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Masters Athletes Exhibit Larger Regional Brain Volume and Better Cognitive Performance than Sedentary Older Adults

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Abstract

Purpose—To investigate differences in the age-related decline in brain tissue concentration between Masters athletes and sedentary older adults.

Materials and Methods—Twelve Masters athletes (MA) (3 females, age=72.4±5.6yrs, endurance training>15yrs), 12 sedentary elderly (SE) similar in age and educational level (4 females, age=74.6±4.3yrs), and 9 young controls (YC)(4 females, age=27.2±3.6yrs) participated. T1-weighted-high-resolution (1×1×1mm³) images were acquired. Voxel-based analysis was conducted to identify clusters showing tissue concentration differences with t-tests. Cognitive function was assessed using a standard clinical battery focused on executive function and memory.

Results—Two Masters athletes and 2 sedentary elderly were unable to complete MRI study. Both SE and MA showed lower GM concentrations than YC in the superior, inferior and middle frontal gyrus, superior temporal gyrus, postcentral gyrus and the cingulate gyrus ($P_{FDR-corrected}<0.001$) and lower WM concentrations in the inferior frontal gyrus and precentral gyrus ($P_{FDR-corrected}<0.005$). Notably, MA showed higher GM and WM concentrations than SE in the sub-gyral, cuneus, and precuneus regions related to visuospatial function, motor control, and working memory ($P_{FDR-corrected}<0.005$). After controlling for estimated intelligence, MA outperformed SE on tasks of letter ($p<0.01$) and category ($p<0.05$) fluency.

Conclusion—Life-long exercise may confer benefits to some aspects of executive function and age-related brain tissue loss in the regions related to visuospatial function, motor control, and working memory in older adults.

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Keywords

Aging; brain; cognition; exercise; MRI

INTRODUCTION

Aging is the single most important risk factor for cognitive decline and Alzheimer's disease(1). The rapid growth of the aging population presents a great challenge to the modern society to maintain cognitive vitality and improve quality of life in older adults. Brain volume reduces with age(2, 3) and may reflect changes in underlying neural substrates for age-related declines in cognitive function(4). Conversely, accumulating evidences suggest that physical activity is a modifiable factor and may ameliorate age-related brain volume loss and improve cognitive function in older adults(5).

Previous studies showed that aerobic exercise training from several months to a year increased brain volume in both gray and white matter in the prefrontal and temporal regions in older adults(6). Moreover, the magnitude of changes in regional brain volume were associated physical fitness level(7). Functional magnetic resonance imaging (fMRI) studies suggest that physical activity modulates brain activation during executive or memory tasks(8) and increased functional connectivity between the frontal, posterior, and temporal cortices within the default mode network and frontal executive network(9). These findings, although preliminary, support the hypothesis that physical activity plays an important role in dynamic brain reorganization in older adults.

"Masters athletes" (click to view website) is a unique group of older adults who have participated in life-long exercise training and contended in sports competitively. Previous research has shown marked cardiovascular benefits accredited to life-long aerobic training(10). At present, impact of life-long aerobic training on brain structure and function remains unknown. The purpose of this cross-sectional study was to determine if there were differences in brain structure and cognitive functions between Masters athletes and sedentary but otherwise healthy older adults.

Voxel-based morphometry (VBM) is a method used to reveal changes or differences in regional brain tissue concentration(11). Previous studies using VBM have revealed age-related decreases in brain tissue concentration in the prefrontal, temporal and parietal lobes(2). The advantages of VBM are that it does not need a prior assumption of differences in regional brain tissue concentration and is less influenced by the intra- or inter-operator variability based on manual tracing of brain regions(12). In this study, we used VBM to assess brain gray and white matter tissue concentration in the Masters athletes and sedentary older adults.

MATERIALS AND METHODS

Subjects

The Institutional Review Board of the University of Texas Southwestern Medical Center and Texas Health Presbyterian Hospital Dallas approved this study. Informed consent was obtained from all participants. Convenience sampling was conducted for recruitment; and these participants were admitted to the study: 1) Twelve Masters athletes with a history of endurance training >15 yrs, and still engaged in endurance exercise at the time of this study. The Masters athletes were regionally or nationally ranked runners and were recruited mainly from the running clubs or the records of competitive running events. 2) Twelve sedentary but otherwise healthy older adults similar in age, sex, and educational level to the Masters

athletes were recruited locally with newsletters or from senior centers. A sedentary lifestyle was defined as moderate/high intensity aerobic exercise <30 minutes, 3 times/week over the past two years. 3) Sedentary but otherwise healthy young adults between 21-35 years old were also recruited. All participants were free of medical problems and did not regularly consume alcohol, use recreational drug or undergo chemotherapy or hormone therapy. Participants were excluded if they had clinical evidence of cardiovascular or cerebrovascular diseases, psychiatric or neurologic disorders.

Experimental protocol

All subjects underwent MRI and cognitive testing on 2 separate visits in random order that were at least 48 hours apart.

Measurement of aerobic fitness

Maximal oxygen uptake was assessed in the sedentary elderly and Masters athletes using a modified Astrand-Saltin protocol on a treadmill previously described in detail(13). Specifically, ventilatory gas exchange at rest and during exercise testing was assessed with the Douglas bag technique to estimate oxygen uptake (VO_2). Based on the American College of Sports Medicine guidelines(14), $\text{VO}_{2\text{max}}$ were determined by meeting at least 3 of the following criteria: 1) VO_2 ceased to increase with increasing workloads (plateau), 2) heart rate (HR) reached the age-predicted value [$220 - \text{age}$], 3) respiratory exchange ratio (RER) > 1.1, and 4) blood lactate > 8.0 mmol/l. These methods have been tested and validated extensively in previous studies of elderly subjects(15-17).

Magnetic resonance imaging

MRI scans were performed on a 3T scanner (Philips, Best, The Netherlands). T1-weighted high-resolution ($1 \times 1 \times 1 \text{ mm}^3$) images were acquired using a sagittal 3D magnetization-prepared-rapid-acquisition-of-gradient-echo (MPRAGE) sequence(18). The parameters were: field-of-view= $256 \times 256 \text{ mm}^2$, number of slices=160, slice thickness=1mm, TR//TE=8.3ms//2.8ms, flip angle= 12° , number of excitation=1, duration=4min.

Voxel-based morphometry

For voxel-based morphometry (VBM), we used a method called Regional Analysis of Volumes Examined in Normalized Space (RAVENS), an image-processing system that allows the visualization and quantification of global and regional brain volumes. (19). Hierarchical Attribute Matching Mechanism for Elastic Registration (HAMMER 1.0, University of Pennsylvania, PA), an automated algorithm for elastic registration of MR images of the brain, was used to generate regional brain tissue concentration maps for statistical analysis(20).

Individual MPRAGE images were pre-processed using the FMRIB Software Library (FMRIB Centre, University of Oxford, Oxford) for skull-stripping and tissue segmentation into gray matter (GM), white matter (WM), and cerebrospinal fluid (CSF). Next, these images were spatially registered to the Montreal Neurological Institute (MNI) template space using the HAMMER to generate RAVENS maps. The intensity of RAVENS maps at a stereotaxic location of the template space is proportional to the tissue concentrations of the corresponding structure in the original brain space. The RAVENS maps were then split into each tissue type (GM, WM, and CSF) for assessment of regional tissue concentration; brain tissue segmentation was performed fully automatically. The RAVENS maps were further smoothed by a Gaussian filter with a full-width-half-maximum (FWHM) of 12mm and scaled by the intracranial volume to account for residual mis-registration and the differences of the brain sizes between the template and individuals.

Voxel-wise analyses of brain tissue concentration based on the signal intensity of RAVENS maps between groups and its correlation with aerobic fitness within groups were performed using Statistical Parametric Mapping (SPM2, University College, London). Two-tailed t-tests were used to identify clusters showing significant differences between groups. Main effects of aging and probable exercise effects on differences in brain tissue concentration were rendered onto a typical subject MNI template and the anatomic locations of significant clusters were labeled(21).

Cognitive function testing

We examined cognitive function in the executive and memory domains which have been shown to be sensitive to age and exercise(22). We first conducted a cognitive screening test using the Montreal Cognitive Assessment (MoCA) to exclude dementia. Global intelligence was assessed using the Wechsler Test of Adult Reading (WTAR). Executive function was assessed by subtests from the Delis-Kaplan Executive Function System (DKEFS), Trail Making tests (Trails-A and B), and Stroop Color-Word test (Stroop C-W). The California Verbal Learning Test-II (CVLT-II) was administered to assess declarative memory. Finally, we assessed working memory, processing speed, and reaction time using the Automated Neuropsychological Assessment Metrics (ANAM) Battery. Based on the application of each test, either raw, scaled or standardized scores were presented.

Statistical analysis

For voxel-wise statistics, p-value was set at $P < 0.005$ using false discovery rate control (FDR-corrected)(23) to correct for multiple comparisons with the cluster threshold > 200 voxels. Statistics were calculated using SPSS 18 (IBM, Somers, NY). T-tests were conducted to detect differences in cognitive performance between groups with a significance level of $p < 0.05$ using Bonferroni corrections for multiple comparisons. In addition, analysis of covariance (ANCOVA) was performed to account for the influence of individual variability in global intelligence on cognitive assessment results across groups.

RESULTS

Two Masters athletes and 2 sedentary elderly were unable to complete MRI study. Subject demographic data and global brain volumetric measures are presented in Table 1.

Volumetric data

No significant difference was found in WM and ICV volumes between 3 groups although young adults showed significantly higher GM concentrations than sedentary elderly and Masters athletes ($p < 0.01$). Notably, age-related brain tissue loss was observed in the precuneus region in SE, but not in MA. Specifically, localized age-related cortical tissue atrophy was observed in the SE in the precuneus regions of right parietal lobe when compared to MA ($p < 0.05$).

Voxel-wise analysis

The sedentary elderly showed lower GM concentrations than the young in the superior, medial, inferior frontal gyrus, precentral gyrus, postcentral gyrus, inferior parietal lobule, superior temporal gyrus, insula, cuneus, and cingulate gyrus in frontal and temporal lobes (Figure 1A, $P_{\text{FDR-corrected}} < 0.001$, cluster > 200 voxels, T threshold = 3.71, max T = 11.16); more specifically, in Brodmann's area (BA) 6, 9, 13, 24 & 31. Furthermore, the sedentary elderly showed lower WM concentrations than the young in the inferior frontal and, precentral sub-gyral regions in frontal lobe as illustrated in Figure 1B ($P_{\text{FDR-corrected}} < 0.005$, cluster > 200 voxels, T threshold = 2.78, max T = 7.59).

Masters athletes also showed lower GM ($P_{\text{FDR-corrected}} < 0.001$, cluster > 200 voxels, T threshold = 3.74, max T = 11.19) and WM ($P_{\text{FDR-corrected}} < 0.005$, cluster > 200 voxels, T threshold = 3.43, max T = 7.89) concentrations than the young subjects with a similar pattern observed in the sedentary elderly (Figure 2A and 2B).

Notably, when compared directly to the sedentary elderly, Masters athletes demonstrated higher GM concentrations (Figure 3A) in the right parietal lobe, occipital lobe (cuneus) and cerebellum (culmen) ($P_{\text{FDR-corrected}} < 0.005$, cluster > 200 voxels, T threshold = 2.78, max T = 4.89); and higher WM concentrations (Figure 3B) in the parietal lobe (precuneus), temporal lobe (inferior temporal sub-gyral), and occipital lobe (sub-gyral). ($P_{\text{FDR-corrected}} < 0.005$, cluster > 200 voxels, T threshold = 2.78, max T = 4.65). Significant clusters demonstrating group difference between the Masters athletes and sedentary elderly are presented in Table 2. Using the whole-brain voxel-wise correlation analysis, we found that $\text{VO}_{2\text{max}}$ correlated with precuneus GM in the parietal lobe ($P_{\text{uncorrected}} < 0.005$, cluster > 100 voxels, T threshold = 3.50, T = 7.26) and with sub-gyral WM in the frontal and occipital lobes ($P_{\text{uncorrected}} < 0.005$, cluster > 100 voxels, T threshold = 3.50, T = 7.61) in Masters athletes.

Cognitive function data

No significant age-related differences in cognitive performance were observed (Table 3). However, Masters athletes outperformed the sedentary elderly on Wechsler Test of Adult Reading. After controlling for global intelligence level, Masters athletes performed better than their sedentary counterparts in Category Fluency and notably, outperformed both young and old sedentary groups in Letter Fluency (Table 3).

DISCUSSION

The new findings of this study indicate that life-long aerobic training may attenuate age-related brain tissue concentration loss in the regions associated with visuospatial function and motor control and may benefit some aspects of executive function in older adults.

Age-related brain tissue loss

The age-related difference in brain tissue concentration was clearly demonstrated by a global reduction in GM and increases in CSF volume. Furthermore, lower concentrations of GM and WM in a variety of brain regions in older compared to young adults were observed. These findings are consistent with previous studies that showed age-related global and regional brain tissue concentration loss in older adults (2, 3, 12, 24). One of the strengths of this study is that the participants were rigorously screened to exclude cardiovascular diseases which are well-known risk factors for age-related brain tissue concentration loss (25). Thus, our data provide evidence that even in the absence of cardiovascular comorbidities, aging results in loss of brain tissue concentration.

We found GM loss in older adults in the frontal, temporal, limbic, parietal, and occipital regions. We also observed age-related WM loss in the inferior frontal gyrus, precentral gyrus, and sub-gyral regions in the frontal lobe. Notably, the extent of regional brain tissue concentration loss with aging was more prominent in the GM than in WM, consistent with previous studies in non-demented older adults (2, 12).

The underlying mechanisms by which brain tissue concentration reduces with advancing age are unclear. Recent studies suggest that age-related brain tissue concentration loss is due primarily to the reductions in synaptic density and/or shrinkage of neuron or glial cell volume rather than an extensive neuron death (26). In addition, age-related differences in WM are more likely to be reflected by deteriorations in the neuron-axonal structural

integrity rather than changes in volume(27). In this regard, further studies are needed to determine the impact of exercise on WM integrity as measured by the presence of white matter hyperintensities and diffusion tensor imaging.

Difference in brain tissue concentration associated with life-long exercise

We found that Masters athletes had higher GM and WM concentrations mainly in the right parietal and occipital lobes when compared to their sedentary counterparts (Table 2). Furthermore, whole-brain voxel-wise analysis demonstrated that brain tissue concentration in the right parietal and occipital lobes was correlated with aerobic fitness level in Masters athletes.

Brodmann's area 7 (secondary sensorimotor cortex in the parietal lobe) and 19 (secondary visual cortex in the occipital lobe) are well-known to be associated with visuospatial processing and motor control(28). Functional magnetic resonance imaging studies have reported an occipital-parietal interaction when participants were given visual cues that required spatial attention, suggesting connectivity between the parietal and occipital lobes during tasks that stimulated visuospatial processing(28). Furthermore, the dogma of "use it or lose it" for brain volumetric plasticity is supported by the studies in individuals who had an enlarged regional brain volume associated with long-term training in particular areas(29, 30). Thus, the preserved brain tissue concentration in the right parietal and occipital lobes in Masters athletes may be associated with life-long visuospatial and/or motor stimulation during exercise.

Of note, no significant differences in regional brain tissue concentration were observed in the prefrontal and medial temporal lobes between the Masters athletes and their sedentary counterparts. In contrast, previous studies have observed associations between aerobic fitness and increases in regional brain tissue concentration in the prefrontal and medial temporal lobes including the hippocampus in older adults(6, 7). However, these results were preliminary and further validations of exercise benefit on brain tissue volume are much needed. At present, the underlying mechanisms leading to these discrepancies are unknown. It is possible that differences in experimental design (cross-sectional vs. longitudinal), subject population (high-functioning elderly in this study vs. large-population based studies of others), exercise intensity and duration all may influence the study outcomes.

It should be highlighted that the differences in regional GM and WM concentrations observed in the parietal and occipital lobes between the Masters Athletes and their sedentary counterparts did not overlap completely with those of age-related differences in brain tissue concentration. Thus, it is possible that life-long exercise training not only may attenuate age-related differences in brain tissue concentration, but also may preserve brain tissue concentration in those regions which are less influenced by age.

Effects of life-long exercise on cognition

Our cognitive testing showed that Masters athletes outperformed sedentary elderly on the tasks of the letter and category fluency after controlling for the level of global intelligence. A recent study also showed that aerobic training even for a short period of time improved verbal fluency in patients with mild cognitive impairment(31). Furthermore, an fMRI study showed that brain activation in multiple regions in the frontal, parietal and temporal lobes was enhanced during a name discrimination task in physically active older adults(8). These findings have been interpreted to indicate that physical activity modulates semantic memory processing related to the executive function. Thus, in line with these and many other observations, the better performance in the letter and category fluency observed in the

Masters athletes supports the hypothesis that exercise training or physical activity benefits executive function in older adults.

The findings of no significant differences in cognitive assessments between the young and older adults were unexpected (Table 3). Cognitive decline with aging in executive function, working memory, and processing speed is well known(32). However, marked individual variability also exists for cognitive aging(3). Thus, no age-related differences in cognitive outcomes may reflect the limitation of small sample size of this study. Individual genotype, early-life experience, level of education and overall health conditions all can play a role in brain aging(33). The older adults of this study were healthy and had a high level of education suggesting a high cognitive reserve. Thus, cognitive function may be well preserved in these subjects despite the observed brain tissue concentration loss with aging.

Potential mechanisms of exercise benefits

The physiologic mechanisms underlying the salutary effects of physical activity on brain structure and function are unclear. Studies in animals suggest that exercise increases the level of brain-derived neurotrophic factor (BDNF) and neurogenesis in the dentate gyrus of the hippocampus associated with improvement in learning and memory(34, 35). In addition, exercise may enhance brain angiogenesis and/or vasculogenesis associated with increase in brain perfusion which in turn may slow or even reverse age-related brain tissue concentration loss(36). However, whether these mechanisms observed in rodents can explain changes in brain structure and function associated with physical activity in humans need to be confirmed.

Study limitations

We acknowledge that the findings of this study were based on a small sample size recruited via convenience sampling method. Thus, the results must be interpreted with caution. Nonetheless, by utilizing the VBM analysis, we were able to detect differences in regional brain tissue concentration between the Masters athletes and their sedentary counterparts. Previous VBM studies have used statistically less stringent parameters to reveal age-related differences in brain tissue concentration based on a large sample size(24). In this study, we implemented a more rigorous protocol ($P_{FDR-corrected} < 0.005$, cluster size > 200 voxels) to reduce the probability of false findings which could be associated with a small sample size.

Given the limitations of cross-sectional study design, no cause-effect conclusion can be obtained. Furthermore, the differences in the regional brain tissue concentration and cognitive function observed in the Masters athletes cannot be attributed solely to exercise training. Many uncontrolled genetic and lifestyle factors may confound the findings of this study (e.g. Masters athletes may have more social interactions attributing to active lifestyle). In addition, given the previous observations that regional brain tissue concentration may change even after several months of exercise training(6), our study design was unable to separate the effect of an “acute”, an “early-life” or “life-long” training. Nonetheless, we did implement a stringent screening protocol to control for potential cardiovascular confounding factors and have made every effort to recruit the sex, age and education matched subjects between the Masters athletes and their sedentary controls to minimize the discussed uncertainties (although we did not obtain equal number of participants between males and females despite these efforts).

We also acknowledge the limitations of the cognitive battery used in this study. First, the tests may have some ceiling effects, particularly the Automated Neuropsychological Assessment Metrics, and thus may be unable to distinguish among the sedentary elderly, young and the physically fit older adults (Table 3). Second, the tests used were focused on

the executive and memory domain and were not designed prospectively to reveal the motor and visuospatial function. Thus, we cannot infer if the differences in regional brain tissue concentration observed between groups are related to any difference in function. In this regard, further fMRI studies in combination with visuospatial function measurement may provide insights into these issues.

In summary, our data demonstrated differences in brain tissue concentration in the regions related to visuospatial function and motor control between Masters athletes and sedentary elderly. In addition, life-long exercise may benefit some aspects of executive function in older adults even they did not have marked cognitive decline with aging. Our findings suggest that exercise training in older adults may confer salutary effects to brain health.

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Figure 1.

(A) Represented in 6 different anatomical views, sedentary elderly showed global lower gray matter concentrations than young adults in several brain regions (see text for details). (B & C) Sedentary elderly showed lower white matter concentrations when compared to young adults. MNI coordinate indicates the center of the significant cluster. The color bar represents T score; brighter colors represent larger T values. All voxels shown are significant voxels above the T threshold projected onto a standard MNI template. R=right, L=left, A=anterior, P=posterior, PG=precentral gyrus, IIFG=left inferior frontal gyrus.

Figure 2.

(A) Represented in 6 different anatomical views, Masters athletes showed lower gray matter concentrations than young adults in the brain regions similar to Figure 1A. (B) — Masters athletes showed lower white matter concentrations when compared to young adults. R=right, L=left, A=anterior, P=posterior. IIFG=left inferior frontal gyrus.

Figure 3.

Masters athletes showed higher gray matter concentrations in the (A) SPL and (B) IOG and (C) higher white matter concentrations than sedentary elderly in sub-gyrus region in the right occipital lobe than the sedentary elderly. SII=secondary sensorimotor cortex, SPL=superior parietal lobule, V2=secondary visual cortex, IOG=inferior occipital gyrus, O3-WM=inferior occipital gyrus white matter. A=anterior, P=posterior.

Table 1Subject demographic data. Values are means $\pm$ SD

	MA (n=12)	SE (n=12)	YC (n=9)
Male/Female	9/3	8/4	5/4
Age _(years)	72.4 $\pm$ 5.6	74.6 $\pm$ 4.3	27.2 $\pm$ 3.6 ^{**}
Education _(years)	16.2 $\pm$ 2.2	15.8 $\pm$ 2.3	14.7 $\pm$ 1.6
Height _(cm)	177.0 $\pm$ 8.0	171.0 $\pm$ 7.0	170.0 $\pm$ 9.0
Weight _(kg)	74.0 $\pm$ 13.0	73.0 $\pm$ 13.0	70.0 $\pm$ 15.0
BMI	23.7 $\pm$ 2.9	25.1 $\pm$ 3.6	24.3 $\pm$ 4.3
Resting HR _(bpm)	53.9 $\pm$ 5.9 ^{**}	65.3 $\pm$ 6.5	72.3 $\pm$ 12.9
MAP _(mmHg)	89.1 $\pm$ 10.7	89.5 $\pm$ 9.3	83.7 $\pm$ 8.6
VO _{2max} (ml/kg/min)	40.6 $\pm$ 5.9 [*]	23.4 $\pm$ 4.1	N/A
	MA (n=10)	SE (n=10)	YC (n=9)
ICV _(ml)	1629.7 $\pm$ 129.7	1660.6 $\pm$ 167.8	1608.6 $\pm$ 137.5
GM _(% ICV)	34.4 $\pm$ 1.9%	34.2 $\pm$ 2.7%	44.4 $\pm$ 2.3% ^{***}
WM _(% ICV)	32.0 $\pm$ 1.8%	30.7 $\pm$ 4.1%	34.3 $\pm$ 5.3%
CSF _(% ICV)	19.3 $\pm$ 1.9%	19.6 $\pm$ 1.6%	13.0 $\pm$ 1.4% ^{**}

MA=Masters Athlete

SE=Sedentary Elderly

YC=Young Control

BMI=Body Mass Index

HR=Heart Rate

MAP=Mean Arterial Pressure

ICV=Intracranial Volume

GM=Gray Matter

WM=White Matter

CSF=Cerebral Spinal Fluid (in ventricles only)

^{*} Significantly higher than the SE group (p<0.01).^{**} Significantly lower than other 2 groups (p<0.01).^{***} Significantly higher than other 2 groups (p<0.01).

Table 2

Clusters showing Masters athletes with higher GM and WM concentrations than the sedentary elderly. Coordinates represent the center of each significant cluster in standardized MNI space with a right-handed coordinate system and the center of the anterior commissure as the origin (N=20).

Mean Differences in GM Tissue Concentrations – Masters athletes > sedentary elderly				
<i>MNI coordinates</i>			<i>lobe – brain regions/Brodman's Area</i>	<i>T</i>
x	y	z		
22	–52	56	parietal – BA 7	4.03
16	–92	28	occipital – cuneus/BA 19	4.89
18	–54	–22	cerebellum anterior lobe – culmen	3.66
Mean Differences in WM Tissue Concentration – Masters athletes > sedentary elderly				
<i>MNI coordinates</i>			<i>lobe – brain regions</i>	<i>T</i>
x	y	z		
44	–80	36	parietal – precuneus	4.65
46	–64	–14	occipital – sub-gyral	3.23
64	–48	–18	temporal – inferior temporal sub-gyral	3.42

$P_{FDR-corrected} < 0.005$, cluster threshold > 200 voxels, T threshold = 2.78.

MA=Masters Athlete

SE=Sedentary Elderly

MNI=Montreal Neurologic Institute

T=T-statistic

Table 3

Cognitive performance (N=33). Values are means±SD

	MA (n=12)	SE (n=12)	YC (n=9)
<i>Cognitive & Intellectual Status</i>			
^a Montreal Cognitive Assessment	25.75±2.99	24.75±2.99	27.89±1.45 [*]
^b Wechsler Test of Adult Reading	114±7.72 [*]	104±9.68	106±10.49
<i>Executive & Memory Function</i>			
^c Letter Fluency	14.42±3.42 ^{***}	9.42±2.54	10.89±3.06
^c Category Fluency	14.58±3.83 ^{**}	9.83±3.41	12.00±1.58
^c DKEFS Sorting: Correct Sorts	13.17±2.92	12.00±2.52	9.67±2.96
^c DKEFS Free Sorting	12.75±3.28	11.83±2.69	9.67±3.24
^c DKEFS Sort Recognition	11.50±3.61	11.25±2.26	10.00±3.46
^c DKEFS Composite	12.33±3.47	11.67±2.06	9.89±3.55
^c DKEFS Contrast	8.42±1.98	9.33±3.50	10.33±1.73
^d Trails A	53.50±10.33	45.08±7.95	50.89±9.75
^d Trails B	56.83±8.86	54.58±18.26	50.44±7.76
^d Stroop C-W	52.67±7.18	47.50±9.45	48.22±8.83
^d CVLT-II	57.33±12.40	58.83±12.60	51.00±6.76
<i>Automated Neuropsychological Assessment Metrics (ANAM)</i>			
^a Simple Reaction Time (40 max)	39.92±0.29	39.73±0.65	39.44±0.88
^a 2-Choice Reaction Time (40 max)	37.92±2.35	38.45±2.12	37.44±1.51
^a Matching Grids (20 max)	19.08±1.38	19.27±0.79	19.67±0.50
^a Matching Sample (20 max)	17.00±2.73	17.00±2.72	18.78±0.97
^a Logical Reasoning (24 max)	22.17±2.33	21.91±2.66	22.33±4.44
^a Memory Search (40 max)	38.67±1.56	38.36±3.20	38.56±2.24

^a=Raw score^b=Standard score^c=Scaled score^d=T-score.

Scaled scores interpretations:

1-3: Extremely low/deficient

4-5: Borderline

6-7: Low average

8-11: Average

12-13: High average

14-15: Superior

16-19: Very superior

T-scores interpretations:

T-scores interpretations:

<20: Severely impaired

20-24: Moderately to severely impaired

25-29: Moderately impaired

30-34: Mildly to moderately impaired

35-39: Mildly impaired

40-44: Below average

45-54: Average

>55: Above Average

DKEFS=Delis-Kaplan Executive Function System

* Performed significantly better than the SE group ($p<0.05$).

** Performed significantly better than the SE group ($p<0.005$, WTAR adjusted, $F(2, 28)=3.45$).

*** Performed significantly better than other 2 groups ($p<0.01$, WTAR adjusted, $F(2, 28)=5.72$).