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Association of cognitive performance with overall, dosage, intensity, and domain physical activity in aging: NHANES 2011–2014

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Abstract

Background The specific relationship between PA in detailed types and cognition is still unclear due to limited evidence. Our study aimed to investigate the relationship between cognitive performance and various aspects of physical activity, including overall activity, dosage, intensity levels [moderate physical activity (MPA), vigorous PA], and different domains of activity [occupational PA (OPA), transportation PA (TPA), and leisure-time PA (LTPA)] in older adults using data from the NHANES database.

Methods This cross-sectional analysis used data from 2 cycles of NHANES (2011–2014). PA was determined through participants' self-reports using the Global Physical Activity Questionnaire (GPAQ). Cognitive performance was evaluated by the presence of psychometric mild cognitive impairment (p-MCI), identified based on a composite measure derived from three cognitive tests including the Consortium to Establish a Registry for Alzheimer's Disease (CERAD), the Animal Fluency test, and the Digit Symbol Substitution test (DSST). Logistic regression models were used to evaluate the association.

Results A total of 2588 participants aged 60 years or older were included, with an average age of 69.4 years and 48% being male. In the fully adjusted model, compared to no PA, performing 300 min of PA, and MPA were associated with 44%, and 33% reductions in the prevalence of p-MCI, respectively. Additionally, engaging in 1–149 min/week [OR 0.56, 95% CI (0.33–0.92)] and ≥ 300 min/week [OR 0.66, 95% CI (0.44–0.96)] of OPA, as well as ≥ 300 min/week [OR 0.56, 95% CI (0.36–0.86)] of LTPA, were also associated with a lower prevalence of p-MCI. Additionally, engaging in a diverse range of PA had better outcomes.

Conclusions Our results suggested a positive association between higher levels of PA and enhanced cognitive performance. Different intensities and domains of PA have varying impacts on cognition. Future exploration, such as objectively measured PA and longitudinal studies were needed to validate our conclusion.

Keywords Physical activity, Cognitive performance, NHANES, Mild cognitive impairment

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Introduction

The twenty-first century is an era of an aging population. According to United Nations [1], currently, 12.3 percent of the world's population is aged 60 and older and is expected to rise to about 22 percent by 2050. Aging is often associated with a decline in cognitive abilities [2]. Cognition refers to the mental process of gaining knowledge and understanding through thought, experience, and the senses [3]. Cognitive decline among older adults is associated with various adverse outcomes. It can lead to reduced physical mobility, such as difficulty walking on uneven surfaces, poor balance, and an increased risk of falls as individuals may struggle with complex daily activities, and it can also lead to worse mental health outcomes such as an increased incidence of depression and anxiety [4–7]. Moreover, cognitive decline can significantly increase the risk of 30-day rehospitalization, is strongly associated with the incidence of frailty, and acts as a major contributor to mortality among the elderly [8–10]. The cost and care burdens can be quite substantial for families of individuals who experience cognitive impairment. On average, the paid costs for those who become cognitively impaired in the United States can exceed $280,000, and the value of unpaid care provided by families and friends is also significant [11].

Considering the significant health consequences and economic burden related to cognitive decline, effective interventions are of great importance. Physical activity (PA) has gained increasing attention recently, especially after the FINGER study demonstrated that multidomain interventions can prevent or slow down cognitive decline [12–14]. Existing literature has established a positive correlation between PA and improved cognition [15]. Therefore, current guidelines suggest engaging in at least 150–300 min of moderate-intensity activities (MPA) or 75–150 min of vigorous-intensity activities (VPA) per week, or an equivalent combination of both for gaining health consequences [16]. However, current recommendations and studies have some limitations. First, although PA guidelines recommend certain dosages for overall health improvements [16], the specific relationships between these recommended dosages and particular health outcomes have been investigated recently. For example, a study conducted by Fan et al. [17] using data from the National Health and Nutrition Examination Survey (NHANES) reported that any dosage of PA was linked to a lower risk of depressive symptoms. Similarly, another previous study [18] using data from the UK Biobank found that engaging in 150 to 300 min/week of MPA or more was significantly associated with decreased risk of all-cause mortality among hypertensive individuals. These findings suggest that PA dosage recommendations may vary depending on the specific condition. Given the high risk for cognitive decline among older adults, it is particularly important to clarify the relationship between the specific PA dosages and cognitive improvements in this population. Second, PA is a complex behavior that includes different intensities (i.e., moderate or vigorous) and domains [i.e., occupational PA (OPA), leisure-time PA (LTPA), and transportation-related PA (TPA)]. Significant differences exist between these intensities and domains, yet most current studies have primarily focused on total PA [19, 20], with limited research examining the impact of different PA domains. The results are inconsistent. For instance, a study from Norway [21] reported that a sustained engagement in occupations involving moderate to high levels of PA was associated with a higher risk of cognitive decline. In contrast, another study identified OPA as a protective factor against cognitive decline [22]. These mixed findings highlight the need for more research to clarify the specific effects of different types of PA on cognition.

Therefore, we aimed to investigate the association of cognitive performance with overall, dosage, intensity (MPA, and VPA), and domain PA (OPA, TPA, and LTPA) in aging.

Methods

Participants

This cross-sectional analysis used data from 2 cycles of NHANES (2011–2012, 2013–2014). The NHANES was conducted by the Centers for Disease Control and Prevention (CDC) in the United States, collecting information from participants on topics including health, demographics, socioeconomic status, and dietary patterns. A complex, multistage stratified cluster sampling method was used in NHANES to ensure a representative sample of the civilian, noninstitutionalized U.S. population. All study protocols were approved by the National Centers for Health Statistics Ethics Review Board, and all participants provided written informed consent (https://www.cdc.gov/nchs/nhanes/irba98.htm).

Measures

PA

Participants self-reported their PA using the Global Physical Activity Questionnaire (GPAQ) [23]. The GPAQ assessed three PA domains (i.e., occupational, transportation, and leisure-time PA), along with their intensity (vigorous or moderate). OPA is work-related activities such as household chores, and harvesting food. Transportation activities including walking and bicycling are regarded as TPA. LTPA involves sports, fitness, and recreational activities. Participants reported both vigorous and moderate PA done during work (OPA) and in their leisure time (LTPA) in a typical week. VPA requires hard physical effort, resulting in significantly elevated breathing or heart rate, and MPA would cause a slight increase in breathing or heart rate.

Based on participants' self-reported data, we calculated both moderate occupational PA (MOPA) and vigorous occupational PA (VOPA) weekly. Following NHANES guidelines, we doubled VOPA to convert it into MOPA equivalents, thus deriving the total OPA [24]. The same approach generated calculations for moderate leisure-time PA (MLTPA), vigorous leisure-time PA (VLTPA), and total leisure-time PA (LTPA). We calculated the total MPA by summing MOPA, MLTPA, and TPA. Similarly, total VPA was determined by adding together VOPA and VLTPA. PA was the sum of MPA, and VPA. According to the 2018 PA guidelines [16], which recommend a minimum of 150–300 min per week of moderate-intensity or 75–150 min of vigorous-intensity activities, or an equivalent combination of both. All variables related to moderate-intensity PA, including total PA, total MPA, OPA, MOPA, LTPA, MLTPA, and TPA, were further categorized into four groups: 0 min/week, 1–149 min/week, 150–299 min/week, and ≥ 300 min/week. Similarly, variables related to vigorous-intensity PA, such as total VPA, VOPA, and VLTPA, were divided into 0 min/week, 1–74 min/week, 75–149 min/week, and ≥ 150 min/week [17, 25]. Using the calculated MOPA, VOPA, MLTPA, VLTPA, and TPA, we determined the number of activity types for which each participant met the recommended levels. Participants were then categorized into groups based on achieving the recommended levels in 1, 2, or ≥ 3 types of PA. This categorization enabled us to investigate more effective combinations of PA.

Cognitive tests

Cognitive function in NHANES participants was evaluated using three tests: the word learning and recall modules from the Consortium to Establish a Registry for Alzheimer's Disease (CERAD), the Animal Fluency test, and the Digit Symbol Substitution test (DSST). To represent each participant's overall cognitive performance, we summed, standardized and normed individual test scores. Psychometric mild cognitive impairment (p-MCI) was defined as having total composite scores that are less than 1 SD below the mean to reflect the clinical significance of cognitive tests [26].

Covariates

Covariates considered include sociodemographic characteristics: sex, age (60–69 years, 70–79 years, and 80 + years), race (Mexican American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black, Non-Hispanic Asian and Other race), education (less than 9th grade, 9-11th grade, high school graduate, some college or associate of arts degree, and college graduate or above), marital (yes or no), family income to poverty ratios (< 1, 1–1.99, 2–3.99, and ≥ 4), and occupation (yes or no). In addition, lifestyle variables [smoking status, Alcohol intake, and body mass index (BMI)] are also included in covariates. Individuals who have smoked fewer than 100 cigarettes in their lifetime are defined as "Never smokers", those who have smoked 100 or more cigarettes in their lifetime but currently do not smoke are defined as "Former smokers", and the rest are classified as "Current smokers" [27]. Alcohol intake is categorized into "Non-drinker", "1 to < 5 drinks/month", "5 to < 10 drinks/month", and "10 + drinks/month" [28]. Given that clinical characteristics are associated with PA and cognitive function, medical conditions including diabetes, hypertension, heart disease (i.e., congestive heart failure, coronary heart disease, angina, and heart attack), stroke, respiratory disease (i.e., asthma, emphysema, and chronic bronchitis), and cancer are also considered.

Statistical analysis

Categorical variables are presented as frequency (%). After dividing participants into not p-MCI and p-MCI, participants' characteristics were compared using Chi-squared test. Logistic regression models were used to evaluate the association between overall, intensity, and domain PA and the risk of p-MCI (yes or no). Four models were used in all analyses. Model 1 was an unadjusted model. Model 2 was adjusted for age and sex. Model 3 included the model 2 variables plus race, education, marital, PIR, smoking, alcohol, BMI, and occupation. Model 4 included the model 3 variables plus diabetes, hypertension, stroke, heart disease, respiratory disease, and cancer. Model 5 was introduced to examine the dependency relationship of cognitive benefits between intensities of PA (i.e., MPA, and VPA), and domains of PA (i.e., OPA, TPA, LTPA). More specific types of PA (i.e., MLTPA, VLTPA, MOPA, VOPA) were not explored in Model 5 due to the limited sample size. Additionally, to explore the dose–response relationship between PA and cognition, a trend analysis was conducted using PA as an ordinal variable. Adjusted odds ratios (ORs) and their 95% confidence intervals (CIs) were calculated to assess the relationship between each PA category and the presence of p-MCI. All data manipulations, analyses, and visualizations were performed using R (version 4.3.1) and R Studio (version 2023.12.0.369). A two-sided $p < 0.05$ was considered statistically significant.

Results

Characteristics of Participants

A total of 19,931 participants participated in the NHANES during 2011–2014. Our study included 2588 participants after exclusions (Fig. 1). Table 1 shows the sociodemographic, lifestyle, and clinical characteristics of the study population, categorized by the presence of p-MCI, which was identified in 436 participants. Study participants were primarily 60–69 years (55%), female (52%), non-Hispanic white (49%), having some college or associate of arts degree (29%), and married (55%). 49% of participants were never smokers, and the most common alcohol consumption category was 1 to < 5 drinks per month (48%). Clinically, hypertension was reported by more than half of the participants. 37% and 35% of participants reached the recommended PA and TPA, respectively, while only 18% of participants reached the recommended LTPA.

Association between overall, intensity PA and cognitive performance

Figure 2 illustrates the findings from our logistic regression analysis, adjusted for all considered potential confounders, to evaluate the association between the levels of overall PA, MPA, and VPA with the presence of p-MCI. In model 4 (detailed in supplementary files), the analysis revealed that participants engaging in higher levels of PA (≥ 300 min/week) had a lower risk of p-MCI compared to those with lower PA levels (1–74 min/week, and 75–149 min/week). The analysis indicated a dose–response relationship for both overall PA [OR(CI) 0.79 (0.56–1.12) vs. 0.77 (0.51–1.15) vs. 0.56 (0.40–0.76)] and MPA [OR(CI) 0.85 (0.60–1.19) vs. 0.68 (0.45–1.01) vs. 0.63 (0.45–0.86)]. Specifically, participating in 300 min of PA and MPA weekly was associated with 44% reduction and 37% reduction in the prevalence of p-MCI, respectively. Performing VPA at 300 min/week was associated with a lower risk of p-MCI [OR 0.54, 95% CI (0.32–0.89)]. In model 5 (shown in Fig. 2), VPA was included as a confounder in the analysis of the association between MPA and cognition. While minor changes were observed, these changes did not affect the significance of the results [OR 0.67 95% CI (0.48–0.93)]. Conversely, when MPA was introduced as a confounder in the analysis of the association between VPA and cognition, the cognitive benefits of VPA became non-significant [OR 0.62, 95% CI (0.36–1.03)].

Association between domain PA and cognitive performance

Table 2 presents the associations between OPA, LTPA, TPA, and the number of types meeting recommended activity levels with the prevalence of p-MCI across four different models. The findings across these models remained consistent, suggesting stable associations. In model 4, adjusted for all considered confounders, indicated that compared to individuals with no PA, those engaging in 1–149 min/week [OR 0.56, 95% CI (0.33–0.91)] and ≥ 300 min/week [OR 0.63, 95% CI (0.42–0.91)] of OPA, as well as ≥ 300 min/week [OR 0.54, 95% CI (0.35–0.81)] of LTPA, were associated with a lower prevalence of p-MCI. Model 5 was also introduced to

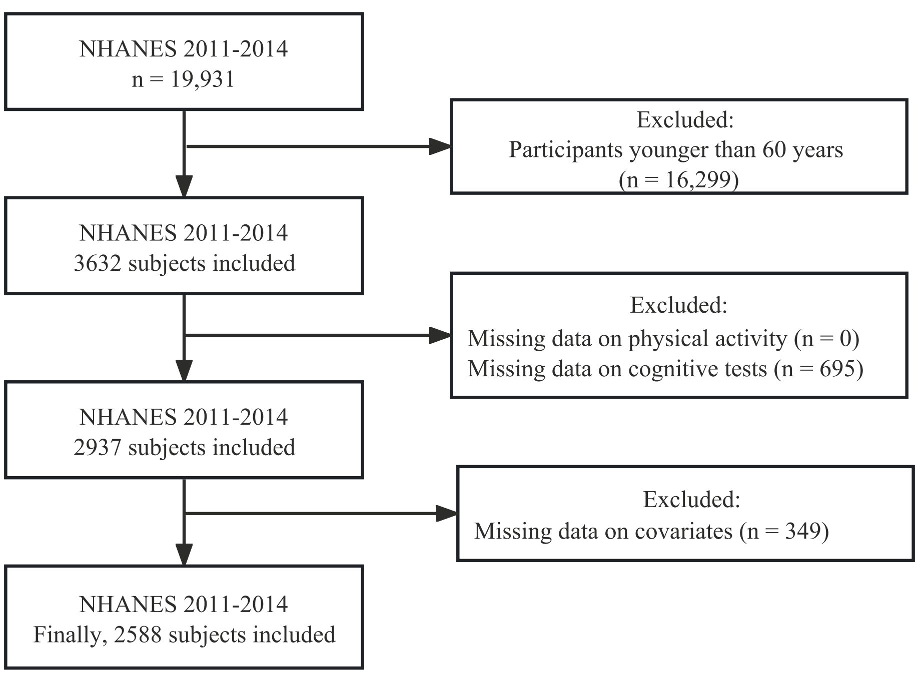

Fig. 1 Flow diagram of the included survey participants

Table 1 Sample characteristics (adults aged ≥ 60 years): NHANES, 2011–2014

	All (*N* = 2,588[a])	**Not p-MCI** (*N* = 2,152[a])	**p-MCI** (*N* = 436[a])	P^b
Sex				0.011
Male	1,251 (48%)	1,016 (47%)	235 (54%)	
Female	1,337 (52%)	1,136 (53%)	201 (46%)	
Ages				< 0.001
60–69 years	1,414 (55%)	1,259 (59%)	155 (36%)	
70–79 years	765 (30%)	605 (28%)	160 (37%)	
80 + years	409 (16%)	288 (13%)	121 (28%)	
Race				< 0.001
Mexican American	219 (8.5%)	164 (7.6%)	55 (13%)	
Other Hispanic	257 (9.9%)	178 (8.3%)	79 (18%)	
Non-Hispanic White	1,271 (49%)	1,139 (53%)	132 (30%)	
Non-Hispanic Black	605 (23%)	468 (22%)	137 (31%)	
Non-Hispanic Asian	199 (7.7%)	170 (7.9%)	29 (6.7%)	
Other Race	37 (1.4%)	33 (1.5%)	4 (0.9%)	
Education				< 0.001
Less than 9th grade	271 (10%)	109 (5.1%)	162 (37%)	
9-11th grade (Include 12th grade with no diploma)	351 (14%)	262 (12%)	89 (20%)	
High school graduate/GED or equivalent	602 (23%)	508 (24%)	94 (22%)	
Some college or AA degree	754 (29%)	695 (32%)	59 (14%)	
College graduate or above	610 (24%)	578 (27%)	32 (7.3%)	
Marital				< 0.001
Married	1,428 (55%)	1,233 (57%)	195 (45%)	
Other	1,160 (45%)	919 (43%)	241 (55%)	
PIR				< 0.001
< 1 (lowest income)	432 (17%)	290 (13%)	142 (33%)	
1–1.99	777 (30%)	604 (28%)	173 (40%)	
2–3.99	688 (27%)	617 (29%)	71 (16%)	
≥ 4 (highest income)	691 (27%)	641 (30%)	50 (11%)	
Occupation				< 0.001
Yes	674 (26%)	613 (28%)	61 (14%)	
Other	1,914 (74%)	1,539 (72%)	375 (86%)	
Smoking status				0.4
Never smoker	1,268 (49%)	1,057 (49%)	211 (48%)	
Former smoker	996 (38%)	834 (39%)	162 (37%)	
Current smoker	324 (13%)	261 (12%)	63 (14%)	
Alcohol intake				< 0.001
Non-drinker	811 (31%)	642 (30%)	169 (39%)	
1 to < 5 drinks/month	1,253 (48%)	1,035 (48%)	218 (50%)	
5 to < 10 drinks/month	112 (4.3%)	101 (4.7%)	11 (2.5%)	
10 + drinks/month	412 (16%)	374 (17%)	38 (8.7%)	
BMI				0.13
Underweight (< 18.5)	36 (1.4%)	26 (1.2%)	10 (2.3%)	
Normal (18.5 to < 25)	651 (25%)	530 (25%)	121 (28%)	
Overweight (25 to < 30)	909 (35%)	767 (36%)	142 (33%)	
Obese (30 or greater)	992 (38%)	829 (39%)	163 (37%)	
Self-reported comorbidities				
Diabetes: yes	608 (23%)	462 (21%)	146 (33%)	< 0.001
Hypertension: yes	1,622 (63%)	1,309 (61%)	313 (72%)	< 0.001

Table 1 (continued)

	All (*N* = 2,588[a])	Not p-MCI (*N* = 2,152[a])	p-MCI (*N* = 436[a])	*P*[b]
Heart disease: yes	449 (17%)	350 (16%)	99 (23%)	0.001
Stroke: yes	176 (6.8%)	119 (5.5%)	57 (13%)	< 0.001
Respiratory disease	508 (20%)	428 (20%)	80 (18%)	0.5
Cancer	525 (20%)	459 (21%)	66 (15%)	0.003
PA: achieved recommendation[c]	946 (37%)	846 (39%)	100 (23%)	< 0.001
OPA: achieved recommendation[c]	455 (18%)	411 (19%)	44 (10%)	< 0.001
TPA: achieved recommendation[c]	189 (35%)	159 (35%)	30 (35%)	> 0.9
LTPA: achieved recommendation[c]	415 (16%)	378 (18%)	37 (8.5%)	< 0.001

Abbreviations: *GED* general educational development, *AA* Associate of Arts, *PIR* Family income to poverty ratios, *BMI* Body mass index, *PA* Physical activity, *OPA* Occupational physical activity, *TPA* Transportational physical activity, *LTPA* Leisure-time physical activity

[a] n (%)

[b] Pearson's Chi-squared test

[c] Achieved the PA recommendation (≥ 150 min/week of moderate activity)

Name	Event/N (%)	OR (95% CI)	*P* -value	*P* for trend
PA				**<0.001**
0 min/week	209/885 (23.62)	1 (Ref)	-	
1-149 min/week	74/437 (16.93)	0.79 (0.56, 1.12)	0.20	
150-299 min/week	53/320 (16.56)	0.77 (0.51, 1.15)	0.20	
≥300 min/week	100/946 (10.57)	0.56 (0.40, 0.76)	<0.001	
MPA				**0.012**
0 min/week	215/952 (22.58)	1 (Ref)	-	
1-149 min/week	77/490 (15.71)	0.84 (0.60, 1.19)	0.30	
150-299 min/week	51/366 (13.93)	0.69 (0.46, 1.04)	0.08	
≥300 min/week	93/780 (11.92)	0.67 (0.48, 0.93)	0.02	
VPA				0.826
0 min/week	402/2101 (19.13)	1 (Ref)	-	
1-74 min/week	5/87 (5.75)	0.40 (0.13, 0.98)	0.07	
75-149 min/week	7/83 (8.43)	1.32 (0.50, 3.01)	0.50	
≥150 min/week	22/317 (6.94)	0.62 (0.36, 1.03)	0.08	

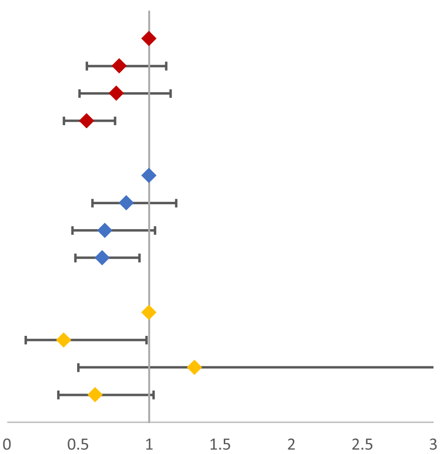

Fig. 2 Multivariable OR for p-MCI based on the dosage of PA. PA: physical activity; OR: odds ratio; CI: confidence interval. All ORs were adjusted for age, sex, race, education, marital, PIR, smoking, alcohol, BMI, occupation, diabetes, hypertension, stroke, heart disease, respiratory disease, cancer and MPA or VPA

explore the dependency relationship between different domains of PA. In this model, each PA domain was treated as a confounder for the others, and the results showed no significant changes. The trend analysis demonstrated a dose–response relationship between LTPA and cognition ($P = 0.026$). However, TPA did not show a statistically significant association with p-MCI prevalence. In addition, model 4 revealed a dose–response relationship, showing a significant reduction in p-MCI prevalence among individuals who met recommended activity levels in at least three types of activities [OR(CI) 0.73 (0.55–0.98) vs. 0.71 (0.44–1.13) vs. 0.42 (0.17–0.89)], compared to those not meeting any recommendations.

Association between various PA types and cognitive performance

The detailed associations between various PA types and cognitive performance across four models were presented in supplementary files. In addition to the associations between intensity, domain PA, and cognition mentioned in previous sections. We further examined the association between activity levels in various types (MOPA, VOPA, MLTPA, and VLTPA) and p-MCI prevalence. In model 4, no statistically significant associations were observed between specific types of PA and p-MCI prevalence, except for MLTPA. Individuals engaging in 300 min/week of MLTPA experienced a 40% reduction in the prevalence of MCI. A

Table 2 Multivariable OR for p-MCI based on the dosage of PA

			Model 1			Model 2			Model 3			Model 4			Model 5			
		Event/N (%)	**OR**	**95% CI**	***p*-value**	**OR**	**95% CI**	***p*-value**	**OR**	**95% CI**	***p*-value**	**OR**	**95%CI**	***p*-value**	**OR**	**95%CI**	***p*-value**	***P* for trend**
OPA	0 min/week	357/1791 (19.93)	1	Referent		1	Referent		1	Referent		1	Referent		1	Referent		0.111
	1–149 min/week	25/234 (10.68)	**0.48**	**0.31, 0.73**	**< 0.001**	**0.47**	**0.30, 0.71**	**< 0.001**	**0.58**	**0.34, 0.93**	**0.028**	**0.56**	**0.33, 0.91**	**0.024**	**0.56**	**0.33, 0.92**	**0.026**	
	150–299 min/week	10/108 (9.26)	**0.41**	**0.20, 0.76**	**0.008**	**0.42**	**0.20, 0.78**	**0.011**	0.51	0.22, 1.08	0.1	0.57	0.24, 1.21	0.2	0.59	0.25, 1.24	0.2	
	≥ 300 min/week	44/455 (9.67)	**0.43**	**0.30, 0.59**	**< 0.001**	**0.48**	**0.34, 0.66**	**< 0.001**	**0.59**	**0.40, 0.87**	**0.008**	**0.63**	**0.42, 0.91**	**0.018**	**0.66**	**0.44, 0.96**	**0.035**	
LTPA	0 min/week	305/1470 (20.75)	1	Referent		1	Referent		1	Referent		1	Referent		1	Referent		**0.026**
	1–149 min/week	54/405 (13.33)	**0.59**	**0.43, 0.80**	**<0.001**	**0.62**	**0.45, 0.84**	**0.003**	0.79	0.54, 1.13	0.2	0.79	0.54, 1.13	0.2	0.79	0.54, 1.14	0.2	
	150–299 min/week	40/298 (13.42)	**0.59**	**0.41, 0.84**	**0.004**	**0.61**	**0.42, 0.86**	**0.007**	0.87	0.56, 1.33	0.5	0.88	0.56, 1.35	0.6	0.91	0.58, 1.40	0.7	
	≥ 300 min/week	37/415 (8.92)	**0.37**	**0.26, 0.53**	**< 0.001**	**0.37**	**0.25, 0.53**	**< 0.001**	**0.54**	**0.35, 0.81**	**0.004**	**0.54**	**0.35, 0.81**	**0.004**	**0.56**	**0.36, 0.86**	**0.009**	
TPA	0 min/week	350/2053 (17.05)	1	Referent		1	Referent		1	Referent		1	Referent		1	Referent		0.713
	1–149 min/week	37/218 (16.97)	1	0.68, 1.43	> 0.9	1.09	0.74, 1.58	0.7	0.88	0.56, 1.36	0.6	0.93	0.59, 1.44	0.7	0.96	0.61, 1.49	0.9	
	150–299 min/week	19/128 (14.84)	0.85	0.50, 1.37	0.5	0.98	0.57, 1.60	> 0.9	0.93	0.50, 1.65	0.8	0.97	0.52, 1.72	> 0.9	1.01	0.54, 1.81	> 0.9	
	≥ 300 min/week	30/189 (15.87)	0.92	0.60, 1.36	0.7	1.07	0.69, 1.61	0.7	0.76	0.45, 1.25	0.3	0.81	0.48, 1.34	0.4	0.88	0.51, 1.47	0.6	
Number	0	289/1384 (20.88)	1	Referent		1	Referent		1	Referent		1	Referent					**0.037**
	1	111/769 (14.43)	**0.64**	**0.50, 0.81**	**< 0.001**	**0.67**	**0.51, 0.86**	**0.002**	**0.7**	**0.52, 0.93**	**0.015**	**0.73**	**0.55, 0.98**	**0.039**				
	2	28/298 (9.40)	**0.39**	**0.26, 0.58**	**< 0.001**	**0.49**	**0.31, 0.74**	**0.001**	0.68	0.41, 1.07	0.11	0.71	0.44, 1.13	0.2				
	≥ 3	8/132 (6.06)	**0.24**	**0.11, 0.47**	**< 0.001**	**0.33**	**0.14, 0.66**	**0.004**	**0.41**	**0.17, 0.86**	**0.029**	**0.42**	**0.17, 0.89**	**0.035**				

Model 1 was the crude model

Model 2 controlled for age and sex

Model 3 included the model 2 variables plus race, education, marital, PIR, smoking, alcohol, BMI and occupation

Model 4 included the model 3 variables plus diabetes, hypertension, stroke, heart disease, respiratory disease and cancer

Model 5 included the model 4 variables plus OPA, LTPA, or TPA

PA Physical activity, *OPA* Occupational physical activity, *LTPA* Leisure-time physical activity, *TPA* Transportational physical activity, *Number* The number of different types of PA that meet the 2018 PA guidelines, *OR* Odds ratio, *CI* Confidence interval dose–response relationship was also identified, as indicated by the P for trend analysis ($P=0.031$).

Discussion

Main findings

In this cross-sectional study using data from the nationally representative NHANES survey, we had four main findings. First, we observed dose–response associations between PA and MPA with the prevalence p-MCI, suggesting that PA may be a modifiable factor influencing cognitive health. Second, engaging in at least 300 min/week of PA, and MPA was significantly associated with a lower prevalence of p-MCI. Third, higher levels of OPA and LTPA, but not TPA, were associated with better cognitive performance. Fourth, meeting the recommended activity levels in at least three different types of physical activities was notably associated with enhanced cognitive performance, suggesting a beneficial impact of diverse PA on cognitive health.

Interpretation of results

Association between overall, intensity PA and cognitive performance

The relationship between PA and cognitive function has been explored in several previous studies. Hamer, M. et al. [19] examined the association in the English Longitudinal Study of Ageing, finding that PA was associated with the preservation of cognitive function. Similarly, Wang et al. [20], using NHANES data, observed that high levels of PA were inversely associated with the incidence of cognitive impairment, corresponding to a 20% reduction in risk. In a cross-sectional study [29] with a sample size of 31,464 participants in India, it was found that frequently physically active older men and women had increases in cognitive function scores by 0.98 and 1.32 points, respectively, compared to less active older adults. These results were consistent with our findings.

The potential mechanisms by which PA enhances cognitive performance are as follows. Firstly, regular PA would increase cerebral blood flow by decreasing blood pressure, reducing plasma levels of low-density lipoproteins, inhibiting platelet aggregability, activating the brain, or enhancing cerebral metabolic demands [30]. Secondly, the neuroprotective effects of PA may be attributed to its role in enhancing the release of brain-derived neurotrophic factors (BDNF), which are crucial for brain health [31, 32]. Thirdly, PA may also exert an indirect effect on other modifiable factors related to cognitive function, including depression, and diabetes [33, 34]. Lastly, PA may decrease brain atrophy through higher levels of aerobic fitness and induce functional network changes [35, 36].

According to the 2018 PA guidelines [16], at least 150–300 min/week of MPA, or 75–150 min/week of VPA, or an equivalent combination of both was required for substantial health benefits. In addition, the guidelines suggest that engaging in PA beyond the equivalent of 300 min/week of MPA may offer additional health benefits. In our study, individuals who engage in more than 300 min/week of either PA or MPA showed a lower risk of developing p-MCI compared to those who did not engage in any intensity of PA. Another important finding in this result section is that in model 5, after introducing MPA as a confounder in the analysis of the relationship between VPA and cognition, the cognitive benefits of VPA became non-significant. The reason was that MPA and VPA were not independent of each other.

Association between domain PA and cognitive performance

Several studies have investigated the association between domain-specific PA and cognitive function. A French randomized controlled trial [37] explored the relationship between LTPA, housework PA, and gardening PA with cognitive performance, finding that higher levels of LTPA were associated with better function. Similarly, a meta-analysis of 93 original studies also observed that LTPA was positively associated with mental health [38]. These findings were in agreement with our results, revealing that engaging in LTPA for at least 300 min/week was significantly associated with a reduced risk of developing p-MCI. Possible explanations for this phenomenon were as follows. The 2020 Lancet Commission identified social isolation in older adults as one of the risk factors for dementia [39]. In our study, LTPA, defined as activities involving sports and fitness includes sports such as basketball or football that require social interaction with others, thereby improving cognitive performance [40, 41]. Additionally, individuals who had higher cognitive function tended to choose LTPA because they knew the importance of PA in promoting health [38]. Apart from that, previous studies [42, 43] showed that compared with PA with no choice, PA involving choice such as LTPA was connected to enjoyment and satisfaction, which were positively correlated with cognitive function [44].

Individuals engaging in 1–149 min/week and ≥ 300 min/week of OPA were more likely to experience improved cognitive performance in our study. The reason why the cognitive benefits of 150–299 min/week was not detected might be the limited sample size ($N=108$) along with a large number of confounders. OPA refers to the time people spend doing work, which includes physical exertion alongside added mental demands. Higher mental demands in the workplace were observed to have a longitudinal association with enhanced cognitive performance among the aging [45, 46], and this could be explained by the concept of cognitive reserve and use-it-or-lose-it-hypothesis. Cognitive reverse suggested that individuals with it were able to maintain cognitive function through compensatory approaches, thereby mitigating the adverse effects of dementia pathology on cognition [45, 47]. Furthermore, use-it-or-lose-it-hypothesis stated that keeping mentally active would help prevent age-related mental decline [48, 49]. The association between OPA and cognitive performance was proved in previous studies. A cross-sectional survey found that moderate to high levels of work-related PA were beneficial for enhancing cognitive function in older adults [22]. A study using data from the HUNT4 70+study concluded that working in a job with moderate or high PA regularly was connected to a higher risk of developing MCI [21]. TPA referred to walking or bicycling in our study, and it was categorized as MPA. Only TPA demonstrated no association with cognitive performance may be due to its simplicity [38].

The number of types of PA achieving the recommendation was also explored in our study, and we found that having more than or equal to three types of PA that met the recommendation is associated with a 58% reduction in the prevalence of MCI. This observation may indicate a positive correlation between a diverse range of PA and improved cognitive performance, a conclusion that aligned with findings from previous studies [50]. The evolutionary theory of adaptation may partly explain this phenomenon. It proposed that survival depended on the ability to adapt to new situations. In line with this, mental stimulation through exposure to enriched environments was also beneficial for the brain, thereby improving cognitive function [51, 52]. However, this conclusion should be treated with caution because, in our study, individuals meeting the recommendation in a greater variety of PA may be related to them engaging in more PA overall. Therefore, the amount of physical activity is an important confounder.

Future research directions

Based on our results and previous discussions, the following research directions are suggested. Firstly, due to the limited sample size and conflicting findings from previous studies, the specific relationship between the level of OPA and cognitive benefits has not been clarified remains unclear and warrants further investigation. Secondly, identifying the optimal PA strategies should be another direction as our evidence only suggest that a combination of various PA types is more beneficial. Thirdly, whether VPA should be recommended for older adults still lacks sufficient evidence, particularly given the low sample size in the study. Fourthly, the assessment of NHANES is performed in non-gerontologic settings as part of a global survey, which presents challenges for routine health assessments. The GPAQ is used for PA evaluation; however, it is not specifically designed for older adults, and recall bias may be more pronounced in this population. Therefore, there is a need to improve assessment tools for PA in older adults. Additionally, future studies should incorporate objectively assessed PA using wearable fitness trackers to ensure the accuracy of PA measurements. Cognitive assessment also requires professional staff due to their complexity, highlighting the need for sufficient training when assessing cognition in older populations. Lastly, more rigorous study designs, such as cohort studies and Mendelian randomization, are needed to validate our findings and provide stronger causal evidence.

Clinical implications

In this section, we outline specific recommendations for clinical practice to assist healthcare professionals in integrating evidence into their routine care. The implications are categorized into immediate clinical implications and typical multidimensional geriatric management implications.

Immediate clinical implications

Regarding intensity PA, we summarized that traditionally, VPA is often considered less suitable for older adults. Therefore, engaging in more than 300 min/week of MPA may be a more appropriate and beneficial approach for improving cognition in older adults. Furthermore, regarding the clinical implications of domain PA, we concluded that participating in 300 min/week of LTPA, especially MLTPA, and OPA at any level, is recommended.

Typical multidimensional geriatric management implications

In the aging era, older adults face many health challenges such as chronic diseases, polypharmacy, and psychological health problems, influencing their quality of life [53]. Integrating PA into multidimensional geriatric management holds great promise due to its extensive benefits across physiological, psychological, and social domains, contributing to the overall health of older adults [54]. As discussed in previous section, PA enhances physiological health by increasing cerebral blood flow, boosting BDNF levels, and reducing brain atrophy. Moreover, LTPA supports psychological and social well-being by reducing social isolation, promoting social interaction, and providing older adults a sense of enjoyment and satisfaction. Additionally, Cognitive reserve and use-it-or-lose-it hypothesis mentioned in the OPA section further highlight the psychological benefits of PA. Enhancing older adults' adherence to PA and integrating it into their daily lives should be carefully considered.

Strengths and limitations

Our study has several strengths. We explored the relationship between cognitive performance and PA comprehensively, examining not only total PA but also the intensity and domain-specific aspects of PA. Given PA's complexity, clarifying the specific influences of different types of PA on cognition is crucial. We used data from 2 cycles of NHANES (2011–2012, 2013–2014), a representative survey of the civilian, noninstitutionalized U.S. population to ensure the generalization of our results. Apart from that, recognizing that cognitive function and PA were influenced by multiple factors, we employed different models to adjust for potential confounders (i.e., sociodemographic, lifestyle, and clinical factors) to reveal the real association between these variables, enhancing the study's internal validity and credibility. Lastly, NAHNES used three cognitive tests including CERAD, the Animal Fluency test, and the DSST to assess the cognitive performance of participants. We identified populations with p-MCI based on these assessment results, assigning clinical significance to the cognitive assessment results. However, there were some limitations in our study. Firstly, PA was assessed using GPAQ, which was self-reported by participants, and influenced by participants' subjective memories to underestimate or overestimate PA levels, thereby reducing accuracy. Secondly, owing to the cross-sectional study nature of NHANES, we only provided data at one point in time rather than capturing the stable levels or trajectories of PA, thereby finding the association between PA and cognitive performance rather than the causal relationship. Thirdly, we failed to explore the best PA strategy due to the relatively small sample size. Therefore, we only found that a wide variety of PA may be related to better cognitive performance. Additionally, the sample size of older adults engaging in VPA was limited, and the combination of a small sample size with a high number of confounding variables made the specific effects of VPA on cognition unclear. Similarly, this limitation also applies to OPA.

Conclusions

In conclusion, our results suggested a positive association between higher levels of PA and enhanced cognitive performance. Specifically, engaging in at least 300 min/week of MPA, LTPA, or OPA, as well as 1–149 min/week of OPA, and embracing a diverse range of PA, were all significantly correlated with improved cognitive function. Future exploration, such as objectively measured PA and longitudinal studies were needed to validate our conclusion.

Abbreviations

PA	Physical activity
OPA	Occupational physical activity
TPA	Transportational physical activity
LTPA	Leisure-time physical activity
MPA	Moderate physical activity
VPA	Vigorous physical activity
MOPA	Moderate occupational physical activity
VOPA	Vigorous occupational physical activity
MLTPA	Moderate leisure-time physical activity
VLTPA	Vigorous leisure-time physical activity
CERAD	The consortium to establish a registry for Alzheimer's disease
DSST	The digit symbol substitution test
p-MCI	Psychometric mild cognitive impairment
GED	General educational development
AA	Associate of arts
PIR	Family income to poverty ratios
BMI	Body mass index

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Authors' contributions
S-J.L. was responsible for Conceptualization, Methodology, Writing the original draft, as well as Reviewing and Editing the manuscript. H-M.M. contributed to Conceptualization, Methodology, and Data curation. A-Q.W. worked on Software, Data curation, and Formal Analysis. R-Y.P. was involved in Methodology, Software, and Data curation. X–Y.T. contributed to Reviewing and Editing the manuscript. G-N.L. focused on Conceptualization. Y.Z. handled Methodology, Formal Analysis, Supervision, and was involved in Reviewing and Editing the manuscript. M-H.P. was responsible for Conceptualization, Methodology, Formal Analysis, Supervision, as well as Reviewing and Editing the manuscript. All authors reviewed the manuscript.

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Data availability
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
The authors are consent for publication.

Competing interests
The authors declare no competing interests.

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