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Cognitive ability and motor performances in the elderly

Kognitivne sposobnosti i motoričke performanse starijih osoba

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Abstract

Background/Aim. Aging entails a wide range of cognitive processes that are not independent of one another. It leads to changes in physical-motor characteristics and sometimes to disability. The aim of this study was to examine the association between multiple cognitive performances in elderly subjects and their physical-motor abilities. **Method.** The study included 98 elderly participants (60+) (16 males and 82 females). Cognitive abilities were assessed by the Montreal Cognitive Assessment (MoCA)/Serbian version, and physical measures were assessed by the Senior Fitness Test with its five subtests, supplemented by the Walking Speed Test. **Results.** Several MoCA items demonstrated relatively low variability, i.e., they proved to be too easy for most of the participants. The participants exhibited the lowest performance on the memory relating to other domains, followed by executive functions, visuospatial skills, attention, concentration, and working memory domains, with the highest performance on temporal and spatial orientation relating to other domains. Executive functions and language correlated most significantly with physical strength. Agility and dynamic balance, lower- and upper-body strength, and aerobic endurance correlated moderately and positively. **Conclusion.** This study underlines the positive correlation between physical fitness and cognitive level in the elderly and emphasizes the importance of physical fitness for cognitive functions, especially those of executive type in elderly subjects. Clinicians should consider the association between cognitive function and physical-motor performances when dealing with functioning improvement in the elderly. The importance of designing the most efficient exercise programs to achieve maximal somatic and cognitive effects is emphasized.

Key words:
aging; cognition; exercises; aged; physical fitness.

Apstrakt

Uvod/Cilj. Proces starenja podrazumeva promene na širokom spektru kognitivnih procesa koji nisu nezavisni jedni od drugih. On, takođe, dovodi do promena u fizičko-motoričkim karakteristikama, a ponekad i do invaliditeta. Cilj istraživanja bio je da se ispita povezanost između više kognitivnih performansi kod starijih ispitanika i njihovih fizičko-motoričkih sposobnosti. **Metode.** U istraživanju je učestvovalo ukupno 98 starijih ispitanika (60+) (16 muškog i 82 ženskog pola). Kognitivne sposobnosti procenjene su Montrealskom skalom kognicije (*Montreal Cognitive Assessment* – MoCA)/srpska verzija, a mere fizičkih sposobnosti su procenjene *Senior Fitness* testom koji se sastoji od pet subtestova, dopunjenih testom brzine hoda. **Rezultati.** Na nekoliko subtestova MoCA rezultati su ukazali na relativno malu varijabilnost, tj. pokazalo se da su previše jednostavni za većinu ispitanika. Ispitanici su pokazali najslabije rezultate u funkcionisanju memorije u odnosu na druge domene, a zatim slede izvršne funkcije, vizuelno prostorne veštine, pažnja, koncentracija i radna memorija, sa najvišim performansama na vremenskoj i prostornoj orijentaciji u odnosu na druge domene. Izvršne funkcije i jezik su najznačajnije korelirali sa fizičkom snagom. Spretnost i dinamična ravnoteža, snaga donjih i gornjih ekstremiteta i aerobna izdržljivost su korelirali umereno i pozitivno. **Zaključak.** Studija ukazuje na pozitivne korelacije između fizičko-motoričkih sposobnosti i kognitivnog nivoa kod starijih osoba i naglašava značaj fizičke spremnosti za kognitivno funkcionisanje, a naročito u domenu izvršnih funkcija kod njih. Kliničari bi trebalo da imaju u vidu povezanost između kognitivnih funkcija i fizičko-motoričkih performansi, kada se bave poboljšanjem funkcionisanja starijih osoba. Ukazuje se na važnost dizajniranja najefikasnijih programa vežbanja za postizanje maksimalnih somatskih i kognitivnih efekata.

Ključne reči:
starenje; saznanje; vežbanje; starije osobe; sposobnost, fizička.

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Introduction

Aging is accompanied by a decline in a wide range of cognitive and physical processes, including psychomotor speed, working memory, executive functions, memory, linguistic abilities, and general knowledge [1]. The decline in cognition during aging is gradual and, in general, is not statistically significant until after 60 years of age [1]. Processes observed in cognitive aging are not independent of one another. Processing speed is reduced in more complex tasks such as noticing and responding to sudden situational changes. According to actual theories, slowing effects increase with age, hence older adults are disproportionately more affected if compared to younger adults as tasks increase in complexity [2].

Age-related or pathological cognitive changes are known to affect abilities in instrumental activities of daily living, i.e., those with executive demands. Performance on cognitive tests tends to show subtle declines well before everyday functioning is affected and could, therefore, be a useful clinical predictor [3].

Aging is a multifactorial process leading to changes in skeletal muscle quantity and quality, which causes muscle weakness and can lead to disability as an outcome in the aging population. Several mechanisms may be involved in the onset and progression of muscle mass loss (sarcopenia), such as protein synthesis, proteolysis, neuromuscular integrity, and muscle fat content [4]. The rate of muscle loss has been established to range from 1% to 2% per year past the age of 50, as a result of which 25% of people over the age of 70 years and 40% of those over the age of 80 years are sarcopenic [5].

The mechanisms accounting for a decline in muscle strength can be attributed to a combination of “neural” and “muscular” factors. It is known that muscle strength is not solely dependent on muscle size. Some relatively recent studies indicate that the decline in muscle strength is much more rapid than the concomitant loss of muscle mass [6]. In addition, advancing age is associated with a reduction of spinal excitability [7], altered motor unit discharge properties, and reduced motor unit size and numbers [8]. Some findings indicate that aging is associated with widespread qualitative and quantitative changes in the motor cortex and spinal cord, reducing the ability to modulate the activity of motor networks when required and reducing cortical plasticity [9]. Collectively, these changes are likely to contribute to age-related reductions in motor performance, although the exact relationship to strength loss is yet to be determined [6].

Sarcopenia is a loss of muscle mass and can be regarded as an early marker of physical and cognitive decline [10]. The relationship between sarcopenia and dynapenia (loss of muscle strength) with cognitive decline and dysfunction is not well-defined. It is widely accepted that motor neuron dysfunction can lead to decrements in muscle mass and strength, but a reverse association is not confirmed. However, studies are indicating that muscle strength, walking ability, and balance are significant predictors of cognitive performance in healthy older adults [11].

It has been confirmed that a decline in cognitive performance results in gait and balance deterioration [12]. Moreover, there are suggestions that there is a motor gait phenotype associated with a decline in cognitive performance, which could be used to improve the prediction of dementia, even before the prodromal stage [12].

There is an association between gait slowing and cognitive impairment [13]. It is supported by a shared neural substrate that includes a smaller right hippocampus. This finding underscores the value of long-term gait slowing as an early indicator of dementia risk [14]. It has been found that upper-body flexibility and agility/dynamic balance correlate with cognitive functioning [15]. These studies accentuate the relation between physical and cognitive status in the elderly. It is still not clear whether they are independently affected by some mutual factors or connected by a causal relationship.

The aim of the study was to examine the association between multiple cognitive performances in elderly subjects and their physical abilities measured by a variety of tests.

Methods

Sample

The sample consisted of 98 participants ranging in age from 61 to 85 years [mean = 68.50, standard deviation (SD) = 4.57], 16 males and 82 females. Before taking part in the research, the participants were introduced to the nature of the research; they also gave their informed consent for participation.

The following inclusion criteria were used: the absence of serious previous diseases and damage to the central and peripheral nervous system; participant’s ability to cooperate during examination and testing; blood pressure within the normal range, with or without therapy (controlled hypertension); the absence of severe diseases of the heart, lung, liver, kidney, and other organs; the absence of/or well-controlled diabetes mellitus.

The exclusion criteria were: previous stroke or other severe neurological brain diseases; diagnosis of dementia (the presence of damage to at least two cognitive areas accompanied by everyday functional impairments); decompensated cardiomyopathy; uncontrolled arterial hypertension; the presence of malignant disease; hepatic, renal, or pulmonary insufficiency; uncontrolled diabetes mellitus with hypo- and hyperglycemia, and quarterly glycosylated hemoglobin (HbA1c) above 7%.

Instruments and measures

Cognitive measures

The Montreal Cognitive Assessment (MoCA) [16] is a screening instrument for detecting mild cognitive dysfunction [17]. The MoCA consists of a variety of tasks measuring different cognitive domains: executive functions, attention and concentration, memory, language, visuoconstructional skills, conceptual thinking, calculation, and orientation. The instrument contains the following subtests: alternating trail making, digit span forward and backward, serial 7 subtraction, learning and delayed recall of the 5-word list; naming, sentence repetition, verbal fluency test, clock drawing test, abstract reasoning, and orientation in time and space. For this research, we used the Serbian version of the MoCA [18]. The administration time is approximately 10 min. The total score is obtained by summing scores for individual items and adding one point for the individuals with 12-year formal education or less, for a possible maximum of 30 points. The final total score of 26 and above is considered normal. The battery demonstrates good psychometric properties and a six-factor structure [19].

Physical measures

Six tests were used in order to comprehensively assess participants' overall physical fitness – five subtests from the Senior Fitness Test (SFT) [20], supplemented by the walking speed test [21]. The tests used in this study serve as indicators of the lower limb muscle strength and upper-body strength and assess overall aerobic endurance, the elasticity of soft tissue, and functional mobility. They indicate whether the person is in the zone of risk of physical incapacity in the near future. The following six physical measures were used: 1) Up and Go test [20] (SFT subtest). The participant's task is to stand up from a chair, walk 2.5 m, and then get back in the sitting position. The score is the time (measured in seconds) needed to perform the task. Performance in this test reflects agility and dynamic balance; 2) Chair Stand Test [20] (SFT subtest). This test is designed for the assessment of lower-limb muscle strength. It requires participants to repeatedly stand up from and sit down on a chair for 30 sec, and the number of stands is recorded; 3) Arm Curl Test [20] (SFT subtest). The test assesses upper-body strength. It requires the participant to repeatedly lift a weight of 3.5 kg for men and 2.5 kg for women for 30 sec. The score is expressed as the number of flexions performed in 30 seconds; 4) Chair Sit and Reach Test [20] (SFT subtest). The test measures lower-body flexibility and elasticity of the soft tissues of the lower extremities. The test is performed from a seated position on a chair with an extended leg and arms reaching towards the toes. The performance is a distance (in cm) that remains between the fingers of the arm and the toes at a maximum reach; 5) Back Scratch Test [20] (SFT subtest). Performance in the test is indicative of upper-body flexibility. The test assesses how close the hands can be brought together behind the back. The score is expressed as the distance (in cm) between the middle fingers of each hand; 6) Walking Speed Test [21]. This test measures the participants' aerobic endurance. The participant is required to walk 4 m, and the time needed to pass the route is measured.

Procedure

The local Ethical Committee of the University Clinical Center Zvezdara approved the study, and all participants provided a signed informed consent before the assessments. The study was conducted in accordance with the Declaration of Helsinki postulates. The research was conducted at the Gerontology Center of Belgrade at Daily Centers and Clubs for Aged People, located in the territory of Belgrade, as well as at the Department of Geriatrics of the Internal Medicine Clinic of the University Clinical Center Zvezdara, Belgrade, where outpatients were tested. Testing procedures were completed in a single day. The test schedule included taking anamnestic data, then the MoCA test, and physical testing at the end.

Results

Sample characteristics

Descriptive statistics related to the participants' age and their sociodemographic structure are presented in Table 1. Male and female subsamples did not differ in terms of their age [t (96) = 0.119, p = 0.119]. Regarding their educational status, only three participants completed primary school, while 47 of them finished secondary school and received a

Table 1

Socio-demographic characteristics of the sample

Variable	Male (n = 16)	Female (n = 82)	Total (n = 98)
Age (years), min-max	65–81	61–85	61–85
(mean ± SD)	(68.63 ± 5.15)	(68.48 ± 4.49)	(68.50 ± 4.57)
Education (n)			
elementary school	0	3	3
high school	4	44	48
higher education	2	12	14
university education	10	23	33
Marital status (n)			
married	14	33	47
single	1	3	4
divorced	1	14	15
widow/er	0	32	32
Financial status (n)			
below average	3	16	19
average	2	30	32
above average	11	36	47

SD – standard deviation; n – number of participants.

university degree. According to marital status, 47 participants were married, while the rest were widowed, divorced, or single. Only 19 participants assessed their financial status as below average.

Cognitive domain

Table 2 presents descriptive statistics for cognitive measures, i.e., MoCA's individual items and total score. Several items have demonstrated relatively low variability, i.e., they proved to be too easy for most of the participants (drawing cube, clock's contour, naming all items, forward digit span, vigilance, orientation, and subtraction 1), and consequentially the majority of these items showed low or non-existent correlations with the overall performance on MoCA. However, the instrument showed satisfactory reliability.

In line with the recommendations given by the MoCA authors and empirical evidence of the instruments, six-factor solution scores for six cognitive domains were calculated: executive functions – derived from the alternating trail making, verbal fluency, and abstraction items; language – derived from the naming, sentence repetition items and verbal fluency; visuospatial skills – calculated from drawing items; memory – derived from delayed recall items; attention, concentration, and working memory – calculated from forward and backward digit spans, vigilance, and subtraction items; and temporal and spatial orientation – derived from the orientation items [16, 19]. Table 3 displays descriptive statistics for scores of the aforementioned cognitive domains.

Due to the high non-normality of scores in the analyses to follow, nonparametric tests were used. The Friedman's test pointed to the differential performances in the tests of six cognitive domains [χ^2 (5) = 249.97, p < 0.001]. Namely, *post-hoc* tests (Wilcoxon signed-rank test) (Table 4) revealed that the participants demonstrated the lowest performance in memory in relation to other domains, followed by executive functions, visuospatial skills, and attention, concentration, and working memory domains while compared to others the greatest performance was recorded in temporal and spatial orientation.

Rank correlations between six cognitive domains are presented in Table 5. Executive functions and language correlated most significantly since both subscales include verbal fluency items. Language and visuospatial skills demonstrated a similar pattern of correlations, i.e., both measures correlat-

Table 2

Descriptive statistics for MoCA's individual items and total score

Items	Mean ± SD	Min–Max	r
Alternating Trail Making	0.51 ± 0.50	0–1	0.210*
Visuoconstructional Skills (Cube)	0.91 ± 0.29	0–1	0.129
Visuoconstructional Skills (Clock): Contour	0.98 ± 0.14	0–1	0.226*
Visuoconstructional Skills (Clock): Numbers	0.74 ± 0.44	0–1	0.242*
Visuoconstructional Skills (Clock): Hands	0.54 ± 0.50	0–1	0.296**
Naming 1	0.99 ± 0.10	0–1	-0.066
Naming 2	0.94 ± 0.24	0–1	0.184
Naming 3	0.99 ± 0.10	0–1	0.063
Forward Digit Span	0.92 ± 0.28	0–1	0.196
Backward Digit Span	0.76 ± 0.43	0–1	0.359**
Vigilance	0.97 ± 0.17	0–1	0.053
Subtraction 1	0.99 ± 0.10	0–1	0.030
Subtraction 2	0.85 ± 0.36	0–1	0.361**
Subtraction 3	0.84 ± 0.37	0–1	0.351**
Subtraction 4	0.78 ± 0.42	0–1	0.432**
Subtraction 5	0.78 ± 0.42	0–1	0.448**
Sentence repetition 1	0.48 ± 0.50	0–1	0.248*
Sentence repetition 2	0.83 ± 0.38	0–1	0.334**
Verbal fluency	0.70 ± 0.46	0–1	0.336**
Abstraction 1	0.82 ± 0.39	0–1	0.351**
Abstraction 2	0.53 ± 0.50	0–1	0.334**
Delayed recall – word 1	0.46 ± 0.50	0–1	0.384**
Delayed recall– word 2	0.42 ± 0.50	0–1	0.498**
Delayed recall– word 3	0.46 ± 0.50	0–1	0.358**
Delayed recall– word 4	0.46 ± 0.50	0–1	0.274**
Delayed recall– word 5	0.64 ± 0.48	0–1	0.473**
Orientation: date	0.96 ± 0.20	0–1	0.144
Orientation: day	0.97 ± 0.17	0–1	0.203*
Orientation: month	0.96 ± 0.20	0–1	0.258*
Orientation: year	0.99 ± 0.10	0–1	0.095
Orientation: place	0.97 ± 0.17	0–1	0.278**
Orientation: city	0.99 ± 0.10	0–1	0.159
MoCA total score	230.95 ± 30.18	15–30	α = 0.693

MoCA – Montreal Cognitive Assessment; *r* – item-total correlations; α – internal consistency of the instrument (Cronbach's alpha).
***p < 0.05; **p < 0.01.**

ed with executive functions, attention, concentration, and working memory and were not related to the memory domain, while only language correlated with the temporal and spatial orientation. Attention, concentration, and working memory correlated with all other domains, including memory, which, on the other hand, achieved the only significant relation with the aforementioned domain. All six domains correlated with the MoCA total score.

Physical-motor domain

Table 6 displays descriptive statistics for six physical measures used in the study. The distribution of participants' scores appeared to be far from symmetrical and substantially skewed in the Chair Stand test and the Back Scratch test. The Kolmogorov-Smirnov test of normality of distribution of scores differs in the Chair Sit and Reach and the Back Scratch tests.

Table 3

Descriptive statistics for six cognitive domains

Domain	Mean	SD	Min	Max	Sk	Ku	K-S
EF	0.64	0.24	0.25	1	-0.107	-0.951	2.124**
LANG	0.82	0.14	0.50	1	-0.0199	-0.811	2.159**
VSS	0.79	0.19	0.25	1	-0.446	-0.573	2.309**
MEM	0.49	0.31	0.00	1	-0.172	-1.013	1.890**
ACWM	0.86	0.19	0.25	1	-1.258	0.665	2.737**
TSO	0.97	0.09	0.33	1	-4.962	32.549	4.876**

EF – executive functions; LANG – language; VSS – visuospatial skills; MEM – memory; ACWM – attention, concentration, and working memory; TSO – temporal and spatial orientation; SD – standard deviation; Sk – skewness; Ku – kurtosis; K-S – Kolmogorov-Smirnov test of normality of distribution of scores.
***$p < 0.05$; **$p < 0.01$.**

Table 4

Differences in performances in six cognitive domains

Domain	LANG	VSS	MEM	ACWM	TSO
EF	-6.919**	-4.996**	-3.792**	-6.566**	-7.845**
LANG		-1.261	-7.481**	-2.670**	-7.120**
VSS			-6.979**	-3.168**	-6.629**
MEM				-7.793**	-8.224**
ACWM					-5.173**

EF – executive functions; LANG – language; VSS – visuospatial skills; MEM – memory; ACWM – attention, concentration, and working memory; TSO – temporal and spatial orientation.
The numbers presented in Table are Wilcoxon signed-rank test statistics.
***$p < 0.05$; **$p < 0.01$.**

Table 5

Correlations between six cognitive domains and Montreal Cognitive Assessment (MoCA) total score

Domain	LANG	VSS	MEM	ACWM	TSO	MoCA
EF	0.541**	0.269**	0.144	0.337**	0.246*	0.519**
LANG		0.276**	0.084	0.304**	0.355**	0.480**
VSS			0.151	0.360**	0.016	0.470**
MEM				0.246*	0.129	0.648**
ACWM					0.274**	0.535**
TSO						0.429**

EF – executive functions; LANG – language; VSS – visuospatial skills; MEM – memory; ACWM – attention, concentration, and working memory; TSO – temporal and spatial orientation.
***$p < 0.05$; **$p < 0.01$.**

Table 6

Descriptive statistics for physical measures

Test	Mean	SD	Min	Max	Sk	Ku	K-S
Up and Go	9.75	1.57	7	15	0.569	0.423	0.863
Chair Stand	14.57	4.41	8	42	2.579	14.167	1.168
Arm Curl	21.42	5.13	12	39	0.795	1.086	1.125
Chair Sit and Reach	2.74	7.57	-17	20	-0.149	0.430	1.534*
Back Scratch	-2.30	7.40	-25.0	11.0	-1.051	1.108	2.215**
Walking Speed	4.46	0.74	2.51	6.85	0.369	0.504	0.622

SD – standard deviation; Sk – skewness; Ku – kurtosis; K-S – Kolmogorov-Smirnov test of normality of distribution of scores.
***$p < 0.05$; **$p < 0.01$.**

Before the correlation analysis, values of the variables for which lower values indicate better performance (time measures) were recorded so that the higher values for all the variables indicate better test performance. The correlation analysis showed that performances in the tests of agility and dynamic balance (Up and Go test), lower- (Chair Stand test) and upper-body strength (Arm Curl test), and aerobic endurance (Walking Speed test) all correlated moderately and positively. On the other hand, the tests of lower- (Chair Sit and Reach test) and upper-body (Back Scratch test) flexibility demonstrated positive intercorrelation, while they did not correlate with strength, agility, and endurance measures. More precisely, the Back Scratch test did not correlate with any other measure, while the Chair Sit and Reach test achieved relatively low correlation only with the Up and Go test (Table 7).

To gain an insight into the latent structure of physical properties, six physical measures were subjected to factor analysis. Factors were extracted using the maximum likelihood method, and the factors were Promax-rotated. Both the Kaiser-Guttman criterion and scree plot suggested the retention of two latent dimensions. Retained factors accounted for 39.03% of the variance of performance in physical tests. The pattern matrix is presented in Table 8.

The first factor is defined by the Walking Speed, Up and Go, Arm Curl, and Chair Stand tests, i.e., aerobic endurance, agility, dynamic balance, and lower- and upper-body strength. The second factor, on the other hand, has appeared to be defined by lower- and upper-body flexibility tests, i.e., Back Scratch and Chair Sit and Reach tests. In line with the primary loadings, the first factor was named physical strength, while the second was named physical flexibility. Two factors were shown to be fairly independent demonstrating a trivial relationship (r = 0.139).

Relationship between cognitive and physical measures

Table 9 displays the correlations between cognitive domains and physical measures.

The executive functions correlated with the physical strength factor mostly due to its relationship with dynamic balance and agility (Up and Go test) and aerobic endurance indicators (Walking Speed test). On the other hand, memory, attention, concentration, and working memory, and temporal and spatial domains were not related to any physical measure. However, language functions correlated with physical flexibility but not with physical strength. Lastly, visuospatial skills demonstrated a negative correlation with the lower-

Table 7

Correlations between six physical measures

Test	Chair Stand Test	Arm Curl Test	Chair Sit and Reach Test	Back Scratch Test	Walking Speed Test
Up and Go Test	0.459**	0.349**	0.225*	0.128	0.531**
Chair Stand Test		0.425**	0.008	-0.121	0.340**
Arm Curl Test			-0.014	-0.067	0.382**
Chair Sit and Reach Test				0.396**	0.105
Back Scratch Test					0.000

***p < 0.05; **p < 0.01.**

Table 8

Pattern matrix for physical measures (Maximum likelihood extraction, Promax rotation)

Test	Factors	
	1	2
Walking Speed	0.717	0.005
Up and Go	0.714	0.217
Arm Curl	0.556	-0.180
Chair Stand	0.346	-0.129
Back Scratch	-0.178	0.678
Chair Sit and Reach	0.055	0.565

Table 9

Correlations between cognitive domains and physical measures and domains

Domain	Up and Go test	Chair Stand test	Arm Curl test	Chair Sit and Reach test	Back Scratch test	Walking Speed test	Physical strength	Physical flexibility
EF	0.217*	-0.013	0.155	0.069	-0.026	0.229*	0.255*	0.058
LANG	0.073	-0.104	-0.021	0.131	0.191	0.047	0.048	0.223*
VSS	0.059	-0.239*	-0.117	0.083	0.109	0.146	0.047	0.147
MEM	0.076	-0.088	-0.057	0.098	0.046	0.034	0.040	0.107
ACWM	0.107	0.007	0.171	0.034	0.023	0.175	0.160	0.044
TSO	-0.015	-0.097	-0.043	0.107	-0.036	-0.075	-0.030	0.046
MoCA	0.125	-0.102	-0.030	0.253*	0.152	0.109	0.127	0.261**

EF – executive functions; LANG – language; VSS – visuospatial skills; MEM – memory; ACWM – attention, concentration, and working memory; TSO – temporal and spatial orientation; MoCA – Montreal Cognitive Assessment total score.

***p < 0.05; **p < 0.01.**

body muscle strength measure (Chair Stand test), and this domain did not correlate with any other physical measure.

Discussion

This study compared data obtained by cognitive and motor tests' performance in individuals over 60 years of age in various levels of physical fitness. Our sample had a substantial predominance of females, thus, sex differences are difficult to assess due to a small number of male participants. Moreover, the predominance of female participants could affect the predictions due to potentially different test results in females and males.

Cognition assessed with the MoCA showed that several items have relatively low variability, i.e., they proved to be too easy for most of the participants (for example, drawing a cube, clock's contour, naming all the items, forward digit span, etc., that show the "ceiling" effect). Vocabulary and forward span are known to be relatively resistant to age-related decline [17]. Statistical analysis showed differences in six MoCA cognitive domains [16, 19] with high significance. Namely, the participants demonstrated the worst performance in memory relative to other domains, followed by the executive functions, visuospatial skills and attention, concentration, and working memory domains, while having the finest performance in temporal and spatial orientation in relation to other domains. Memory is prone to age changes, as it is affected by multiple processes, including speed, working memory, executive functions, and sensory decline. Generally, it is a very demanding cognitive process. According to the compensation-related utilization of neural circuits hypothesis, while performing tasks under lower cognitive demands, older adults engage greater volumes of cortical tissue compared to younger adults, which aids in successful performance [22]. However, under higher demands, older adults have already exhausted their compensatory circuits and reached a resource ceiling, resulting in poorer task performance. In contrast to this, younger adults are able to engage these compensatory circuits to meet the increased cognitive demands [22]. Failures in retrieving previously learned material are an important feature of memory aging [1]. However, some studies report that not all forms of human memory are equally affected by the advancing age [23]. Declarative memory domains such as semantic and episodic memory are differently affected by aging [24]. These findings follow the known vulnerability of recent declarative memory in aging that has several scenarios of decline [25]. While positive age gradients have been found for semantic memory [26], episodic memory is considered to be the form of long-term memory that displays the largest degree of age-related decline [27]. The opinion that implicit memory remains stable during normal aging is widely accepted, but some studies report that priming, as an indicator of implicit memory in older adults, is significantly reduced compared to young adults [28]. Compared to other cognitive tests such as the Mini-Mental State Examination, the MoCA presents a higher episodic memory demand (five words instead of three) [29]. In the study conducted by Cecato et al. [30], the authors found that episodic memory (word recall) was one of the subtests that discriminated participants with mild cognitive impairment (MCI) against cognitively healthy subjects.

The next worst performance was in the executive functions subtest. Executive functions are operations that include task definition, planning, execution, monitoring, updating, mental set-shifting, and the inhibition of prepotent responses, as well as the verification of accomplishment [31]. Age-related differences are observed in the tasks that rely heavily on executive functions in goal maintenance. Compared to younger adults, older adults have more difficulty as the number of relations that must be integrated while performing reasoning tasks increases [1]. Some studies suggest that brain aging affects executive functions through reductions of structural and functional connectivity [32]. In addition, many theoretical frameworks of cognitive aging emphasize the age vulnerability of the prefrontal cortex and its connections with the basal ganglia, especially the *striatum* [33]. One should always be cautious in interpreting cognitive tests as they have common, domain-specific, and test-specific factors [34].

In our subjects, all tests done for physical fitness, i.e., agility and dynamic balance (Up and Go test), lower body strength (Chair Stand test), upper body strength (Arm Curl test), and aerobic endurance (Walking Speed test) correlated moderately and positively. This is in line with the conclusions of the population-based cross-sectional study in Madeira, Portugal, that strength, flexibility, and especially aerobic endurance are crucial for maintaining or improving balance and mobility [35]. Thereby, it seems to be an indicator of a common factor. Statistical analysis showed two factors. The first one was defined by the Walking Speed, Up and Go, Arm Curl, and Chair Stand tests, i.e., aerobic endurance, agility, dynamic balance, lower- and upper-body strength, and the second factor was defined by lower- and upper-body flexibility tests, i.e., Back Scratch and Chair Sit and Reach tests. The first factor was named physical strength and the second physical flexibility.

Our results show that physical strength is an indicator of the lower-extremity function, which is consistent with findings that patients with MCI and Alzheimer's disease have slower walking speed if compared with cognitively healthy persons [36]. Another study conducted among community-dwelling adults indicated that slower the Timed Up and Go test (TUG) time is independently associated with poorer performance in global cognition, executive function, and memory tests and slower processing speed. This highlights that the TUG is more than just a simple mobility task [37]. Another study designed to determine normative values of the TUG in community-dwelling older adults based on cognitive status, gender, and age groups, showed that, generally, older adults with diagnosed MCI took a longer time to accomplish TUG [38]. There are suggestions that differences in lower-extremity function across the cognitive aging spectrum may be explained by atrophy of a neural network, including the dorsolateral prefrontal cortex, cingulate gyrus, parietal association areas, basal ganglia, and medial temporal lobes, particularly the hippocampus [39].

We found that physical fitness correlated with cognitive abilities in the domain of executive functions. The physical strength factors were connected with executive functions. Our findings are in line with the results of a North American study that recruited 56 older adults (60+ years) that found an association between mobility and multiple executive function processes [40]. Higher mobility and physical ability are desired for maintaining executive function capability. In the abovementioned study, mobility was assessed via gait speed, TUG, chair stand, and as a composite physical performance score, and executive functions were assessed with the Trail Making Test, semantic fluency, and phonemic fluency [40]. The connection and correlation between executive functions and walking performances could be explained by the imaging study that showed an association between higher activity in brain regions involved in complex cognitive functions (including the prefrontal cortex and the hippocampus) and increasing complexity of gait [14].

Executive functions in our research correlated with physical strength mostly due to its relationship with dynamic balance and agility (Up and Go test) and walking speed. This can be explained by suggestions about the shared neural basis for fast-paced walking and executive functions in older adults without dementia [41].

In our analysis, both executive functions and language domains included phonemic fluency testing. Verbal fluency in phonemic format is mainly dorsolateral prefrontal function and hence more vulnerable than naming, which is widely spread in the dominant cortex [31]. Language and visuospatial skills correlated with the executive functions, attention, concentration, and working memory and were not related to the memory domain. Only language correlated with temporal and spatial orientation domains. According to the number of authors, a connection between orientation and language can be established. The hippocampus may be responsible for scene construction, drawing on information stored in many regions of the brain but allowing for vivid mental construction and reconstruction of events [42]. This structure contains the so-called “grid cells”, which have spatial functions. Grid cells modulate different levels of spatial resolution, from more detailed to a broader view. This function allows zooming, enabling us to locate ourselves in the surrounding environment [43]. There is a possibility that the generative and recursive nature of language is derived from spatiotemporal imagination. Generativity, defined as a self-contained system from which users draw an independent ability to create, generate, implement or produce new content unique to that system without additional help or input from the system’s original creators, in turn, is grounded in the hippocampal mechanisms for establishing the awareness of location and orientation in space. The generativity of language, then, is not so much a property of the language itself as of the underlying thoughts that we use to convey language [43]. Besides, the findings of Piai et al. [44] reveal that the hippocampal complex contributes to language in an active fashion, relating incoming words to stored semantic knowledge, a necessary process in generating the meaning of a sentence [44]. Linguistic abilities are mainly stable in time and can be considered a measure of premorbid intellectual level [45]. Attention, concentration, and working memory correlated with all other domains, including the memory domain. This is probably because working memory is a system that allows temporary storage and manipulation of information during cognitive tasks and has been linked to activations in many neuroanatomical locations, including frontoparietal networks, occipital cortices, and the cerebellum [46]. This system plays a central role in the human ability to complete a range of everyday activities such as mathematical problem solving, workplace performance, and some other vital activities [47]. Attentional abilities are the general factor included in all other neuropsychological functions, so these findings are to be expected as many complex neuropsychological tests include executive functioning among other factors [17].

The executive functions of the MoCA domain correlated with the physical strength factor. Memory, attention, concentration, and working memory, and temporal and spatial domains were not related to any of the physical measures. These higher cortical functions mostly rely on attentional factors [45]. Language functions domain correlated with physical flexibility but not with physical strength. Lastly, the visuospatial skills domain showed a negative correlation with lower-body muscle strength measures (Chair Stand test) and was independent of other physical measures. A possible connection between visuospatial skills and lower-body muscle strength can be found through testosterone action. Some findings are suggesting that testosterone supplementation improved the strength in the elderly [48] and that there was a positive influence of testosterone on visuospatial skills in the elderly [49]. However, these findings are not in accordance with ours. It is difficult to interpret these findings, but it accentuates the need to explore various effects of physical training on different cognitive abilities.

A comparative study with similar measures to ours was conducted in Japan on 1,552 cognitively non-impaired older participants [50]. They used the Japanese version of the MoCA and handgrip strength, leg strength, sit-to-stand rate, gait speed, and one-leg stand time as physical fitness measures. Each of these five physical fitness measures was positively associated with the MoCA score in multiple linear regression analyses. This study did not include the correlation of subsets of neuropsychological functions and measures of physical fitness.

Our findings underline the positive correlation between physical fitness and cognitive level in the elderly. The latest longitudinal study in Sweden, with a span of 44 years, found that in a population-based sample of women exercising during midlife dementia, the risk was reduced by nearly 90% [51]. High-level fitness contributed more than mid- or low-level fitness. This study and some previous ones pave the way for the development of vascular risk factors control through exercise and other means [52]. Another issue is the immediate effect of fitness on the cognitive level. A specially developed cognitive enhancement fitness program in one session exerted measurable effects on short-term memory (forward digit/word span test) and serum levels of brain-derived neurotrophic factor (BDNF) in healthy middle-aged women [53].

Limitations

A possible limitation of this study is uneven gender representation in our sample. There was limited availability of male elderly subjects who exercise, so the intersex comparison could not have been done, and the results might be biased.

Conclusion

Our study clearly showed the connections between physical fitness (motor performances) and cognitive functions in elderly subjects, especially those of executive type, and emphasizes the need for larger involvement of the general population in physical activities. Further research should be conducted in the form of large population studies on both males and females, encroaching on multiple risk factors and health-enhancing measures. Clinicians need to consider the association between executive function and physical performance when aiming at functional improvement in the elderly population.

Conflict of interest

No potential conflict of interest was reported by the authors.

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