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Physical Activity and Cognitive Function in Middle and Late Adulthood – Results of a Preliminary Study[1]

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Abstract

Objective: The aim of the study was to characterise the physical activity (PA) of middle-aged and older adults and to determine whether the amount of PA was related to their level of cognitive function.

Methods: This was a cross-sectional study of 52 women and 30 men aged 50–80 years. Subtests of the Wechsler Intelligence Scales for Adults Revised Version – Renormalisation WAIS-R(PL) were used to assess cognitive function: Digit span, Block design and Digit symbol, as well as the Colour Trails Test (CTT) and the Link's cube task. Physical activity was measured using the International Physical Activity Questionnaire-Long Version (IPAQ-LF) and a pedometer worn by the volunteers for one week. Associations between cognitive function and PA were estimated using non-parametric correlations. In addition, cognitive function and PA were compared in healthy participants, participants with one chronic condition, and participants with two or more conditions.

Results: Walking, as measured by a pedometer, was at an average level in the study participants, and PA, as reported on the IPAQ-LF questionnaire, was very high. There were

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few associations between PA and cognitive performance. Moderate and vigorous levels of PA reported on the IPAQ-LF were correlated with more accurate performance on the Block design and Link's cube tasks. Higher levels of leisure time PA reported on the IPAQ-LF were correlated with better performance on the CTT. More PA at work was correlated with higher performance on most tasks. Activity measured by number of steps did not correlate with cognitive function. More steps correlated with less time spent inactive on the IPAQ-LF. In addition, healthier participants performed better on cognitive tasks and took more steps than those with chronic conditions.

Conclusion: The research has contributed to the understanding of the relationship between real-life PA and cognitive function in middle-aged and older adults, and has provided important insights into PA in these individuals.

Keywords: neuropsychology of cognitive ageing, physical activity, real-world environment

Physical activity (PA) is the movement of the body produced by muscles and the resulting energy expenditure, ranging from low to high and well above resting levels. The scope of PA includes sport, recreational exercise, and activities performed at work, during leisure time, and at home (Caspersen et al., 1985, after Biddle et al., 2021). According to the World Health Organisation (WHO, 2021), PA strengthens the body, increases physical performance and fitness, reduces all-cause mortality, lowers the incidence of hypertension, cancer and diabetes, and alleviates symptoms of anxiety and depression. It helps prevent falls in older people. Physical activity increases perceived well-being and life satisfaction, improves sleep, boosts energy. It helps maintain independence, improving memory, attention and problem-solving skills. Adults should get at least 150–300 minutes a week of moderate-intensity aerobic exercise, or at least 75–150 minutes of vigorous-intensity aerobic exercise, or a combination, and limit time spent inactive. More activity has additional health benefits. The most recent World Health Organization guidelines on PA and sedentary lifestyles state that "any amount of PA is beneficial for health, and more is better" (WHO, 2021, p. 1; Yoneda et al., 2021), thus emphasising the beneficial effects of engaging in PA as often as possible.

Studies worldwide show that people do not get enough PA. To increase it, individuals are encouraged to monitor their own daily activity through questionnaires that allow a subjective assessment of one's PA, and through wearable devices such as pedometers, smartwatches and phone apps that automatically and objectively measure PA (Macek et al., 2019; WHO, 2018). These methods facilitate both tracking PA and setting PA goals (Biddle et al., 2021; Husu et al., 2016). The most common form of leisure-time physical activity is walking (Tudor-Locke et al., 2011). Healthy adults take between 4,000 and 18,000 steps per day. At 100 steps per minute, walking meets the requirements for moderate-intensity PA (Tudor-Locke et al., 2011; WHO, 2021). Wearable devices have been shown to increase moderate- and vigorous-intensity PA in a range of clinical and non-clinical populations. On average, walking increased by 2000–2500 steps per day. These benefits were found to be lasting after 6 months (Hobbs et al., 2013;

Zubala et al., 2017). The effects of PA control on blood pressure, cholesterol levels, perceived quality of life, mood and well-being were found to be smaller (Ferguson et al., 2022).

The research findings on the association between PA and cognitive functioning in middle and older adulthood are quite mixed. This may be due, on the one hand, to age-related natural changes in musculoskeletal performance evident after 50 years of age and increasing after 70 years of age (e.g. as a result of a decrease in skeletal muscle mass i.e. sarcopenia) (Bowden Davies et al., 2019) and, on the other hand, to age-related natural, but heterogeneous, changes in cognitive performance associated with changes in central nervous system structure and function (Brito et al., 2023). Positive associations between the amount/frequency of PA performed and levels of cognitive function have been found in many, but not all, studies. There has been significantly more research on this topic in older people than in middle-aged people (Cox et al., 2016). Furthermore, studies of neurologically healthy people have had mixed results in comparison with clinical groups of people with probable or diagnosed dementia (Carvalho et al., 2014). Cross-sectional studies have shown that increased time spent in PA is often associated with improved measures of cognitive function, particularly executive function and episodic memory (Burzynska et al., 2020; Cox et al., 2016; Hayes et al., 2015; Umegaki et al., 2018), information processing speed (Cox et al., 2016), and visuospatial memory (Troisi Lopez et al., 2023). The beneficial effects of PA on cognitive function have been demonstrated in longitudinal studies (Carvalho et al., 2014; Yoneda et al., 2021; Zubala et al., 2017), in retrospective studies of PA at different stages of life (Szepietowska & Dąbal, 2023), and in exercise programmes aimed at increasing PA (Biddle et al., 2021; Zubala et al., 2017). A comprehensive review of the existing evidence concluded that consistent practice and increasing PA can improve performance on cognitive tasks. One possible explanation for this is that with age, cognitive performance may improve or decline more slowly in physically active people than in those with a sedentary lifestyle (Ciria et al., 2023). It has also been hypothesised that aerobic PA may prevent or delay the progression of dementia, including Alzheimer's disease (Carvalho et al., 2014; Kirk-Sanchez & McGough, 2014). On the other hand, a study of 334,227 adults in the UK Biobank found no association between PA participation and cognitive function after adjusting for prenatal factors such as genetic risk, early life factors such as childhood PA, education and traumatic events, socio-demographic factors (e.g. socioeconomic status, exposure to pollution), behaviours (e.g. diet, alcohol consumption, smoking) and diseases (e.g. cardiovascular disease, neurological disease, mental disorders) (Campbell & Cullen, 2023).

The physiological pathways by which PA affects the brain and cognitive function in adults have been investigated in numerous human and animal studies. Regular interval training has been shown to result in moderate increases in serum and plasma concentrations of brain-derived neurotrophic factor (BDNF). Intense interval training consists of a series of high-intensity bouts of exercise – at 90% of maximum heart rate – separated by periods of rest. Intervals put stress on the cardiovascular and nervous systems. Studies in rodents have implicated BDNF in synaptic plasticity, neuronal growth, neuronal survival and cognitive processes (García-Suárez et al., 2021). In addition, intense aerobic exercise can cause myelin expansion in humans. More physically active adults have been found to have a better myeloarchitectural profile than less active adults. This finding has important implications for the design of exercise and rehabilitation programmes (Kujawa et al., 2023). Longitudinal studies have also shown that vigorous aerobic exercise (such as fast walking, cycling or dancing) can induce myelination in the brain, whereas less intense aerobic exercise does not increase myelination in healthy people (Kujawa et al., 2023). Higher levels of PA and cardiorespiratory fitness have been found to be associated with improvements in global brain white matter volume (Maleki et al., 2022). Consistent with this, data from 3838 participants aged 18–90 years from eight cohorts of the European Lifebrain Consortium suggested that low levels of PA, in combination with other lifestyle factors such as obesity and high alcohol consumption, may be associated with reduced brain volume. Other important factors associated with smaller brain volumes were poor sleep, overweight, smoking and heavy alcohol consumption (Binnewies et al., 2023). Other meta-analyses have concluded that exercise contributes to a decrease in cardiovascular risk factors and is positively correlated with biomarkers of brain health and improved cognitive performance (Kirk-Sanchez & McGough, 2014). Recent research has examined the effects of PA on resting brain activity, functional organisation of the brain, memory and learning, and executive tasks of varying complexity (Juan et al., 2024).

With regard to Polish studies on PA in middle-aged and older adults, it was found that the majority of individuals choose PA in their leisure time. These are mainly moderate-intensity activities and walking (Biernat & Piątkowska, 2013). Research in Poland has revealed that the frequency of PA among older people is medium to low, and that moderate-intensity activities or walking predominate. Older men are more active than older women (Basińska-Zych & Kaiser, 2017; Krzepota et al., 2013; Skotnicka & Pieszko, 2014). For subjective activity assessment, the short form of the International Physical Activity Questionnaire (IPAQ) was used most often, and the long form of the IPAQ (IPAQ-LF) less often. Studies in Poland have also shown that people who are both physically, occupationally and socially active tend to have better cognitive function (Szepietowska, 2019; Szepietowska & Dąbal, 2023). People who are physically active are more likely to be cognitively normal than people with mild cognitive impairment (Makarewicz et al., 2021). Although walking is recommended for maintaining physical and general fitness (Witkowska & Grabara, 2021), no studies on the relationship between cognitive function in middle-aged and older people and walking were found in the Polish scientific literature. A study on dual-task cognitive-motor training (Wiśniowska et al., 2018, 2023) showed an improvement in performance after training in a group of older people.

The present study was therefore motivated by the limited evidence for a positive association between PA and cognitive function in adults, particularly middle-aged people, and especially in the domains of visuospatial and constructive functions. These domains have rarely been included in studies of PA and cognitive ageing. Another reason was the very limited number of Polish studies on this topic. The results described in this article are part of a larger cross-sectional study. The aim of the study was to characterise PA in middle and late adulthood and to test whether the frequency of PA is associated with visuospatial and constructional processes, short-term and working memory performance, speed of information processing, attention, visuomotor skills and executive functions. Based on previous studies, we hypothesised that individuals who engage more frequently in PA may have better cognitive outcomes, as reflected by higher scores on neuropsychological tests and tasks, than those who are less physically active.

Method

Study Participants

Eighty-two people in middle and late adulthood – 52 women and 30 men aged 50–80 years – participated in the study. Inclusion criteria comprised good health, no visual or hearing impairments, or those that are adequately corrected. Exclusion criteria were past or current mental and neurological illnesses such as Alzheimer's disease, Parkinson's disease, epilepsy, stroke, traumatic brain injury, meningitis, brain tumour, depression, schizophrenia, bipolar affective disorder, limitations preventing normal walking and hand use, untreated chronic illnesses, and inexperience with laptop use (the demographic and activity questionnaires were completed on a computer). This information was obtained in a telephone interview after the person had volunteered. During this interview, volunteers were informed that this was a non-clinical study and that they would not receive individual results.

Measuring Tools

The study used standardised psychological tests and experimental tasks for neuropsychological assessment. These were subtests of the Polish adaptation of the Wechsler Intelligence Scale: Digit span forward and Digit span backward to measure short-term and working memory, Block design to measure visual-spatial ability, constructional praxis, motor skill, problem-solving ability, and Digit symbol to assess working memory and speed of information processing (Brzeziński et al., 1996). The Colour Trails Test was used to evaluate attention, information processing, visuomotor skills and behavioural control (Łojek & Stańczak, 2012). The tests were administered using a standardised procedure. The Link's cube task was carried out in an experimental adaptation (Aleksandra Bala and Aleksander Zębrowski). This task was used to assess visuospatial, constructional and executive functions. A cube consisting of 27 blocks had to be assembled as quickly as possible so that only their outer painted surfaces were visible (Kopp et al., 2014). Performance time and errors were measured, i.e. the number of alignments of the block with the white wall to the centre of the cube and the number of alignments of the block with the wooden wall to the outside of the cube. After placing the cube, it was hidden and participants were tested on how well they remembered it. The questions were: how many blocks were in the cube without a white wall, how many blocks were in the cube with 3 white walls, how many blocks were in the cube with 2 white walls, how many blocks were in the cube with 1 white wall, and how many blocks were in the cube in total. Five correct answers were scored as 5 points. During the interview, participants provided information on age, education, occupation, marital status, chronic diseases, blood pressure, heart rate and smoking. They were also asked about their height and weight, which was used to calculate their stride length and body mass index (BMI).

The IPAQ-LF (Biernat, 2013) was used for the subjective assessment of PA. Each respondent was asked to rate the frequency and duration of moderate-to-vigorous physical activity in the past 7 days at work, while travelling by transport, while walking, while working at home and around the home (gardening/yard work), and during leisure activities. The last questions were about time spent in a sedentary position (i.e. without PA). IPAQ-LF questions on physical effort (i.e. PA intensity) in different life domains help assess total weekly energy expenditure and in each domain. It is possible to calculate the expenditure resulting from specific forms of activity, i.e. walking, moderate-intensity PA and vigorous-intensity PA (Biernat, 2013). The IPAQ-LF classifies respondents into one of three activity categories: low (less than 600 MET minutes/week), moderate (601–2999 MET minutes/week) or high (at least 3000 MET minutes/week). One MET (i.e. one metabolic equivalent) corresponds to the oxygen consumption of a 70 kg person at rest, which is 3.5 ml × min$^{(-1)}$ × kg$^{(-1)}$. Vigorous activities correspond to more MET units than moderate activities and walking.

To objectively measure PA, Onwalk 900 pedometers were used to measure steps, distance, calories burned, average speed and walking time for 7–8 consecutive days. Study participants were asked to follow a usual level of activity during this time.

Procedure

Volunteers were tested individually in two sessions at the Maria Grzegorzewska University in Warsaw. Between meetings, they were asked to wear a pedometer all day for 7 consecutive days. Before starting this part of the study, the participant's weight, height and step length were set on the pedometer. The step length was calculated by multiplying the height in centimeters by 0.413 for women and by multiplying the height in centimeters by 0.415 for men. The IPAQ-LF test was administered at the first visit, during which the volunteers estimated their PA from the week before the study. After the second session, they received a leaflet with the WHO recommendations for healthy PA, a bookstore voucher, and a pedometer. The study was approved by the Maria Grzegorzewska University Research Ethics Committee. It was conducted by five researchers during the spring and summer months between June 2021 and October 2022.

The study was carried out by a psychologist with a PhD in psychology, who was present at each examination, and by psychology students specialising in clinical psychology, who were trained in the research procedure.

Data Analysis

Percentages, means and standard deviations were used to report the demographic, health, neuropsychological and PA outcomes of the study group ($n = 82$) (Table 1a, Table 1b). Normality of variable distributions was assessed using the Shapiro-Wilk test. Associations between PA and cognitive performance and age were tested using non-parametric Spearman's rho correlations. The weekly number of steps and the weekly walking time in minutes were analysed from the pedometers. Metabolic equivalents of PA, i.e. MET minutes/week from the IPAQ-LF questionnaire, were calculated as follows: IPAQ-LF Total work activities MET-minutes/week = walking + moderate-intensity activities + vigorous-intensity activities MET-minutes/week at work; IPAQ-LF Total transportation activities MET-minutes/week = walking + cycling MET-minutes/week as mode of transport; IPAQ-LF Total domestic, garden/yard and family care activities MET-minutes/week = vigorous-intensity gardening/yard work + moderate-intensity gardening/yard work + moderate-intensity inside home chores MET-minutes/week; IPAQ-LF Total leisure-time activity MET-minutes/week = walking + moderate-intensity activities + vigorous-intensity activities in free time MET-minutes/week; IPAQ-LF Total walking MET-minutes/week = walking MET-minutes/week (at work + as mode of transport + at leisure); IPAQ-LF Total moderate-intensity activities MET-minutes/week = moderate-intensity activities MET-minutes/week (at work + gardening/yard chores + inside home chores + in leisure time) + cycling MET-minutes/week as form of transport + vigorous-intensity garden/yard chores MET-minutes/week; IPAQ-LF Total vigorous-intensity activity MET-minutes/week = vigorous-intensity activities (at work + in leisure time) MET-minutes/week; IPAQ-LF Total PA MET-minutes/week = total walking + moderate-intensity activities + vigorous-intensity activities MET-minutes/week; IPAQ-LF Total minutes of sitting per week = (minutes of sitting × 5 days) + (minutes of sitting × 2 weekend days) (Biernat, 2013). Table 2a (p. 191) shows correlations of cognitive scores with IPAQ-LF variables for PA of various intensities (moderate-intensity PA, vigorous-intensity PA, walking, sitting), pedometer steps, and time spent walking. Table 2b (p. 192) shows correlations of cognitive performance with PA as measured by the IPAQ-LF in different domains (PA at work, PA related to transport, PA related to housework, gardening/yard and family care, PA related to recreation and leisure sports), number of steps on the pedometer and time spent walking. Correlations reaching significance levels of $p < .05$, $p < .01$ and $p < .001$ are discussed.

In addition, the study participants were divided into a healthy group, a group treated for one chronic disease, and a group treated for two or more chronic diseases. Given the importance of PA for the health of middle-aged and older people, and the role of health on PA, we decided to compare the results of these groups (Biddle et al., 2021). Data on age, years of education, blood pressure and heart rate in these groups were compared using one-way analysis of variance with Games-Howell *post hoc* comparisons. Data from cognitive tests and PA measures were compared using one-way ANOVA with Games-Howell *post hoc* comparisons and Kruskal-Wallis analysis with Dunn *post hoc* comparisons.

Results

Demographic and Health Characteristics of the Study Participants

Data were analysed from 82 people aged 50–80 years; the mean age of the group was 62 years. There were 30 men (34.5% of the group) and 52 women (59.8%). There were 46 people with higher education (52.9% of the group), 15 people with secondary education (17.2%), 20 people with vocational education (23%) and 1 person with primary education (1.1%). Forty-one people were employed (47.1%), 37 people were retired (42.5%), 2 people were unemployed for at least 6 months (2.3%) and 1 person was in voluntary work (1.1%). Fifty-one people (58.6%) were married or cohabiting. Despite being recruited according to the inclusion and exclusion criteria described above, some people reported medical conditions during treatment. These were mainly hypertension, Hashimoto's disease, type II diabetes and others less common such as asthma, COPD and cardiac arrhythmia. Some people had had COVID-19 (at least six months earlier). A total of 26 people (29.9% of the group) said they were not being treated for any chronic conditions, 37 people (42.5%) were being treated for one chronic condition, and 19 people were being treated for two or more conditions (21.8%). Nine people (11.1%) smoked cigarettes at the time of the survey. The subjects reported their normal blood pressure and heart rate and, for those being treated for high blood pressure, their blood pressure after taking medication. The mean blood pressure of the group was slightly elevated. The demographic, physical and health data of the participants are shown in Table 1a.

Physical Activity of the Study Participants

The results of PA measurements using the IPAQ-LF and pedometers are shown in Table 1a. Energy expenditure in MET minutes/week is shown first. It is the result of the intensity and time per week of each form of PA. The study participants estimated that they spent a lot of energy and time on walking and PA at work. This was followed, on average, by transport PA, leisure PA and then household and gardening PA. They had more moderate-intensity PA per week than vigorous-intensity PA. The range of results was huge – in 66 out of 77 people, the estimated total metabolic cost of weekly PA exceeded the 3000 MET minutes/week equivalent of vigorous PA. In some cases, it was a multiple of 3000 MET minutes/week. The highest value was achieved by a security guard. On average, the volunteers walked about 8260 steps per day. The results from the pedometers – number of steps, distance, calories burned, walking time and average walking speed – also varied between the study participants. In addition, the volunteers walked a total of 33,340 km, roughly the distance from Warsaw to Lisbon.

Table 1a

Descriptive Statistics of Participants' Demographics, Anthropometrics and Physical Activity (n = 82)

Variable	*N*	*M*	*SD*	Min.	Max
Age	82	62	7.2	50.00	80.50
Years of education	82	16.1	3.8	5	28
Height in centimetres	75	169.4	9.7	150	188
Weight in kilograms	75	77.3	16.1	48	130
Step length in centimetres	75	70	4.3	61.00	78.00
BMI	75	26.8	4.4	17.76	40.12
Systolic pressure in mm/Hg	80	126.3	14	90	180
Diastolic pressure in mm/Hg	80	81.9	11.8	50	120
Heart rate	70	74.4	12.3	50	120
IPAQ-LF Total work-related physical activity MET-minutes/week	82	3 129.6	5 700.8	0	29 499.5
IPAQ-LF Total transport-related physical activity MET minutes/week	82	2 717.0	2 781.2	0	10 705.5
IPAQ-LF Total physical activity related to house-work, gardening and family care MET-minutes/week	82	1 735.7	2 655.5	0	12 688
IPAQ-LF Total walking MET-minutes/week	82	4 716.3	4 519.8	0	25 363.8
IPAQ-LF Total moderate-intensity physical activity MET minutes/week	82	2 629.4	2 941.0	0	16 714
IPAQ-LF Total vigorous-intensity physical activity MET minutes/week	82	2 412.5	4 058.7	0	1 6714
IPAQ-LF Total leisure-time physical activity MET-minutes/week	82	2 614.8	3 509.9	0	15 286.6
IPAQ-LF Total physical activity MET-minutes/week	77	10 391.7	8 825	603.9	42 052.8
IPAQ-LF Total sitting time minutes/week	82	2 006.9	1 199	360	5 940
Pedometer number of steps/week	82	57 821	23 529	17 130	129 195
Pedometer distance in kilometres/week	82	40.7	18	12.11	101.00
Pedometer number of calories burned/week	82	4 100.5	1 687.2	1 039	9 278
Pedometer walking time minutes/week	82	493.1	173.7	160	975
Pedometer weekly average speed in kilometres per hour	81	4.6	0.8	2.51	7.74

Note. BMI – Body Mass Index; mm/Hg – millimetres of mercury; IPAQ-LF – International Physical Activity Questionnaire – long version.

Cognitive Function of Study Participants

The results of the neuropsychological assessment of the study participants are presented in Table 1b. The raw scores of the WAIS-R(PL) Digit span forward and Digit span backward subtests and their combined score, the scores of the Block design subtest and the Digit symbol subtest are shown. Scores are also given for the Link's cube task. These are the time taken to arrange the cube correctly or to give up, the number of attentional errors made during arrangement, and the number of correct answers to the cube questions. This is followed by the times taken to complete both Part 1 and Part 2 of the CTT and the rate of interference on the CTT.

Table 1b

Descriptive Statistics of Neuropsychological Scores (n = 82)

Variable	*N*	*M*	*SD*	Min.	Max
WAIS-R(PL) Digit span forward	82	5.8	2	3	11
WAIS-R(PL) Digit span backward	82	5.5	1.9	2	13
WAIS-R(PL) Digit span	82	11.4	3.3	6	24
WAIS-R(PL) Digit Symbol	82	46.2	10.1	22	72
WAIS-R(PL) Block design	81	26.6	8.4	12	44
Link's cube seconds	81	621.9	315.7	123.68	1362
Link's cube errors	80	5.5	4.7	0	25
Link's cube memory	81	3	1.3	0	5
Color Trails Test part 1 seconds	82	45.2	14.7	16	98.43
Color Trails Test part 2 seconds	82	96.8	37.8	39	212.76
Color Trails Test interference index	82	1.2	0.7	0.14	4.03

Note. WAIS-R(PL) – Wechsler Intelligence Scale for Adults – revised version. Polish adaptation.

Physical Activity and Cognitive Functioning of Study Participants

The non-parametric correlations between the cognitive task scores, the IPAQ-LF scores and the pedometers are discussed below. Table 2a shows that increased moderate-intensity PA (IPAQ-LF) was associated with higher scores on the Block design subtest and faster completion of the Link's cube. Increased vigorous-intensity PA (IPAQ-LF) was associated with higher scores on the Block design task. More steps on the pedometer and time spent walking were associated with less time spent in a sedentary position (IPAQ-LF). Older age was associated with lower performance on Digit symbol and Block design tasks, slower performance on Link's cube, CTT Part 1 and CTT Part 2.

Table 2a

Spearman's rho Correlations Between Neuropsychological Scores and Physical Activity (Walking, Moderate-Intensity PA, Vigorous-Intensity PA, Sitting, Pedometer) in the Study Group (n = 82)

	Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Age in years	–													
2	WAIS-R(PL) Digit span	–.16	–												
3	WAIS-R(PL) Digit symbol	**–.25***	–.05	–											
4	WAIS-R(PL) Block design	**–.34****	.19	**.34****	–										
5	Link's cube seconds	**.30****	–.13	–.12	**–.51*****	–									
6	Color Trails Test part 1 seconds	**.26***	–.17	–.06	**–.35*****	**.36****	–								
7	Color Trails Test part 2 seconds	**.31****	–.20	**–.38*****	**–.46*****	**.39*****	**.62*****	–							
8	Color Trails Test interference index	.02	–.10	**–.37*****	–.05	.01	**–.35*****	**.42*****	–						
9	IPAQ-LF Total walking MET-minutes/ week	–.09	.15	.04	–.10	–.03	–.06	–.09	–.12	–					
10	IPAQ-LF Total moderate-intensity physical activity MET minutes/week	–.12	.14	.02	**.24***	**–.37*****	–.08	–.15	–.14	**.30****	–				
11	IPAQ-LF Total vigorous-intensity physical activity MET minutes/week	–.10	.03	.04	**.24***	–.19	–.10	–.20	–.17	**.40*****	**.48*****	–			
12	IPAQ-LF Total sitting time minutes/week	–.10	–.00	.00	.02	.00	.06	.05	.04	**–.25***	–.09	–.10	–		
13	Pedometer number of steps/week	–.00	.05	.16	–.04	–.03	–.04	–.19	–.19	.19	.03	.11	**–.46*****	–	
14	Pedometer walking time minutes/week	.00	.09	.07	–.03	–.05	–.08	–.19	–.15	.19	.04	.14	**–.42*****	**.97*****	–

Note. WAIS-R(PL) – Wechsler Intelligence Scale for Adults – revised version. Polish adaptation; IPAQ-LF – International Physical Activity Questionnaire – long version.

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 2b

Spearman's rho Correlations Between Neuropsychological Scores and Physical Activity (at Work, During Transport, Related to Housework, Gardening and Family Care, During Leisure, Pedometer) in the Study Group (n = 82)

	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Age in years	–													
2	WAIS-R(PL) Digit span	–.16	–												
3	WAIS-R(PL) Digit symbol	**–.25***	–.05	–											
4	WAIS-R(PL) Block design	**–.34****	.19	**.34****	–										
5	Link's cube seconds	**.30****	–.13	–.12	**–.51*****	–									
6	Color Trails Test part 1 seconds	**.26***	–.17	–.06	**–.35****	**.36****	–								
7	Color Trails Test part 2 seconds	**.31****	–.20	**–.38*****	**–.46*****	**.39*****	**.62*****	–							
8	Color Trails Test interference index	.02	–.10	**–.37*****	–.05	.01	**–.35****	**.42*****	–						
9	IPAQ-LF Total work-related physical activity MET-minutes/week	**–.39*****	.16	**.23***	**.36*****	**–.26***	**–.23***	**–.3****	–.04	–					
10	IPAQ-LF Total transport-related physical activity MET minutes/week	–.02	–.03	.04	**–.23***	.12	.07	.10	–.07	.09	–				
11	IPAQ-LF Total physical activity related to housework, gardening and family care MET-minutes/week	.16	.04	–.04	–.06	–.07	.03	–.05	–.19	.00	**.34****	–			
12	IPAQ-LF Total leisure-time physical activity MET-minutes/week	.09	.08	–.02	–.08	–.02	.05	.00	**–.23***	–.05	**.49*****	**.29****	–		
13	Pedometer number of steps/week	–.00	.05	.16	–.04	–.03	–.04	–.19	–.19	–.07	.14	.13	**.28***	–	
14	Pedometer walking time minutes/week	.00	.09	.07	–.03	–.05	–.08	–.19	–.15	–.02	.10	.11	**.27***	**.97*****	–

Note. WAIS-R(PL) – Wechsler Intelligence Scale for Adults – revised version. Polish adaptation; IPAQ-LF – International Physical Activity Questionnaire – long version.

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 2b shows that higher levels of work-related PA (IPAQ-LF) were associated with higher scores on the Block design subtest and the Digit symbol subtest, faster stacking of the Link's cube, and faster completion of the CTT Part 1 and Part 2 tests (47.1% of participants reported having a job, the rest being either retired or unemployed). Higher levels of transport-related PA (IPAQ-LF) were associated with lower scores on the Block design subtest. Higher levels of leisure-time PA (IPAQ-LF) were correlated with lower interference scores on the CTT, i.e. better performance on this test. In addition, more frequent leisure-time PA (IPAQ-LF) was associated with higher pedometer step counts and longer walking times.

Performance of Healthy People, People With One Chronic Condition and People With Two or More Chronic Conditions

The third and final part of the analyses looked at the cognitive performance and PA activity of healthy people and people who reported being treated for chronic conditions. The healthy participants and the group with one reported condition performed better on the Digit symbol subtest of the WAIS-R(PL) than the group with two or more chronic conditions. The healthy participants walked more steps and spent more time walking than those with two or more diseases. The groups did not differ in age or education. Differences were found in mean systolic blood pressure ($F_{(2,77)} = 7.030$, $p = .002$, $\eta^2 = .154$), which was higher ($p = .01$) in the group with two chronic conditions ($M_{\text{systolic blood pressure (mmHg)}} = 135.3$; $SD_{\text{systolic blood pressure(mmHg)}} = 17.8$) than in the healthy group ($M_{\text{systolic blood pressure (mmHg)}} = 120.4$; $SD_{\text{systolic blood pressure(mmHg)}} = 11.6$). The results in the three groups are compared in Table 3.

Table 3

Neuropsychological Scores and Physical Activity Compared Between Healthy Participants (0, n = 26), Participants With One Chronic Condition (1, n = 37) and Participants With Two or More Conditions (2, n = 19)

Variable	Groups	*M*	*SD*	χ^2	*p*	Differences between the groups
WAIS-R(PL) Digit span	0	11.31	2.72	2.116	.347	–
	1	11.81	3.86			
	2	10.89	2.94			
WAIS-R(PL) Digit symbol	0	48.46	8.65	7.744*	.021	0,1 > 2
	1	47.38	10.31			
	2	40.89	9.95			
WAIS-R(PL) Block design	0	27.88	8.75	.710	.701	–
	1	26.33	8.82			
	2	25.37	7.01			
Link's cube seconds	0	537.43	283.76	2.932	.231	–
	1	643.87	338.17			
	2	696.13	302.80			

Continuation of Table 3

Variable	Groups	*M*	*SD*	χ^2	*p*	Differences between the groups
Color Trails Test part 1 seconds	0	44.83	16.82	.515	.773	–
	1	45.85	15.88			
	2	44.58	8.85			
Color Trails Test part 2 seconds	0	95.93	40.58	2.327	.321	–
	1	92.31	35.45			
	2	106.78	38.44			
IPAQ-LF Total work-related physical activity MET-minutes/week	0	2 948.03	3 878.40	1.046	.593	–
	1	3 211.92	6 695.63			
	2	3 217.61	5 968.28			
IPAQ-LF Total transport-related physical activity MET minutes/week	0	3 468.07	3 632.08	1.068	.586	–
	1	2 502.09	2 296.36			
	2	2 107.87	2 153.69			
IPAQ-LF Total physical activity related to housework, gardening and family care MET-minutes/week	0	1 706.31	3 052.29	.784	.676	–
	1	1 622.15	2 354.67			
	2	1 997.11	2 757.43			
IPAQ-LF Total walking MET-minutes/week	0	5 810.54	6 191.38	2.169	.338	–
	1	4 669.05	3 452.67			
	2	3 310.85	3 320.75			
IPAQ-LF Total moderate-intensity physical activity MET minutes/week	0	3 029.88	3 805.27	.049	.976	–
	1	2 445.13	2 526.01			
	2	2440	2 389.92			
IPAQ-LF Total vigorous-intensity physical activity MET minutes/week	0	2 210.11	3 240.95	.025	.987	–
	1	2 491.61	4 681.11			
	2	2 535.21	3 953			
IPAQ-LF Total leisure-time physical activity MET-minutes/week	0	3 559.97	3 919.61	4.749	.093	–
	1	2 605.64	3 664.31			
	2	1 339.11	2 058.41			
IPAQ-LF Total physical activity MET-minutes/week	0	11 971.42	9 978.53	1.426	.490	–
	1	10 154.7	8 715.04			
	2	8 746.42	7 419.8			
IPAQ-LF Total sitting time minutes/week	0	1 819.42	1 104.11	2.697	.260	–
	1	1 907.67	1 054.76			
	2	2 456.84	1 505.39			
Pedometer number of steps/week	0	67 651.62	25 182.99	8.098*	.017	0 > 2
	1	56 791.62	22 079.56			
	2	46 373.11	18 850.19			
Pedometer walking time minutes/week	0	551.88	156.21	7.415*	.021	0 > 2
	1	492.22	177.55			
	2	414.21	165.13			

Note. WAIS-R(PL) – Wechsler Intelligence Scale for Adults – revised version. Polish adaptation; IPAQ-LF – International Physical Activity Questionnaire – long version.

X^2– Kruskal-Wallis test with Dunn *post-hoc* tests; *df* for all comparisons = 2; *. Difference significant at .05 level (two-tailed). Significance for pairwise comparisons was adjusted using the Bonferroni correction.

Discussion

This study was conducted to characterise physical activity in middle and late adulthood and to test whether the levels of PA undertaken are related to cognitive performance. The results showed that:

1. the 50–80 year olds in the study had average levels of pedometer-measured walking and had very high levels of reported PA on the IPAQ-LF questionnaire.
2. higher reported PA correlated with higher levels of visuoconstructive and executive functions in two tasks. Higher leisure PA was associated with lower interference in the CTT. Step count and pedometer time did not correlate with cognitive function.
3. more reported PA at work correlated with improved cognitive function.
4. more steps on pedometers correlated with less time spent inactive. In addition, healthier people performed better on a cognitive task and walked more than those with chronic diseases. Older age was associated with decreased cognitive function.

It is worth noting that the participants in the study walked an average of about 8260 steps per day. This was a comparable number of steps to other groups of people of the same age (50–80 years). In Polish studies of people over 60 years of age, an average of about 6000 steps per day (range 3000 to 10.000; Wesołowska & Czarkowska-Pączek, 2018) was reported. Other studies have found a range of 7.000–8.000 steps per day (Tudor-Locke et al., 2008 and 2011), or 7.500–10.000 steps per day, and about 5.000 steps per day for people over 70 years of age (Husu et al., 2016). At the same time, the study participants rated their PA very highly in the week before the first meeting. Their estimates were higher than predicted by the IPAQ-LF norms (Biernat, 2013). Their ratings were also higher than those of respondents in other groups of middle-aged and older people, groups of adolescents and groups with a wide age range (Biernat & Piątkowska, 2013; Cleland et al., 2018; Krzepota et al., 2013; Mitáš et al., 2019; Nicaise et al., 2014; Skotnicka & Pieszko, 2014). Such study results may be related to the fact that participants were aware of the need to be physically active nowadays and correctly estimated their PA in the IPAQ-LF questionnaire (Chastin et al., 2014; Krzepota et al., 2013). However, they also reported more time spent without PA than other groups of comparable age (Cleland et al., 2018). Therefore, it may have been difficult for them to accurately report the duration and intensity of PA from the previous 7 days and the time spent inactive, despite completing the IPAQ-LF questionnaire with the help of the researchers (Biernat & Piątkowska, 2016; Heesch et al., 2010).

The results obtained from the participants in our study partially support the hypothesis that those with higher levels of PA would have higher levels of visuospatial and constructional functions, information processing speed, attention, working memory, visuomotor skills and executive functions. It was observed that better performance on two visuoconstructive tasks – the Block design subtest of the WAIS-R(PL) and the Link's cube – was associated with more frequent and more intense reported PA. Overall, those who reported more PA at work performed better on the cognitive tests, with half of the group working and half not. A similar correlation was found between reported leisure time PA and the CTT interference rate. However, there was no association between cognitive task outcomes and pedometer metrics. These findings are similar to those of previous studies that have found positive correlations with PA in certain neuropsychological assessment measures or domains, such as executive function, episodic memory, nonverbal learning (Hayes et al., 2015), and complex attention (Umegaki et al., 2018). The results of the present study differ from studies that have shown correlations with multiple cognitive domains (Szepietowska & Dąbal, 2023 – here participants were assessed for lifetime PA levels) or with general cognitive functioning (Lim et al., 2020). The few weak associations found between PA and cognition could be due to the small sample size. They may also be due to the fact that cognitive function in our study was assessed using complex tasks involving multiple functions, such as eye-hand coordination, attention, visuospatial functions, planning, inhibitory control and other aspects of executive functions, on which people perform very differently. Further research with a much larger group of adults is needed to confirm the observed associations, given the large number of variables in the analyses, participants' difficulties in rating their own PA on the IPAQ-LF, and participants' diverse occupational status and age. Physical activity is likely not the only factor that may influence cognitive function. As noted by Hayes and colleagues (2015), it is important for PA research to also consider sedentary lifestyles. In their view, it is possible to engage in vigorous activity and still have a sedentary lifestyle (for example, someone who exercises vigorously for an hour but sits at a desk all day). A sedentary lifestyle has been linked to depression, diabetes and cardiovascular risk factors, which are often associated with poor cognitive performance. A sedentary lifestyle may even negate the benefits of PA. Even among those who do engage in planned PA, long hours of inactivity may be associated with reduced cognitive function (Hayes et al., 2015).

The study demonstrates a new trend in combining assessment of cognitive function with measures of functioning in real-life settings. This trend has emerged in order to meet the need to learn about patients' difficulties and ways of coping in everyday, routine activities, not just in standardised tests. It is known from studies of clinical patients that deterioration and limitation in walking precede decline in performance in activities of daily living and cognitive decline. These associations may also be bidirectional, and it is possible that health or cognitive decline may limit PA or walking (Marcotte et al., 2022; WHO, 2018; Yoneda et al., 2021). In our study, we found that people who thought they were completely healthy and those with a chronic disease scored higher on the Digit symbol subtest of the WAIS-R(PL) and walked more steps than people with at least two chronic conditions. This finding seems consistent with observations that health status may be an important contributor to cognitive function (Makarewicz et al., 2021).

The study is limited by having a cross-sectional design. Therefore, causal relationships between PA and people's functioning (and *vice versa* between cognitive functioning and PA) cannot be inferred. We assume that people with a special interest in PA participated in the study and do not represent the whole population of this age in Poland. Therefore, a study with a representative group of people over 50 is needed. The data on height, blood pressure and heart rate, as well as weight and BMI, are approximations provided by the participants. Measuring PA with pedometers also has limitations, such as people forgetting to wear them. Some conditions reported by study participants (e.g. hypertension, diabetes) can affect brain function through a variety of indirect mechanisms, potentially causing a range of cognitive problems. For example, hypertension appears to have a greater negative impact on cognitive function in middle-aged people than in older people (Nakamura et al., 2023). These observations may be related to the fact that in our study all participants with hypertension or diabetes reported being treated for these conditions. In future studies, it would be useful to obtain a full medical history and cardiovascular examination for each participant.

Practical implications can be drawn from the results of the study, such as the need to promote physical activities in health prevention for people in late adulthood (i.e. gerontological prevention), such as exercise, walking and hiking, sports activities, tourism, etc. It is recommended to enrich and make more attractive existing prevention programmes related to PA, to create new ones, to make such prevention accessible to people in small towns and villages, to broaden the offer. There is a need to increase awareness of the importance of PA for cognition in old age, of the WHO recommendations on the minimum daily amount of PA needed to maintain or improve health, and of the benefits of tracking one's own PA. Psychoeducation should be targeted at middle-aged and older people in general, but also at professional groups such as medical groups, especially general practitioners, allied health professionals and psychology students. In addition, more Polish literature (including popular scientific literature) should be made available on PA's role in adult cognition and brain function. Future studies should include devices to monitor both PA and time spent in sedentary behaviour.

In conclusion, the present study showed few significant associations between reported PA and levels of visuospatial function, construction, attention and executive function in volunteers aged 50–80 years. No association was found between cognitive function and pedometer walking activity. The research adds to our understanding of the behaviour and performance of middle-aged and older people in real-world environments. One result is that healthier people performed better in a task that measured levels of attention, working memory and executive function, and walked more than those with chronic illnesses. Given the small number of participants and the modest number of similar studies carried out in Poland, further work seems necessary to obtain more robust data on PA, walking and neuropsychological correlates in middle-aged and older people. Longitudinal studies are recommended, as it has been suggested that improving PA contributes to maintaining cognitive function and even longevity (Yoneda et al., 2021). The issues raised in the article may be of interest to other researchers in Poland as well as practitioners. They may help to encourage more frequent PA in both ageing healthy people and those with chronic diseases.

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