ± 0.029	1.71 ± 0.027	< 0.001
Uric acid (μmol/L)	321.68 ± 1.1	319.43 ± 1.608	317.59 ± 1.966	320.49 ± 1.822	< 0.001
Total cholesterol (mmol/L)	5.3 ± 0.021	5.29 ± 0.028	5.25 ± 0.032	5.21 ± 0.032	< 0.001

Table 2. Baseline Characteristics of Participants by Physical Activity Levels Status: NHANES,2007–2020. n: sample size; BMI, body mass index (calculated as weight in kilograms divided by height in square meters). MET: metabolic equivalent; Continuous variables were presented by mean ± Standard error (SE), and categorical variables were presented with numbers and percentages.

a medium physical activity level of vigorous recreational activity can reduce the risk of OA, while a high physical activity level of moderate recreational activity can lower the risk of OA. However, a low physical activity level of moderate work activity increases the risk of OA. Furthermore, the correlation between physical activity levels and the risk of OA varies with gender and age.

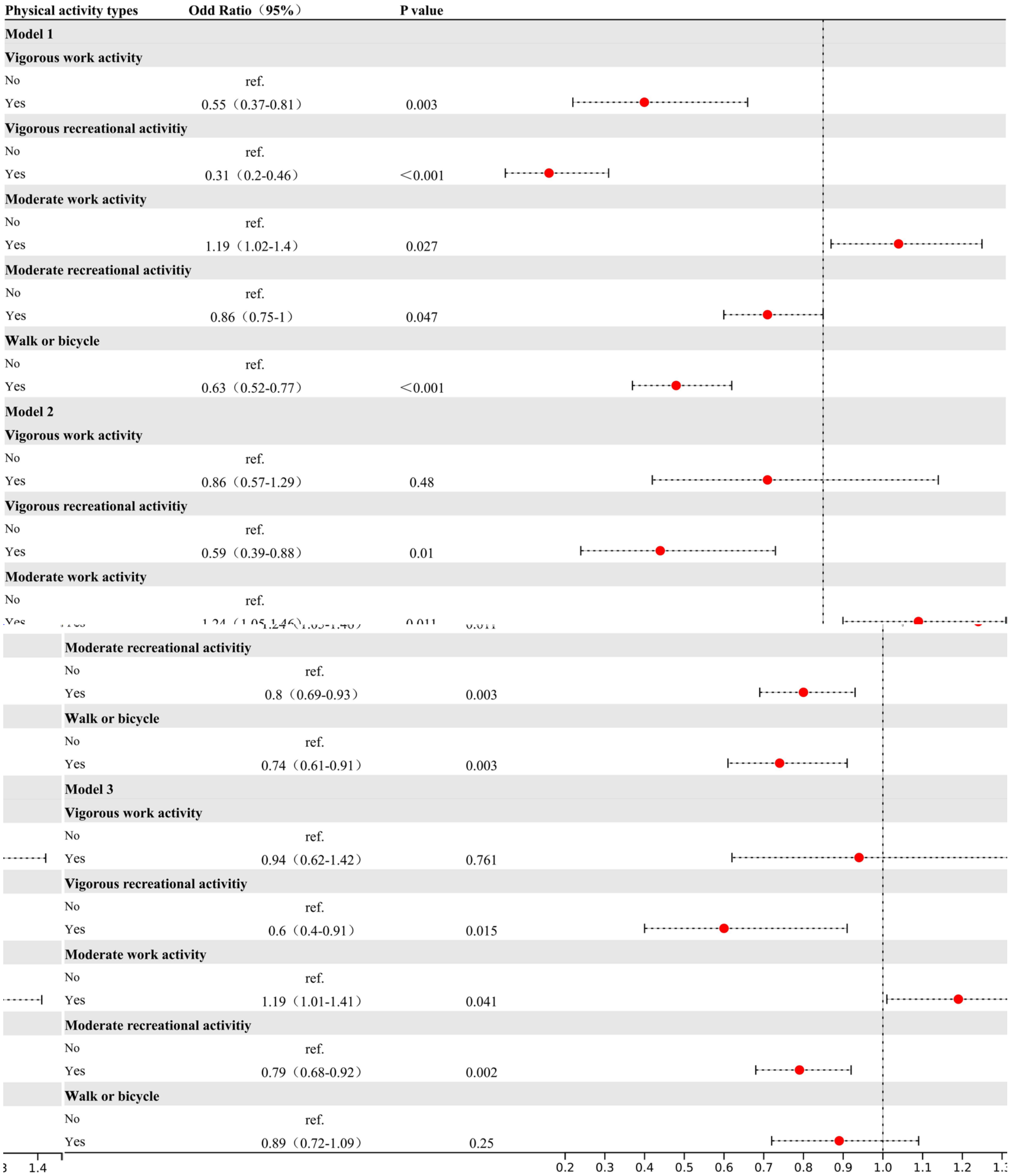

Fig. 2. The association between physical activity types and OA. Model 1: no covariates were adjusted; Model 2 adjusted for gender, age; Model 3 adjusted for age, gender, race, level of education, BMI, smoking status, alcohol consumption, hypertension, diabetes, blood urea nitrogen, total calcium, phosphorus, triglycerides, uric acid, total cholesterol.

The relation between physical activity and OA has long been a focus of discussion. Physical activity, defined as movement of the body and limbs causing energy expenditure through muscle contraction, is a primary therapeutic approach against the health impacts of a sedentary lifestyle. It is also a frontline treatment for OA, with a benefit/risk ratio far exceeding that of drug therapy, supported by high levels of evidence and expert consensus, especially for lower limb OA, as confirmed by numerous studies and meta-analyses[30]. However, in a systematic review in 2016, 18 studies, mainly small to moderate-sized quasi-experimental (non-randomized) clinical ones were identified, providing conflicting evidence on the preventive role of physical activity in knee OA following anterior cruciate ligament injury[31]. Another study demonstrated that moderate physical activity may increase the sGAG content in cartilage and potentially prevent OA. However, when sGAG content in the cartilage is depleted, exercise may induce OA[32]. Therefore, the type, frequency, duration, and intensity of physical activity can have different impacts on OA.

Regarding the impact of work-related activities on OA, this study found that a low physical activity level of moderate work activity increases the risk of OA, mainly due to prolonged standing, sitting, and repetitive movements in occupational activities. From a biomechanical perspective, standing places continuous compressive

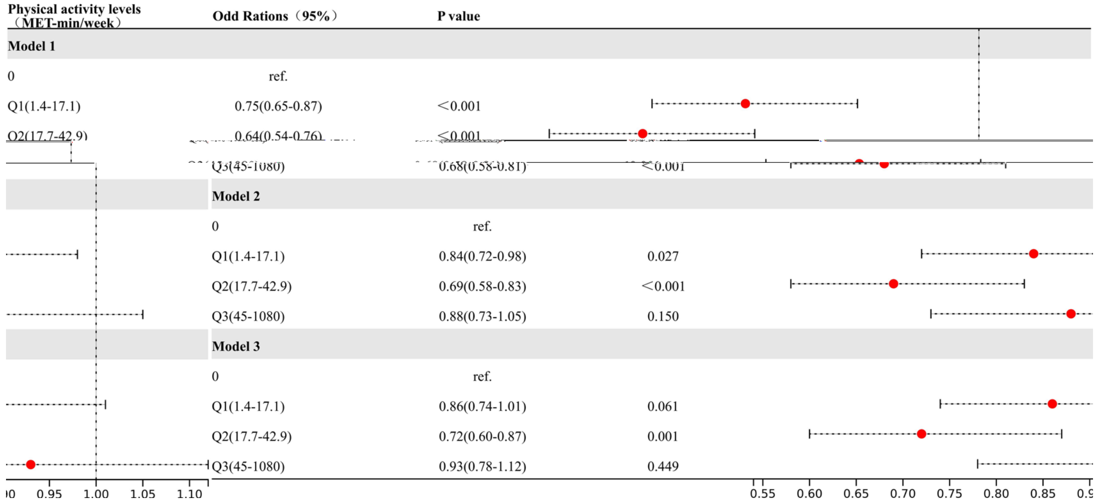

Fig. 3. The association between physical activity levels and OA. Model 1: no covariates were adjusted; Model 2 adjusted for age, gender; Model 3 adjusted for age, gender, race, level of education, BMI, smoking status, alcohol consumption, hypertension, diabetes, blood urea nitrogen, total calcium, phosphorus, triglycerides, uric acid, total cholesterol.

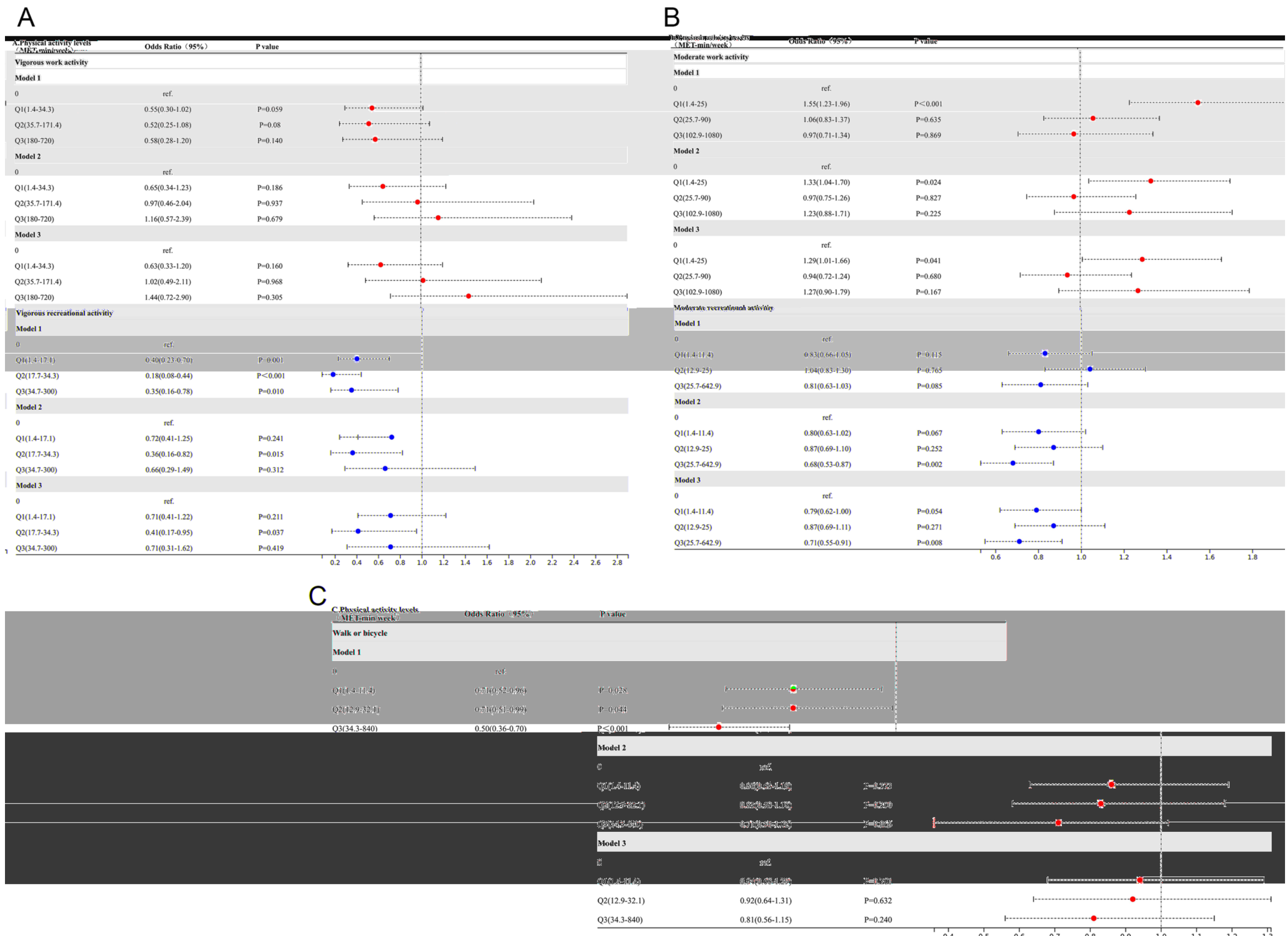

Fig. 4. The association between physical activity levels and OA. Model 1: no covariates were adjusted; Model 2 adjusted for gender, age; Model 3 adjusted for age, gender, race, level of education, BMI, smoking status, alcohol consumption, hypertension, diabetes, blood urea nitrogen, total calcium, phosphorus, triglycerides, uric acid, total cholesterol.

loads on knee cartilage, which induces wear-promoting lubrication modes[33]. Long-term engagement in occupations that involve squatting, kneeling, or climbing stairs can lead to chronic wear of joint cartilage, eventually causing OA[34,35]. A comparative study found that the duration of squatting is positively associated with tibiofemoral OA[36]. For individuals who sit for extended periods, prolonged sitting can lead to increased pressure within the knee joint, muscle atrophy, and joint stiffness[37]. As muscle strength declines, joint stability is reduced, accelerating cartilage degeneration[38,39]. On the other hand, when joints are deprived of regular loading, cartilage degradation may also occur.

In recreational activities, high physical activity levels of vigorous recreational activity and medium physical activity levels of moderate recreational activity both reduce the risk of OA. Various activities, including exercise and fitness have been validated for their protective effects against OA[40–42]. Some activities, including Tai Chi[43], walking[44], water sports[45], and cycling[42], stand out in both the prevention and treatment of OA. However, according to surveys, certain traumatic physical activities, including American football, soccer, weightlifting, and ice hockey, may increase the occurrence of OA[46–48]. Nevertheless, it is the rising rate of knee joint injuries in these groups rather than participation in physical activity itself that elevates the risk of OA.

Among different physical activity levels, a medium physical activity level has a protective effect against OA. In a study, it was found that individuals with the highest level of physical activity were characterized by an elevated risk of knee OA outcomes[49]. Yang et al.[50]demonstrated through histological and protein analysis that moderate-intensity treadmill exercise can improve OA by downregulating TRAIL. They also found that adaptive intensity exercise can lower the sensitivity of cartilage cells to inflammation, while excessive exercise can lead to progressive damage, hinder matrix synthesis, and stimulate the production of matrix-degrading enzymes, thereby increasing the risk of OA[51,52]. Research has revealed that normal joint cartilage and chondrocytes can benefit from mechanical stimuli, but when the mechanical stimuli are excessive or prolonged and cannot be tolerated, it can cause damage[42]. Regular participation in physical activity has been demonstrated to be dramatically conducive to the treatment of knee OA. In addition, if patients cannot maintain activity and become sedentary, it may accelerate joint mechanical damage, potentially resulting in further deterioration of cartilage and aggravating OA[53]. Therefore, maintaining a medium physical activity level and achieving a balance in physical activity is recommended. After conducting subgroup analyses of medium physical activity levels, this study found that the protective effect of medium physical activity levels diminished in individuals aged 65 and above. This could be due, on one hand, to the decline in joint cartilage repair capacity associated with aging[54]. On the other hand, the weakening of muscles that accompanies aging makes joints more prone to damage, meaning that medium physical activity levels might no longer offer effective protection[55]. Additionally, the increased likelihood of comorbidities with advancing age may further impact the effectiveness of physical activity[56].

The subgroup analysis in this study suggests that low and medium physical activity levels are protective against osteoarthritis risk in men, while no significant association was observed in women. This may be related to sex differences in joint cartilage[57]. Jones et al.[58] found that men tend to have more knee cartilage compared to women. Faber et al. [59]noted that, compared to men, women have 19.9% less patellar cartilage and 46.6% less medial tibial cartilage. Additionally, Pachowsky et al.[60] discovered that women have poorer cartilage quality and lower healing capacity compared to men. Moreover, these differences could be related to metabolic variations influenced by hormone levels[61].

Our study collected data from a large-scale, nationally representative sample of U.S. adults with long-term longitudinal follow-up and adjusted for most potential confounding factors. We also used appropriate NHANES sample weights to analyze the data, enhancing the reliability and generalizability of our results. The results indicated that vigorous recreational activity and moderate recreational activity are protective factors against OA. Specifically, at a medium physical activity level, vigorous recreational activity can reduce the risk of OA, while at a high physical activity level, moderate recreational activity can also reduce the risk. However, moderate work activity at a low physical activity level is associated with an increased risk of OA. Based on these findings, we can develop targeted exercise recommendations for individuals at higher risk of OA, guide individual physical activity interventions, and improve public health strategies to reduce the incidence of OA. Finally, multiple subgroup analyses were performed to confirm the robustness of the results.

Despite these strengths, our study has certain limitations. Firstly, it is a cross-sectional study, and NHANES data are typically cross-sectional, providing health and nutrition information at a specific point in time without revealing trends or causal relationships. Secondly, This study relied on self-reported data to determine the presence of OA, which may introduce reporting bias and result in some individuals with actual OA being incorrectly classified as non-OA. This could lead to an underestimation of the true prevalence of OA and potentially impact the statistical analysis results. However, despite the possibility of misclassification of OA cases, the large sample size used in this study enhances the generalizability of the findings. Additionally, the use of multiple models and subgroup analyses to adjust for confounding factors increases the reliability of the results. Therefore, the findings of this study still maintain a certain degree of validity and robustness. Thirdly, despite adjusting for various covariates, some potential confounding factors might still have been overlooked.

Conclusion

To conclude, this study demonstrates the cross-sectional impact of physical activity on OA. Among all types of physical activity, vigorous recreational activity and moderate recreational activity are found to have a preventive effect on OA. In terms of physical activity levels, low physical activity levels of moderate work activity are associated with an increased risk of OA, while moderate physical activity levels are confirmed to have a protective effect against OA in the age groups of 20–44 and 45–64. However, gender-stratified analyses reveal that both low and moderate physical activity levels provide protection against OA in males, with moderate physical activity levels showing a more significant protective effect.

Data availability

The datasets generated and analysed during the current study are available in the National Health and Nutrition Examination Survey repository, https://www.cdc.gov/nchs/nhanes/index.htm.

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Author contributions
Formal analysis, C.H and Z.G.; Funding acquisition, E.G. and L.D.; Z.F. and J.X. prepared Figs. 1, 2, 3 and 4; Z.P. and W.L. prepared additional files 1, 2 All authors have read and agreed to the published version of the manuscript.

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Competing interests
The authors declare no competing interests.

Ethical approval
Ethics approval Informed consent was given by participants prior to performing NHANES and ethics approval was obtained from the Research Ethics Review Board at the National Centre for Health Statistics, https://www.cdc.gov/nchs/nhanes/irba98.htm

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