Relationships of Accelerometer-based Measured Objective Physical Activity and Sedentary Behaviour with Cognitive Function: A Comparative Cross-sectional Study of China's Elderly Population

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Abstract

This study aims to explore the effects of physical activity and sedentary behaviour on the decline of cognitive ability among the elderly. It uses objective measures to compensate for the limitations of self-reported physical activity. A cross-sectional survey of 308 people aged over 60 in Nanjing, China, was conducted. Physical activity was measured using the ActiGraph GT3X+, and cognitive function was measured using the Montreal Cognitive Assessment (MoCA). The overall participant model, adjusted for age, BMI, education, and monthly average income found that light physical activity (LPA; β=0.006, $p<0.01$), moderate-vigorous physical activity (MVPA; β=0.068, $p<0.001$), and total physical activity (β=0.006, $p<0.01$) had a significant linear relationship with cognitive ability, while sedentary time (SED) did not (β=-0.020, $p>0.05$). Further, LPA only affects the cognitive ability of elderly females (β=0.006, $p<0.05$). In addition, there was an inverted ‘U’ dose-response relationship between MVPA and cognitive ability. Dose-effect relationship models found that MVPA in the 22.13 min·day^{-1}~38.79 min·day^{-1} range affected cognitive ability most beneficially. The beta coefficient was higher than the other three groups (β=0.091, $p<0.05$). In conclusion, while physical activity can significantly improve cognitive ability among the elderly, sedentary behaviour has no significant effect on it.

1 Introduction

While an increasing aging population is a current global problem, it is particularly serious in China [1]. Age-related cognitive decline is associated with the loss of independence, the loss of quality of life, premature death, and higher healthcare costs [2]. Since the cognitive decline of the elderly is 0.04-0.05 standard deviations per year, it is more pronounced in patients with mild cognitive impairment, leading, in turn, to dementia [3]. It is estimated that the population of the elderly in China will reach 402 million in 2040, and the number of dementia cases will increase significantly, becoming one of the biggest health threats in the nation [4]. Therefore, reducing the burden of cognitive impairment and its sequelae in a rapidly aging population should be a priority for public health policy makers.

In recent years, evidence from epidemiological studies has shown that regular physical activity can improve cognitive function and reduce cognitive decline in the elderly as detected by the Montreal Cognitive Scale (MoCA) [5]. Cross-sectional research shows that LPA is significantly associated with the performance of cognitive functional assessments [6]. In addition, a cross-sectional study found a dose–response relationship between MVPA% and cognitive function in older adults, with higher levels associated with a 36% or lower risk of cognitive impairment [7]. Further, systematic reviews and meta-analyses of randomised clinical trials of exercise interventions in cognitively healthy older adults have found that exercise has a positive impact on executive function and memory capacity. Although some existing studies of physical exercise provide dose data related to cognitive differences, most of them are observational and rely on participants’ self-reported physical activity assessments, which may be affected by recall bias, cognitive ability, health status, and other factors, especially among older people. This is a limiting factor because cognitive function may affect an individual’s ability to accurately report their activity. Therefore, some scholars believe that the effectiveness of physical activity as a protective

measure to prevent cognitive decline in the elderly remains questionable [8]. Thus, to overcome the limitations of self-reported assessments, objective physical activity measurements are increasingly being used to estimate physical activity and sedentary time more accurately. Accelerometers are a useful tool in this regard, as they allow researchers to measure total physical activity, including LPA and MVPA, which are difficult to recall on self-report questionnaires. However, there are relatively few studies that use accelerometers to assess physical activity among the elderly [9].

In view of the above, this study of the elderly in China used a three-dimensional accelerometer to measure the amount of physical activity, then assessed cognitive ability via MoCA, and finally explored the relationship between physical activity and cognitive ability. It aims to deepen our understanding of the relation between good physical health and cognitive health in the context of aging. Further research is needed to understand the dose-response relationship between physical exercise and its health benefits among the elderly. The results of this study can thus be used to update exercise recommendations and exercise programs for older people with cognitive impairment.

2 Methods

2.1 Sample

This study was conducted in Nanjing, a national central city in eastern Jiangsu Province in China. In 2017, the population of Nanjing reached 8.335 million residents, of whom slightly more than one-fifth (20.850%) were over 60 years of age. The study was a cross-sectional survey. A random sampling method was used to extract 400 subjects (age 68.66, male 200) from Nanjing. The study was approved by the Human Body Committee of Nanjing Normal University and all participants provided written informed consent prior to inclusion in the study.

The inclusion criteria for participants were as follows: a) were over 60 years of age at the time of the survey; b) had been residing in the area for at least six months; and c) were able to communicate normally, so that vision, hearing, and mental state allowed them to complete the cognitive test for older people. Exclusion criteria were, a) severe speech, hearing, and visual impairment; and b) a diagnosis of Alzheimer's disease or mental illness such as severe depression or schizophrenia. The subjects' family members were informed and they provided consent as well. If a subject felt uncomfortable during the study, they could withdraw unconditionally at any time. In order to ensure the uniformity and representativeness of the sample distribution, the subjects were randomly selected from among the elderly aged 60-65 years, 66-70 years, 71-75 years, and 76-80 years, half of whom were male and the other half female. In all, 350 elderly people completed the survey; 42 questionnaires were eliminated as invalid, effectively retrieving 308 questionnaires, with an effective rate of 88.0% [10].

2.2 Measurement of physical activity

Physical activity estimates were gathered using an ActiGraph GT3X+, which provides valid assessment of walking, running, and daily activity through measurement of vertical accelerations or activity counts.

Participants wore the accelerometer at their right hip, during all waking hours except when showering or swimming, for seven consecutive days. They were instructed to return the device immediately after this period. We determined physical intensity using cut points previously developed for adults 60-69 years old. We utilised Miller and colleagues' physical intensity categories based on mean number of minutes of PA per day: SED at 0-100 counts per minute, LPA at 100-1951 counts per minute, and MVPA≥1952 counts per minute, respectively [11]. We defined non-wear time as at least 60 minutes of 0 activity counts. For a participant's accelerometer data to be considered valid for the analysis, at least eight hours of wear time must have been available for three or more of seven days [12]. We validated wear time utilising ActiLife 6 Version 5.5 and an algorithm developed by Troiano and colleagues [13]. Accelerometer PA variables were reported in mean daily minutes and in 10-minute bouts. We allowed for interruptions of 1 or 2 minutes below the threshold in the 10-minute bout. Objective PA variables included mean daily minutes of unbouted (a) SED, (b) LPA, (c) MVPA, and (d) Total physical activity.

2.3 Measurement of Cognitive function

Cognitive function was assessed using the MoCA (available at www.mocatest.org), a one-page 30-point test administered in 10 minutes, to screen for Mild Cognitive Impairment (MCI). It achieves this by assessing the subjects for short-term memory recall, visuospatial abilities, multiple aspects of executive functions, attention, concentration, working memory, language, and orientation to time and place. Each of these domains is evaluated for a certain number of points, with higher points indicating better cognition [14].

2.4 Statistical analysis

We conducted all analyses using SPSS Version 22.0. Multiple regression models were used to analyse the relationship between objective physical activity (SED, LPA, MVPA, and Total physical activity) and cognitive function of the elderly.

First, the demographic variables were described and statistically analysed. Data conforming to the normal distribution were expressed by the mean ± standard deviation (Mean ± SD), and the data that did not conform to the normal distribution were described by the interquartile range. Comparing the male and female groups, the normal distribution data were analysed by a t-test, and the non-normal distribution data by the Mann-Whitney test. Second, Spearman's correlation was used to analyse the correlation between physical activity and cognitive function. Finally, multiple linear regression was used to explore the relationship between physical activity and cognitive function among the elderly. Model 1 is a univariate model to investigate the relationship between SED, LPA, MVPA, and total physical activity, and cognitive function. Model 2 analyses the effects of SED, LPA, MVPA, and total physical activity on cognitive function with demographic factors as covariate.

3 Results

3.1 Demographic information of the subjects

Table 1 shows the demographic characteristics of the 308 respondents, as well as the measurements of SED, LPA, MVPA, and total activity. The average cognitive score was 24.39 (SD 3.03). The independent sample t-test found that the MVPA time of males was significantly higher than that of females ($p<0.05$), while there were no gender differences in SED time, LPA, total physical activity, and cognitive scores.

3.2 Physical activity and cognitive ability

This study used a linear regression model to analyse the relationship between physical activity and cognitive ability in the elderly. As can be seen from Table 2, for the overall participants, model 1, with $F=183.381$, $p<0.001$, can explain 64.4% of the cognitive variability of the elderly; after correction, it is still found that model 2 can explain 69.4% of the cognitive ability of the elderly. After controlling for confounding factors, LPA, MVPA, and total physical activity had significant effects on cognitive ability while SED did not. When the other factors were kept constant, the cognitive performance of the elderly increased by 0.06 points, 0.68 points, and 0.06 points for each 10 min/d increase in LPA, MVPA, and overall activity. Although LPA and overall activity can increase the cognitive scores, the effect is poor; MVPA time is better for improving cognitive ability. Therefore, it is recommended that the elderly regularly engage in MVPA to delay the decline in cognitive ability.

In the case of men, after controlling for confounding factors, Model 2 can account for 61.5% of the variation in cognitive ability. In the case of women, model 1 can account for 71.6% of cognitive variability in the elderly, and model 2 can account for 75.2% after controlling for covariates. For both male and female older adults, MVPA improves cognitive performance better than LPA and total physical activity.

3.3 Dose-effect relationship of MVPA on cognitive ability of the elderly

In order to further refine the relationship between improved cognitive ability and MVPA, the MVPA time data of all subjects was divided into four groups according to the interquartile range; the linear regression results are shown in Table 3. From model 1, we can see that there is a positive relationship between Q2, Q3, Q4 MVPA and cognitive ability of the elderly. The gender-corrected model 2, the adjusted gender, age, BMI model 3 and corrected gender, age, BMI, highest education and monthly average income models 4 were found to be significant. In addition, the study also found that in the four models, the β coefficient of MVPA on cognitive ability in the Q2 group (22.13 min·day^{-1}≤MVPA<38.79 min·day^{-1}) was greater than the other three groups; the Q1 group had no significant effect on cognition. The Q4 group had the lowest effect on improving cognitive ability in the elderly. It indicated that there was an inverted 'U' dose-effect relationship between MVPA and cognitive ability of the elderly. Therefore, MVPA in the range 22.13~38.79 minutes per day had the best effect on improving cognitive ability among the elderly.

4 Discussion

The advantage of this study is that it is based on data obtained by using an objective measurement tool, the ActiGraph GT3X+, rather than self-reported measurements. It uses this data to explore the relatively accurate dose-effect relationship between physical activity and cognitive ability among the elderly in

China’s aging society, and to find out the exercise-related gender differences in this population, providing better evidence to support cognitive improvement and prevention of neurodegenerative diseases. This cross-sectional study’s results show the following: First, physical activity has a positive relationship with cognitive ability, while sedentary time tends to lead to a decline in cognitive ability. Second, there are gender differences in the impact of physical activity on cognitive ability among the elderly. While MVPA and overall activity can improve the cognitive ability of elderly males, among elderly females, LPA, MVPA, and total activity can all promote the same. Finally, it was found that there was an inverted ‘U’ dose-effect relationship between MVPA and the cognitive ability of the elderly. MVPA of 22.13~38.79 minutes per day can appropriately improve the cognitive ability of the elderly. In order to delay cognitive decline in the elderly, interventions should be implemented to promote MVPA in the elderly.

The relationship between physical activity and cognitive ability has been studied previously [15]. A meta-analysis of a prospective cohort study showed that higher levels of physical activity can reduce the risk of dementia and Alzheimer’s disease by 28%-45% [16]. However, all 16 studies included used self-reported physical activity. Self-reported physical activity measurements are not only affected by factors such as memory and physical condition of the elderly, which makes the research results have certain deviations, it is also impossible to investigate the influence of LPA, MVPA, and SED on cognitive ability. Objectively measured data indicate that active elderly people are at a lower risk of cognitive impairment or dementia [17]; cross-sectional studies have found a positive correlation between total physical activity, and visual episodic memory and face name memory accuracy [18]. For the elderly, LPA is a major part of daily physical activity and a popular, relatively safe, and effective form of exercise.

Kerr and colleagues found no correlation between LPA and cognitive ability in the elderly in a cross-sectional study of 215 elderly people over 65 years of age [19]. However, Stubbs and other studies found a sharp contrast: 274 elderly people were selected as subjects, accelerometers were worn for seven consecutive days, and their cognitive abilities were assessed using the AD8 scale [20]. The results showed that LPA is an independent factor that has a unique protective effect on cognitive ability among the elderly. Another recent study also pointed out that LPA is associated with better cognitive ability in the elderly [21]. Therefore, any inconsistencies among studies may be due to differences in cognitive assessment methods, gender differences, and age differences in subjects.

The present study arrived at the result that overall, LPA has a significant impact on cognitive abilities in older adults. LPA confers benefits by preserving frontal, parietal, and temporal cortex grey matter volume and hippocampal volume in older adults. Larger hippocampi and higher fitness levels have been correlated with better spatial memory performance. Collectively, LPA appears to influence the brain in a manner that translates to preserving cognitive function [22].

However, it is worth noting that a stratified study of males and females revealed that there is a gender difference in the influence of physical activity on the cognitive ability of the elderly. While LPA is beneficial to the cognitive ability of elderly females, it has no effect on males. In addition, the study found that MVPA improved the cognitive ability of elderly women better than men. Thus, the association

between physical activity and cognitive abilities of the elderly may be regulated by gender. However, scholars at home and abroad rarely pay attention to the gender differences in the impact of physical activity on cognitive ability of the elderly. At present, the real cause of the gender difference in the impact of physical activity on cognitive ability is not known. How this effect works is beyond the scope of this study and requires further research.

Studies have indicated a higher MVPA%, a 39% reduction in the risk of cognitive impairment in adults, and a 47% reduction in memory and executive function decline; MVPA can significantly reduce the risk of cognitive decline in the elderly (RR=0.85, 95% CI:0.75-0.95) [23]. Another study showed that older adults with MPA and VPA had lower rates of cognitive impairment and performed better in memory and executive functions than LPA [24]. Consistent with the results of this study, MVPA is positively correlated with cognitive ability in the elderly. Higher MVPA can promote the maintenance of cognitive ability in the elderly; MVPA improves the cognitive function of the elderly better than LPA and overall activity. This may suggest that since the intensity of activity is likely to be a key factor in promoting the relationship between physical activity and cognitive ability, MVPA is more effective in maintaining cognitive ability in the elderly and should therefore be promoted among them. Although most studies have pointed out the positive effects of MVPA on cognitive abilities in the elderly, some differences have been found in Umegaki and other studies, and there is no significant correlation between MVPA and cognitive ability in the elderly [25]. These differences may be due to the choice of the study population, the measurement of physical activity and cognitive ability, and the limitations of the methodology.

Epidemiological studies have shown that there is a dose-effect relationship between physical activity and cognitive ability. Loprinzi et al. used self-reported physical activity to find that there is an inverted U-shaped relationship between physical activity and cognitive ability of the elderly [26]. It concluded that 6000~7999 MVPA MET-min-month may be the best physical activity range for improving cognitive ability. Through longitudinal studies of 6452 elderly people, Zhu et al. pointed out that there is a dose-effect relationship between objectively measured MVPA% and cognitive ability of the elderly. Higher levels of MVPA% are not only conducive to better maintaining the memory and execution function of the elderly, but can also reduce the risk of cognitive impairment among them. This study found that there is an inverted 'U' dose-response relationship between MVPA and cognitive ability in the elderly, consistent with Loprinzi's findings using subjective measures.

The non-linear relationship between physical activity and the cognitive abilities of the elderly is consistent with recent findings that assess the relationship between physical activity and cardiovascular disease biomarkers and mortality [27]. They observed that higher levels of physical activity did not result in greater survival benefits than less high levels of physical activity. Similarly, a meta-analysis by Kramer et al. suggests that long-term exercise is not as beneficial as moderate-length exercise in improving cognitive performance in older adults [28]. In the process of aging, there is also an inverted 'U' relationship between exercise and oxidative stress-related physiological functions and quality of life. Taken together, these findings suggest that there may be an optimal dose of physical activity to improve cognitive performance in the elderly. This study concluded that MVPA between 22.13 to 38.79 minutes per day had

the best effect on improving cognitive ability in the elderly. According to the WHO's global physical activity guidelines, the elderly need at least 150 minutes of MVPA per week for overall health, including cognitive ability. The results of this study support this recommended amount.

Physical activity may ameliorate the impact of aging on the cognitive abilities of the elderly through a variety of physiological mechanisms. First, physical activity can enhance neurological connectivity. Moreover, it has been confirmed in animal experiments that physical activity can mediate a positive effect on cognitive ability by promoting mechanisms such as nerve conduction, synapse formation, angiogenesis, and the release of neurotrophic factors [29]. Second, physical activity can enhance cerebral cortical plasticity, that is, physical activity may help balance the detrimental effects of aging and neurodegenerative diseases on neuroplasticity and function [30]. Third, LPA or general activity is associated with lower levels of the plasma inflammatory marker c-reactive protein (CRP), a hallmark of systemic inflammation, often associated with cognitive decline. The findings suggest that physical activity may be beneficial in reversing the negative consequences of systemic inflammation [31]. Finally, studies have pointed out that gait speed is related to cognitive ability [32]. Increasing habitual activity is associated with faster gait speed. More LPA and total physical activity may represent more habitual activities, and individuals involved in more habitual activities may have a faster gait speed and better cognitive ability, which may suggest that LPA and total physical activity are the link between activity and cognitive ability.

It is worth mentioning that our study found that 22.13 $min \cdot day^{-1} \leq MVPA < 38.79\ min \cdot day^{-1}$ improved the cognitive ability of the elderly better than 38.79 $min \cdot day^{-1} \leq MVPA < 65.43\ min \cdot day^{-1}$ and $MVPA \geq 65.43\ min \cdot day^{-1}$. It shows that for improving the cognitive ability of the elderly, the highest possible MVPA is not necessarily the best. Higher intensity physical activity can increase the body's oxidative stress and have a negative impact on brain function.

Therefore, according to the physical characteristics of the elderly, moderate and high-intensity physical activity should be appropriately arranged to improve cognitive ability. The physical activity of MVPA at doses of 22.13 to 38.79 minutes per day can be recommended to optimise the cognitive ability of the elderly. This conclusion is important for older people and health promotion professionals because it is not wise for older people to adopt the common ideology of 'more is better'.

There are some limitations in our design that should be noted. First, accelerometers cannot capture upper limb movements and thus may underestimate MVPA time; second, the cognitive ability assessment is of a single and cross-sectional design, therefore prospective and longitudinal experimental studies are needed in the future to further validate the causal relationship between physical activity and cognitive ability of the elderly; last, the relatively small sample size may also affect the outcome of sedentary behaviour, and future research should further expand the study area and the number of subjects in order to obtain more universal results.

Therefore, in conclusion, in order to delay cognitive decline among the elderly, policy makers should actively promote physical activities among them, especially MVPA, such as running, and square dancing. Even non-exercise, daily life activities such as walking, carrying loads such as while shopping, and using public transport systems, can improve the cognitive ability of the elderly. We thus recommend that public health researchers and officials should create a supportive environment for the elderly in public spaces, conducive to increased physical activity levels and thus improved cognitive ability among this population.

5 Conclusion

This study confirmed that physical activity can significantly improve the cognitive ability of the elderly. Further, the linear relationship between MVPA (22.13～38.79 min·day^{-1}) and cognitive ability among the elderly is better than between LPA and total physical activity. It, does, however, have a ‘U’ dose effect. Therefore, the optimal dose of MVPA could contribute to checking the decline of cognitive ability among the elderly.

Declarations

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to maintain participant privacy and confidentiality requirements but are available from the corresponding author on reasonable request

Author contributions

WZJ and WZY drafted the manuscript. WZJ, HBQ, ZXH, and WHL assisted with the data collection and participated in study coordination. ZF and LFH modified and approved the final version. All authors took part in research meetings concerning data analysis goals, strategies and challenges. All authors have read and approved the final manuscript as submitted.

Ethics approval and consent to participate

This study does not involve invasive interventions on the human body. It is only a questionnaire survey, so it was approved orally by the Humanities Research Ethics Committee of Nanjing Normal University. All participants read a statement that explained the purpose of the survey and provided written informed consent before participation in the study. For those not willing to take part in the study, their right was respected to withdraw from the study. The study did not adversely affect the rights and welfare of the subjects and no financial compensation or provision was made.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1 List of basic information of respondents (n = 308)

	Male (n = 131)	Female (n = 177)	Total (n = 308)	Sig.
Year	69.24 ± 5.20	68.23 ± 5.46	68.66 ± 5.37	0.100
BMI（kg/m2）	25.38 ± 2.87	26.72 ± 20.07	26.15 ± 15.33	0.452
BMI rating（%）				
normal	15.6	23.7	39.3	—
overweight	18.2	23.1	41.2	—
obesity	8.8	10.7	19.5	—
Highest level of education (%)				
Elementary school	3.6	8.4	12.0	—
Junior high school	14.9	23.1	38.0	—
Senior high school	13.3	22.4	35.7	—
University	10.7	3.6	14.3	—
Elementary school				
Average monthly income（%）				
Below ¥1000	5.1	5.5	10.7	—
¥1001-2000	2.3	8.1	10.4	—
¥2001 or more	35.0	43.8	78.9	—
SED ($min·day^{-1}$)	586.01 ± 129.58	594.26 ± 105.14	590.75 ± 116.03	0.539
LPA ($min·day^{-1}$)	161.32 ± 47.71	179.46 ± 61.54	171.74 ± 56.71	0.172
MVPA ($min·day^{-1}$)	50.00 ± 31.07	43.25 ± 31.41	46.12 ± 31.39	0.040
Total physical activity	211.32 ± 59.91	221.17 ± 49.13	216.98 ± 62.49	0.080
Cognitive ability	24.69 ± 2.74	24.18 ± 3.22	24.39 ± 3.03	0.133

Table 2 Results of linear regression analysis of the impact of physical activity on cognitive ability

	model		B	SE	Sig.	R^2
Total	1					0.644
		SED	-0.020	0.001	0.061	
		LPA	0.006	0.003	0.003	
		MVPA	0.068	0.004	0.000	
		Total physical activity	0.007	0.002	0.002	
	2					0.694
		SED	-0.020	0.010	0.065	
		LPA	0.006	0.002	0.003	
		MVPA	0.065	0.004	0.000	
		Total physical activity	0.006	0.002	0.002	
Male	1					0.545
		SED	-0.003	0.001	0.029	
		LPA	0.006	0.002	0.116	
		MVPA	0.053	0.007	0.000	
		Total physical activity	0.008	0.004	0.036	
	2					0.615
		SED	-0.002	0.001	0.121	
		LPA	0.004	0.003	0.184	
		MVPA	0.053	0.005	0.000	
		Total physical activity	0.008	0.004	0.034	
Female	1					0.716
		SED	0.000	0.001	0.930	
		LPA	0.006	0.003	0.025	
		MVPA	0.079	0.006	0.000	
		Total physical activity	0.006	0.003	0.039	
	2					0.752
		SED	-0.001	0.001	0.468	
		LPA	0.006	0.003	0.029	
		MVPA	0.074	0.005	0.000	
		Total physical activity	0.006	0.003	0.021	

Note: Model 1: Uncorrected; Model 2: Corrected age, BMI, highest education, monthly average income.

Table 3 β of MVPA impact on cognitive ability (95% CI)

Model	Q1	Q2	Q3	Q4
M1	0.057(-0.038,0.152)	0.100*(0.024,0.176)	0.091*(0.043,0.140)	0.032*(0.014,0.051)
M2	0.063(-0.033,0.159)	0.100*(0.024,0.177)	0.096*(0.046,0.146)	0.029*(0.012,0.047)
M3	0.090(0.000,0.179)	0.099*(0.023,0.175)	0.090*(0.040,0.141)	0.029*(0.011,0.046)
M4	0.089(0.000,0.176)	0.091*(0.009,0.172)	0.079*(0.036,0.122)	0.031*(0.014,0.048)

Note: *, $P < 0.05$; M1: uncorrected; M2: corrected gender; M3: corrected gender, age, BMI; M4: corrected gender, age, BMI, highest education, monthly average income. The mean quartile of MVPA time per day ($\min\cdot day^{-1}$): Q1: MVPA < 22.13; Q2: 22.13 ≤ MVPA < 38.79; Q3: 38.79 ≤ MVPA < 65.43; Q4: MVPA ≥ 65.43.