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The relationship between aerobic capacity and cognitive/academic performance in medical students

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Abstract. The positive relationship between aerobic capacity and cognitive performance is well known, but there is little information regarding young adults. Therefore, we aimed to test the hypothesis that aerobic capacity (VO_{2max}) correlates with cognitive and academic performance in medical students who have higher academic achievement with academic performance. We included 65 volunteer medical students who were in term 2/6 in this descriptive, cross-sectional study. Body composition and the International Physical Activity Questionnaire and cardiopulmonary exercise test results of all participants were analyzed. Lumosity application with 6 categories of cognitive tests was applied to evaluate cognitive performance. The university entrance exam scores of the students were taken into consideration to assess their academic performance. We observed a significant "positive" relationship between aerobic capacity and some domains of cognitive performance, especially problem solving ($p < 0.05$), but we did not find a significant relationship between aerobic capacity and academic performance. Consequently, although we confirmed the existence of a positive effect of high aerobic capacity on cognitive performance stated in the literature, we couldn't confirm this for all cognitive domains or academic performance. These results suggest that more comprehensive studies on this subject are needed.

Key words: VO_{2max} — Aerobic capacity — Cognition — Cognitive performance — Academic performance — Lumosity

Abbreviations: BMI, body mass ındex; BMR, basal metabolic rate; CGPA, cumulative grade point average; CPET, cardiopulmonary exercise test; ECG, electrocardiography; GPA, grade point average; IPAQ, International Physical Activity Questionnaire short form; LPI, lumosity performance index; MET, metabolic equivalent; RER, respiratory exchange ratio; RT, reaction time; SPSS, Statistical package for social sciences; VCO_2, carbon dioxide production; VE, minute ventilation; VO, oxygen uptake; WHR, waist-hip ratio; WRAT, wide range achievement test.

Introduction

Aerobic capacity is the capacity to deliver oxygen to skeletal muscles, which is necessary to obtain energy during exercise. The most reliable measure of aerobic capacity is maximum oxygen consumption, so-called "VO_{2max}" (Åstrand 1992). VO_{2max} is defined as the highest amount of oxygen that the body can receive and use during exercise (Bassett and Howley 2000).

Some factors affect the VO_{2max} in humans. Physical activity increases the VO_{2max}. Along with regular exercise, the increase in cardiac output, pulmonary diffusion capacity, blood's oxygen-carrying capacity *via* hemoglobin, a mitochondrial enzyme, and capillary density in the skeletal

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muscle system cause the increase in VO_{2max} level. However, cardiac output has the biggest effect on this increase and limits most of the VO_{2max} levels. VO_{2max} has been found higher in athletes than non-athletes in the same age groups (Åstrand et al. 2003).

Athlete or not, aerobic exercise is a powerful stimulant for improving mental health and structural changes in the brain (Thomas et al. 2012). Animal trials have shown that exercise or physical activity causes more different and specific changes in the brain than those caused by learning or new experiences (Black et al. 1990). Aerobic exercise increases hippocampal neuron number and cerebral blood volume in animal trials, and this increase in cerebral blood volume and hippocampal volume has been reported in human studies, too (Van Praag et al. 1999; Chaddock et al. 2010; Thomas et al. 2012).

The use of computer and mobile phone applications to evaluate cognitive performance has become increasingly common in recent years. These applications have been used in improving cognitive performance and even in scientific research recently. One of these applications, lumosity, is a cognitive education platform that can be reached from the web or mobile phone application. Some studies have used the Lumosity's cognitive test for the cognitive status determination (Finn and Mcdonald 2011; Rattray and Smee 2013; Shute et al. 2015; McLaughlin et al. 2018). Most of these studies have been conducted on children or seniors, however, there are few studies on young adults (Shute et al. 2015; Boland 2016).

Although some studies are showing that exercise affects cognitive functions, limited studies are showing the relationship between exercise and academic performance. Academic performance is measured by evaluating people's performance and grade point average (GPA) at school, or various achievement tests based on standard scores. Higher aerobic capacity is associated with higher scores in academic performance and standardized success tests (Davis and Cooper 2011; Van Dusen et al. 2011; Haapala 2013).

There are not many studies on the relationship between aerobic capacity and academic performance. Although there are some studies suggesting the relationship between aerobic capacity and cognitive performance, there are very few studies on young adults (Blondell et al. 2014; Cox et al. 2016). Therefore, we designed this study to investigate the hypothesis that aerobic capacity correlates with cognitive parameters and academic performance in medical students who have higher academic achievement.

Methods

Study design

This study was designed as descriptive and cross-sectional research.

We performed a prior power analysis to determine the minimum required sample size for the study. We accepted the effect size (correlation between aerobic capacity and academic performance) as r = 0.30. This value is accepted as a moderate effect size (Schäfer and Schwarz 2019). In addition, Type I error and prior power level was accepted as 5% and 80% respectively. Based on this information, the suitable sample size was calculated as 65. However, considering that there might be a drop out during the study and that the participants could be withdrawn from the study for various reasons, approximately 20% of the required sample size was also added and it was decided to recruit 80 students for the study. G*Power (ver. 3.0.10) statistical program was used for power analysis.

Volunteer Form

"Volunteer Form" was applied to students, and diseases that constitute a contraindication to the exercise test were identified. In addition to demographic (age, sex, etc.) and university data, features such as cognitive or non-cognitive games played, caffeine/alcohol consumption habits, sleep patterns, computer skills (good/medium/bad), and systematic ability to study were questioned.

Participants, inclusion, and exclusion criteria

The criteria for inclusion were to study in the 2nd year (term 2/6) of 240 people at Istanbul Medeniyet University Faculty of Medicine in 2017–2018 and to volunteer to participate in the study. Exclusion criteria from the study were determined as exercise test contraindications, being younger than 18 years of age, grade repetition in medical faculty, or lateral transfer from another school.

Term 1/6 was not suitable because we wanted to see a cumulative grade point average (CGPA) of at least 2 years. In addition, the other terms (3 to 6 out of 6) were not suitable as they could have been in hospital or clinical rotation.

Due to the information in the "Volunteer Form" that 80 people voluntarily filled in and according to their statements, 15 students were excluded from the study. Among these 15 students, 10 students gave up participating in the study, 3 students came from another school as a lateral transfer, 1 student did grade repetition in medical faculty and 1 student had asthma. Finally, data from 65 students were analyzed (Fig. 1). These students voluntarily signed the informed consent form and participated in all measurements from the beginning to the end of the study.

Body composition analysis

First, body composition analysis was made for each participant in the morning on an empty stomach by using the TANITA BC-418 device with the bioelectrical impedance method.

International Physical Activity Questionnaire (IPAQ)

After the body composition analysis, the International Physical Activity Questionnaire short form (IPAQ), which was validated in Turkish (Saglam et al. 2010), was applied. According to the IPAQ result, the metabolic equivalent (MET) values of the participants were calculated, and the participants were classified into three categories: category 1 (low), category 2 (moderate), and category 3 (high). After information was given for aerobic capacity measurement (VO_{2max}) and cognitive test application, an appointment was made for the dates of the tests, and measurements were carried out on the test days.

Aerobic capacity measurement

Aerobic capacity was measured by a cardiopulmonary exercise test (CPET). COSMED Quark CPET mixing chamber system device (PFT Suit, Italy, Rome) was used.

We wanted participants to be confident that our measurements were of high quality, accurate, and safe before CPET. By the recommendations applied before CPET, participants were instructed to keep away from caffeinated and alcoholic beverages and intense exercise and not to take nourishment for at least 2 h before the measurement. We suggested that they wear loose-fitting clothing and flat shoes such as sneakers. Measurements were carried out at the exercise physiology laboratory in our hospital. After calibrations, a respiratory function test was performed before the exercise test for all participants. A treadmill ergometer (HP Cosmos) was used for aerobic capacity measurement. Modified Bruce Protocol was applied, and the patient achieved maximum exercise performance by gradually increasing elevation and/or speed at three minutes intervals during the exercise. During the exercise test, parameters such as oxygen uptake (VO_2), carbon dioxide production (VCO_2), minute ventilation (VE) and respiratory exchange ratio (RER), and heart rate were measured. Electrocardiography (ECG) in twelve leads, blood pressure, and oxygen saturation were recorded. During the test, the patient's perception of difficulty with exercise and symptoms such as dyspnea, chest pain, and fatigue were evaluated and the point at which the patient wouldn't be able to continue the test was determined.

Cognitive performance measurement

To neutralize the effect of sleepiness in the first hours of the morning on the study results, the cognitive tests in our study was made between 11:00 and 16:00 when the students were not hungry. The application took approximately 60 min for each participant.

The cognitive functions of "speed, memory, attention, cognitive flexibility, problem-solving, and math" were assessed by applying a Lumosity test (6 tests in total) for each function. Selected tests and their properties were presented in Table 1. Each test was applied 5 times. The 3^{rd}, 4^{th}, and 5^{th} test scores were used to visualize the test scores (we assumed the first 2 tests as warm-ups). However, the lumosity performance index (a standard performance metric created by lumosity; LPI) is based on the results of these 5 games.

In this study, the cognitive functions of the brain were evaluated with different components such as "processing speed, spatial memory, attention, problem-solving, flexibility, and mathematics", and university grades were reviewed as an indicator of academic success.

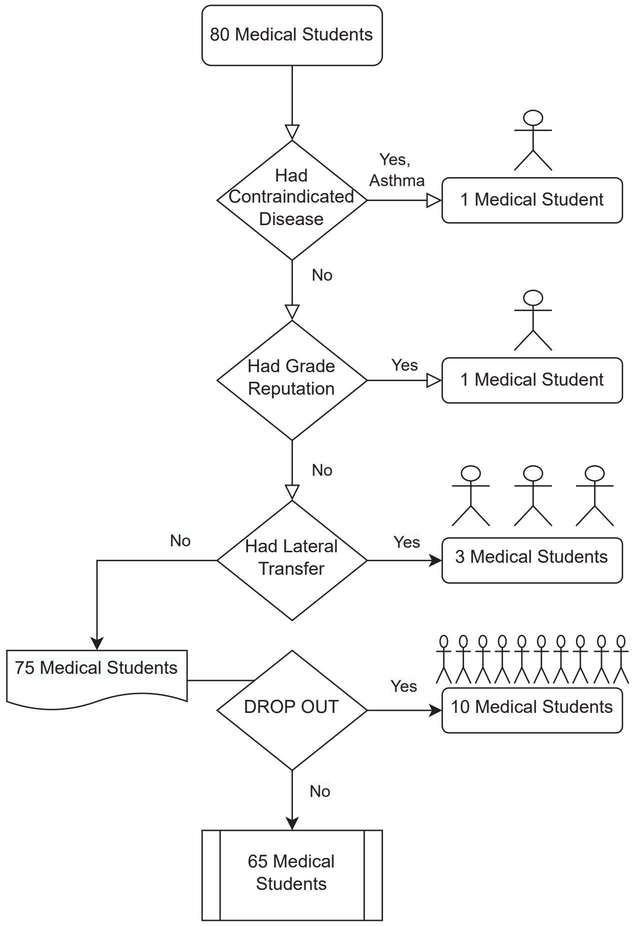

Figure 1. Flow diagram of the study.

Academic performance

The GPA of the study participants for the 2016–2017 and 2017–2018 terms, CGPA, and the score on the university entrance exam was taken from the student affairs department with the deanery's permission.

Table 1. Cognitive performance measurement tests and features

Cognitive test name	Memory matrix	Speed match	Lost in migration	Ebb and flow	Masterpiece	Rain drops
Cognitive performance category	**Memory**	**Speed**	**Attention**	**Flexibility**	**Problem solving**	**Math**
Cognitive function	*Spatial recall* (Your ability to track location and position within an environment)	*Information Processing* (Information processing is the initial identification and analysis of incoming sensory input)	*Selective Attention/ İnhibitory control* (The ability to focus on relevant information while ignoring irrelevant distractions)	*Task Switching* (The process of adapting to changing circumstances, switching from one goal to another)	*Spatial Reasoning* (The ability to visualize spatial relationships and analyze them to conclude)	*Numerical calculation* (The ability to perform simple arithmetic operations including addition, subtraction, multiplication, and division)
Practice	In Memory Matrix, you quickly memorize a group of tiles on a grid. That means remembering their location, and maybe even the shapes they create.	A symbol appears briefly in the middle of the screen and is then replaced by another. The aim is to determine if the new symbol matches the previous one. It is tried to give as much correct answer as possible in a period of 45 seconds.	The flock of five birds appears on the screen. The arrow key showing the direction of the bird in the middle of the flock should be pressed. The direction of the central bird can be the same or different with other birds. The goal is to get as many accurate answers as possible in a 45 second period.	Sorted leaves are moving. Depending on the direction of the leaves (green leaves) and the direction of movement (yellow leaves), it is desired to press the direction keys. It is necessary to give correct answers one after another without mixing according to direction or color.	There are geometric shapes on the screen and large space in the middle. The task ends by filling the gap by placing and combining geometric shapes in appropriate places.	Simple arithmetic equations appear inside droplets that fall from the top of the screen. The correct answer must be entered before the droplets reach the ground. Droplets accelerate over time. As the droplets reach the water, the water level rises and the task ends.

Ethical approval

This study was approved by the Ethics Committee of Istanbul Medeniyet University Goztepe Training and Research Hospital (approval number: 2017/0270, date: 15.08.2017). This study was performed in compliance with the Declaration of Helsinki.

Statistical analysis

Descriptive statistics of the collective data were presented as average, standard deviation (SD), minimum (Min) – maximum (Max) values, numbers, and percentage frequencies based on the data properties, and they were summarized in the tables.

Non-parametric statistical methods were used. For comparison of two non-normally distributed groups Mann Whitney U test was used. For comparison of more than two non-normally distributed groups Kruskal Wallis test was used. The χ^2 test was used for categorical variables and expressed as observation counts (and percentages). Spearman's rho correlation analysis was used for the final analysis. $p < 0.05$ was accepted as a statistical significance level. IBM SPSS-23 (Statistical Package for Social Sciences-Version 23, Chicago, IL, USA) program was used for analysis. In SPSS, control was provided by putting the independent variable of sex in the "controlling for" section of the Partial Correlation section.

Results

Demographic data

A total of 65 medical students were evaluated in this study. Of these, 53.8% (n = 35) were male. Body composition and

Table 2. Students' measurement data according to sex

	Male (n = 35)	Female (n = 30)	Total (n = 65)	U	p	Test
Age	20.20 ± 1.02	20.33 ± 0.76	20.26 ± 0.91	470	0.44	TANITA
Metabolic Age	18.46 ± 2.41	20.97 ± 3.90	19.62 ± 3.4	341	0.02	
BMI	23.61 ± 2.36	22.14 ± 2.91	22.93 ± 2.71	370	0.04	
WHR	0.80 ± 0.04	0.72 ± 0.04	0.76 ± 0.06	76.5	<0.001	
Fat mass (kg)	10.75 ± 3.33	14.19 ± 5.86	11.11 ± 4.95	337.5	0.01	
Fat (%)	14.72 ± 3.65	24.34 ± 7.44	19.16 ± 7.45	128.5	<0.001	
Impedance	578.3 ± 61.06	694 ± 61.88	631.7 ± 84.23	78.5	<0.001	
BMR	1,821 ± 170.9	1,312 ± 89.06	1,586 ± 290.5	6.5	<0.001	
MET (min/week)	2,897 ± 2,444	1,369 ± 1,11	2,169 ± 2,062	264.5	0.01	IPAQ
VO_2 rest (ml/min/kg)	7.54 ± 2.81	6.02 ± 2.66	6.84 ± 2.83	359	0.03	CPET
VO_2 LT (ml/min/kg)	24.96 ± 4.76	19.30 ± 2.33	22.35 ± 4.75	169	<0.001	
VO_2 pred% (ml/min/kg)	81.09 ± 15.30	79.87 ± 9.64	80.52 ± 12.92	507.5	0.82	
VO_2max (ml/min/kg)	40.84 ± 7.38	31.83 ± 3.78	36.68 ± 7.48	164	<0.001	
VO_2max (ml/min)	2,865 ± 582.3	1,746 ± 231.4	2,348 ± 721.5	37.5	<0.001	

Data are means ± SD.

CPET analysis values according to sex were given in Table 2. The mean height of male students was 174.63 ± 4.49 cm (range, 163–185 cm) and the mean height of female students was 159.33 ± 4.62 cm (range, 149–167 cm). The mean weight of male students was 72.01 ± 7.78 kg (range, 53.50–94.80 kg), and the mean weight of female students was 56.18 ± 7.83 kg (range, 39.60–72.60 kg).

Body mass index (BMI), basal metabolic rate (BMR), waist-hip ratio (WHR) were considerably higher in males than females while metabolic age, impedance, fat mass, and fat percentage were higher in females.

Resting, lactate threshold (LT), and peak/max values of VO_2 (ml/min/kg) were considerably higher in males. The VO_{2max} distributions are shown in Table 2; there was a considerable difference between males and females.

In the results of activity status from IPAQ, 16 students (24.6%) had high activity. Males appeared to be more physically active than female participants (Fig. 2).

In the analysis, it was determined that there was a statistically significant difference (Pearson coefficient: $\chi^2 = 9.7$, $p = 0.02$). In a *post-hoc* analysis, it has been determined that male with high activity was distributed significantly differently than female ($p = 0.01$).

High activity students in the IPAQ were found to have significantly higher VO_{2max}, and MET (Table 3).

Flexibility category scores in one of the cognitive performance tests were found considerably higher in males in the evaluation of cognitive performance measures and academic performance scores ($p = 0.01$).

Lost in Migration's 4^{th} score (attention), Ebb and Flow's 3^{rd}, 4^{th}, 5^{th} scores (flexibility), and Raindrops' 3^{rd}, 4^{th}, and 5^{th} scores (math) were also found considerably higher in males than females ($p < 0.05$) (Table 4; Fig. 3). There was a trend for females to have a higher mean memory LPI score than males but the difference was not statistically significant ($p > 0.05$) (Table 4; Fig. 4). There was no significant

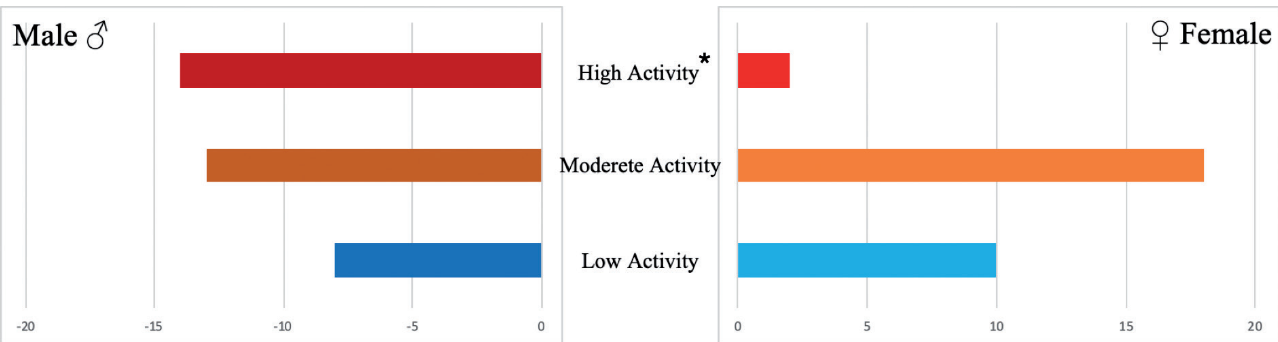

Figure 2. Distribution of physical activity classification of International Physical Activity Questionnaire (IPAQ) according to sex. * $p < 0.05$ male *vs.* female.

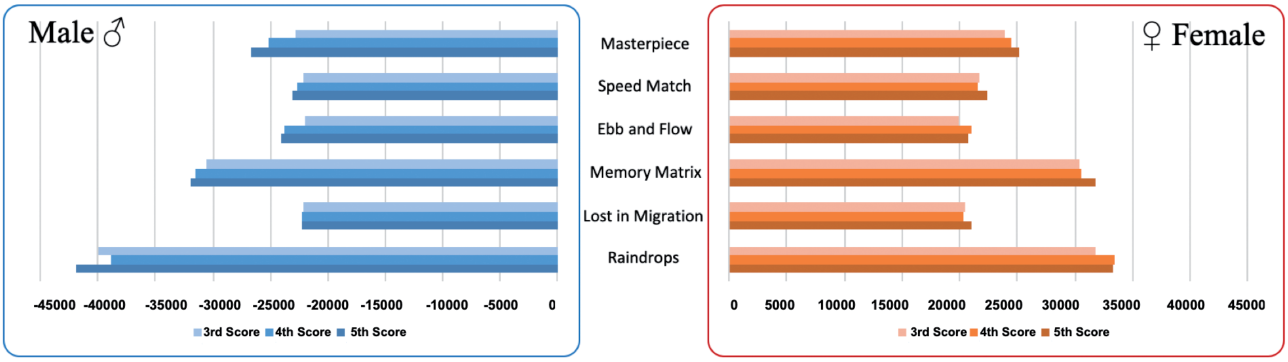

Figure 3. 3rd, 4th, and 5th scores of Lumosity Games according to sex.

difference between males and females in terms of academic performance (Table 4).

Figure 5 shows the relationship between aerobic capacity and cognitive and academic performance. We found significant correlations in 5 of the parameters we investigated ($p < 0.05$, $r \geq 0.25$). However, there was no significant correlation found between cognitive test scores and academic performance ($p > 0.05$, $r < 0.25$).

When we look at the cognitive scores according to the activity status, it was determined that there was a significant difference only in Ebb and Flow 3rd and 5th scores. As a result, Flexibility score was found to be significantly higher in people with high activity scores ($p < 0.05$).

A positive linear relationship was found between VO_{2max} (ml/kg/min) and flexibility and problem-solving category scores which were among the cognitive performance parameters. Also, a positive linear relationship was determined between VO_{2max} (ml/min) and the attention and flexibility categories. There was no significant correlation between VO_{2max} (ml/kg/min) and VO_{2max} (ml/min) and academic performance.

The relationship between aerobic capacity, and cognitive and academic performance scores was examined after controlling the effect of sex on VO_{2max}. Only a positive linear relationship was found between VO_{2max} (ml/kg/min) and problem-solving category score. No significant correlation was determined for other parameters.

The students defining their computer skills as "good" were found to have considerably higher cognitive performance scores, except for spatial memory, and their total cognitive scores ($p < 0.05$).

All academic performance scores of those studying regularly, except for the university entrance exam score, were

Table 3. Students' measurement data according to activity status

	Low-moderate activity ($n = 49$)	High activity ($n = 16$)	U	p	Test
Age	20.27 ± 0.88	20.25 ± 1	383	0.88	TANITA
Metabolic age	20 ± 3.58	18.44 ± 2.5	309.5	0.21	
BMI	22.58 ± 2.75	23.99 ± 2.36	249	0.03	
WHR	0.75 ± 0.05	0.8 ± 0.04	143.5	<0.001	
Fat mass (kg)	12.78 ± 5.45	10.98 ± 2.6	318.5	0.26	
Fat (%)	20.37 ± 8.04	15.46 ± 3.27	248.5	0.03	
Impedance	651.2 ± 77.88	571.9 ± 76.18	163.5	0.01	
BMR	1,513 ± 258.6	1,808 ± 276.1	181	0.01	
MET (min/week)	1,261 ± 862.3	4,836 ± 2,263	9	<0.001	IPAQ
VO_2 rest (ml/min/kg)	7.01 ± 3.09	6.32 ± 1.76	339.5	0.42	CPET
VO_2 LT (ml/min/kg)	21.6 ± 4.68	24.63 ± 4.33	236	0.02	
VO_2 pred% (ml/min/kg)	80 ± 12.64	82.13 ± 14.05	368	0.72	
VO_{2max} (ml/min/kg)	35.45 ± 7.4	40.43 ± 6.59	223	0.01	
VO_{2max} (ml/min)	2186 ± 652	2845 ± 713	198	0.01	

Data are means ± SD.

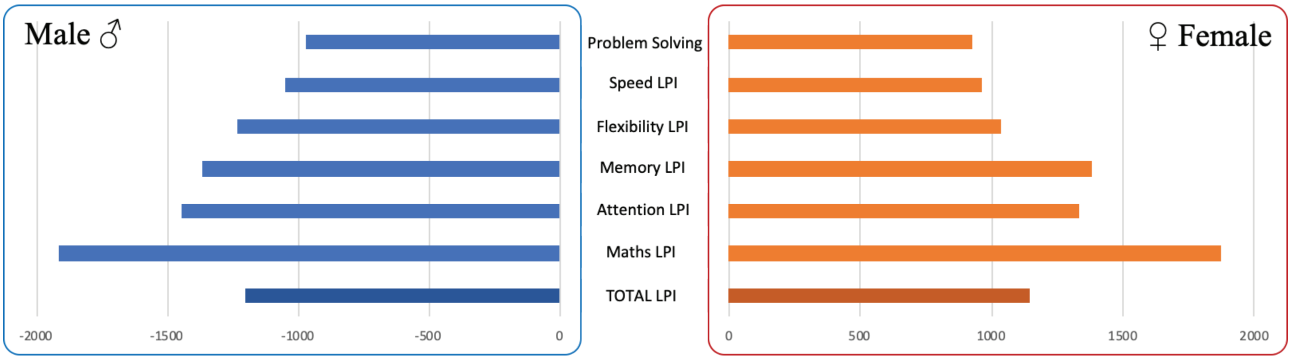

Figure 4. Cognitive performance results according to Lumosity performance indices (LPI) according to sex.

Table 4. The descriptive analysis of cognitive and academic performance according to sex

		Score	Male (n = 35)	Female (n = 30)	Total (n = 65)	U	p
Cognitive performance							
Masterpiece		3	22.765 ± 5.117	23.863 ± 6.548	23.721 ± 5.800	455	0.45
		4	25.229 ± 4.855	24.428 ± 4.843	24.860 ± 4.828	471	0.51
		5	26.725 ± 5.271	25.181 ± 5.835	26.012 ± 5.549	456	0.27
Speed Match		3	22.099 ± 6.123	21.740 ± 4.779	21.933 ± 5.504	476	0.8
		4	22.663 ± 5.877	21.578 ± 5.613	22.162 ± 5.738	442	0.45
		5	23.026 ± 6.014	22.351 ± 5.076	22.716 ± 5.568	483.5	0.63
Ebb and Flow		3	21.970 ± 3.806	19.910 ± 3.801	21.019 ± 3.913	370	0.03
		4	23.730 ± 4.447	21.055 ± 4.100	22.495 ± 4.464	341.5	0.02
		5	24.076 ± 3.812	20.740 ± 3.524	22.536 ± 4.019	273.5	<0.001
Memory Matrix		3	30.594 ± 4.335	30.333 ± 4.572	30.474 ± 4.413	503.5	0.81
		4	31.534 ± 5.452	30.575 ± 4.215	31.091 ± 4.906	490.5	0.44
		5	31.953 ± 5.775	31.792 ± 3.965	31.879 ± 4.985	504.5	0.9
Lost in Migration		3	22.150 ± 4.323	20.447 ± 2.988	21.364 ± 3.835	403	0.07
		4	22.224 ± 4.347	20.305 ± 2.783	21.339 ± 3.805	335	0.04
		5	22.239 ± 4.491	21.080 ± 2.541	21.704 ± 3.739	408	0.22
Raindrops		3	40.000 ± 12.439	31.833 ± 8.080	36.231 ± 11.341	312.5	0.01
		4	38.929 ± 12.044	33.367 ± 7.574	36.362 ± 10.529	400.5	0.01
		5	41.871 ± 14.111	33.350 ± 9.339	37.939 ± 12.792	334.5	0.01
LPI	Problem Solving		972.5 ± 289	928 ± 309.3	952 ± 297	476	0.55
	Speed		1.053 ± 339.6	966 ± 267.7	1.013 ± 309.3	441	0.26
	Flexibility		1.236 ± 293.6	1.039 ± 253.4	1.145 ± 291	321	0.01
	Memory		1.366 ± 260.9	1.381 ± 224.5	1.373 ± 243	524.5	0.81
	Attention		1.444 ± 296.5	1.334 ± 219.6	1.393 ± 267.7	370	0.09
	Mats		1.915 ± 104.9	1.872 ± 87.60	1.895 ± 98.9	353.5	0.08
	Total		1.203 ± 226	1.146 ± 201.6	1.177 ± 215.1	440	0.3
Academic performance							
Term 1 Final Exam Grade Point			73.50 ± 8.65	74.30 ± 6.82	73.87 ± 7.81	496	0.7
Term 1GPA			73.17 ± 8.19	74.47 ± 6.02	73.77 ± 7.24	461	0.4
Term 2 Final Exam Grade Point			69.45 ± 10.84	65.11 ± 8.86	67.45 ± 10.14	393.5	0.08
Term 2 GPA			71.97 ± 9.42	70.40 ± 6.99	71.25 ± 8.36	511.5	0.86
Weighted CGPA (2 years)			2.61 ± 0.41	2.59 ± 0.36	2.60 ± 0.389	517.5	0.92

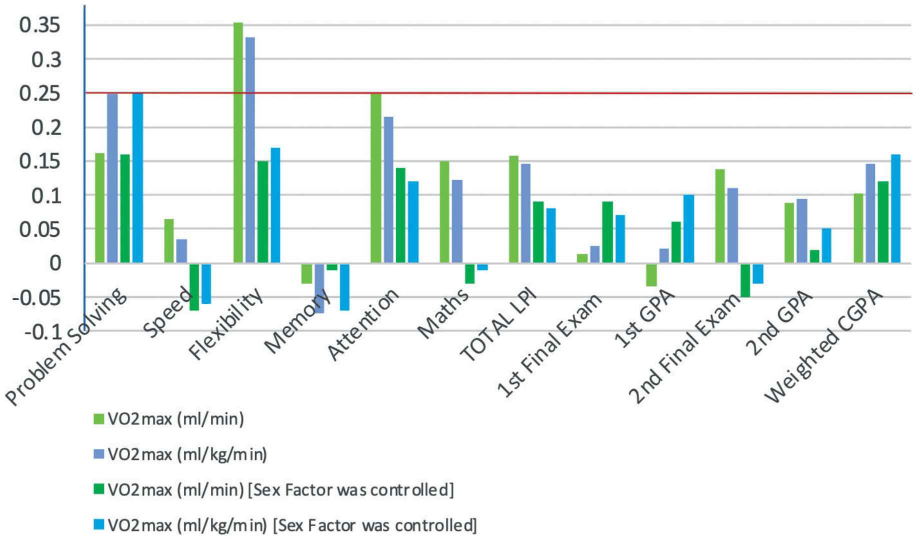

Figure 5. The correlation of aerobic capacity with cognitive and academic performance according to the effect of sex confounding factor. Significant parameters: 'Problem Solving', 'Flexibility (only sex factor was not controlled)' and 'Attention (only sex factor was not controlled)' ($p < 0.05$). The horizontal bold line is the limit of significance. CGPA, cumulative grade point average; GPA, grade point average; LPI, Lumosity performance indices.

higher ($p < 0.05$). However, spatial memory and problem-solving category scores of those who did not study regularly were found to be significantly higher ($p < 0.05$).

Finally, no significant correlation was found between the caffeine (tea/coffee) consumption of medical students and their aerobic capacity which was measured by VO_{2max}.

Discussion

A positive relationship between physical activity and VO_{2max} in the literature (Åstrand et al. 2003) was also found in the results of our study (Table 3). We compared cognitive and academic performance with VO_{2max} in our study, assuming that individuals with high activity would have high VO_{2max}. In this study, we wanted to find this effect in a sample of young adults with high academic achievement, in line with the evidence in the literature, because we realized that this subject has not been studied enough on young adult people who have high academic achievement. We found that higher aerobic capacity increased problem-solving, flexibility, and attention abilities, which are cognition parameters (Fig. 5).

While conducting our study analysis, we detected the presence of confounding factors caused by sex, which we see not considered in the literature and may affect the results of the study. We saw very significant differences in body composition analyses according to sex (Table 2). And the IPAQ, a valid scale we used in the study, we found that male was more physically active than female (Fig. 2). When we look at the cognitive game results by sex, we also saw that there were significant differences in the results of some games, if not all (Table 4; Fig. 3).

However, we predicted that this confounding factor would affect almost all the parameters and findings of the study in the continuation of analyzes and therefore we controlled for this factor in all our analyzes. In the end, we found that higher aerobic capacity increased only problem-solving ability, which is a cognition parameter (Fig. 5).

On the other hand, we could not detect a statistically significant effect of aerobic capacity on academic performance (Fig. 5). We suspect that the already high level of academic achievement of these individuals may be an obstacle to this statistically significant increase.

VO_{2max} and cognitive performance

In the literature, the benefits of exercise and physical activity on cognitive performance have been reported in many studies. The effects of structural changes caused by exercise are not the same in all areas of the brain. In addition to the increase in the volume of the gray matter in the frontal, temporal and cingulate regions of the cortex, an increase in the number and curve of blood vessels were detected all over the brain (Colcombe et al. 2006; Bullitt et al. 2009). While most studies focused on "gray matter" in the cortex, it was reported that white matter increased as much as gray matter in the elderly after 6 months of exercise (Colcombe et al. 2004). And again, in the elderly, it was stated a correlation between white matter integrity and VO_{2max} scores after one year of fitness training (Voss et al. 2013). In most of the studies, it was found that cognitive function is related to aerobic capacity levels, especially in adolescents and adult populations (Shay and Roth 1992; Buck et al. 2008; Pontifex et al. 2011; Voss et al. 2011, 2013; Pantzar et al. 2018). These studies suggest the fact that aerobic activity is truly a powerful modulator in structural brain plasticity. We can say that we have seen this effect (especially cognitive performance), albeit relatively, in our study conducted with the young adult age group.

VO_{2max} and attention

The 'Eriksen flanker task' is most used to measure selective attention and high-level aerobic capacity was associated with more correct responses in this test. Functional magnetic resonance imaging (fMRI) showed that children with a high level of aerobic capacity had more effective neural activation and cognitive adaptation than the children with a lower aerobic capacity level during the Eriksen flanker task test (Pontifex et al. 2011; Voss et al. 2011; Chaddock et al. 2012). In our study, we came to this conclusion from the results of the Lumosity test and found that VO_{2max} increased inhibitory control/selective attention (when sex was not considered).

VO_{2max} and flexibility

We found that the VO_{2max} value increased the cognitive flexibility when the sex factor was not considered. In the literature, higher levels of aerobic capacity were associated with better selective attention and cognitive flexibility in adolescents. Moreover, by applying the diffusion model, reaction time (RT), correct response number, selective attention, and cognitive flexibility scores were evaluated separately (Westfall et al. 2018). The scores in our study were the standardized scores provided by lumosity for the games, and lumosity did not present these scores to us separately as RT/number of correct responses.

Higher aerobic capacity was associated with better cognitive flexibility (Westfall et al. 2018). Similarly, higher VO_{2max} was correlated with faster reaction on tests measuring selective attention in children and high school students (Kao et al. 2017; Wengaard et al. 2017).

Exercise intensity and cognitive flexibility category scores increased in tasks requiring visual-spatial processing considerably (Masley et al. 2009). In order to interpret this situation, it would be useful to conduct more studies in the adult young sample group.

VO_{2max} and memory

It was reported that students aged 9–10 with higher aerobic capacity performed better in the working memory and selective attention test (Scudder et al. 2014). In addition, children with higher levels of aerobic capacity performed better in cognitive memory tests (Chaddock et al. 2011). But we found no significant correlation between VO_{2max} and cognitive performance parameters, spatial memory, and working memory categories. The difference between our results and those reported in the literature may be due to the differences in factors such as age group and education level of the samples.

VO_{2max} and Maths/Speed

Higher levels of aerobic capacity were reported to be associated with better mathematics and reading performance (Davis and Cooper 2011; Bass et al. 2013). In another study, participants with high VO_{2max} levels had less gray matter volume in certain cortex areas and also performed better on the math section of the wide range achievement test (WRAT) (Chaddock-Heyman et al. 2015). However, we did not detect a significant difference in the Maths and Speed scores. In order to interpret this situation, it would be useful to conduct more studies in the adult young sample group.

VO_{2max} and problem solving

A study reported that individuals with high aerobic capacity performed better especially by cognitive performance and cycle ergometer tests (Shay and Roth 1992). The relationship between aerobic exercise time and cognitive performance in the elderly without cognitive inefficiency over 65 years of age was examined, and it was shown that there was an amount-response relationship between tasks requiring visual-spatial processing and aerobic exercise time (Vidoni et al. 2015). Like these studies, we found that the "problem solving" test category scores were higher in individuals with high aerobic capacity, based on the results of the "Masterpiece" game, which measures visuospatial reasoning, one of the cognitive performance functions. Additionally, we were able to replicate this result when we controlled for the sex as confounding factor. If exercise strengthens the problem-solving cognition ability of medical students, it is understood that those dealing with medical education should pay attention to this issue. In this respect, further studies are inevitably needed.

Volunteer form results

In addition, we found that those who said that they did not work regularly in 'volunteer form' had more developed memory and problem-solving functions. We can conclude that computer usage skills and gaming experience have an impact on cognitive performance scores from results of volunteer form, too. However, in the volunteer form, these questions were subjective, and we questioned how the person perceived himself. This situation should be standardized in further studies, and cognitive performance measurement should be done.

VO_{2max} and academic performance

One of the main issues we wondered about in our study was the possibility that VO_{2max} might have a positive relationship with academic performance. Higher physical activity was reported as related to higher academic performance and cognitive functions of brain (Castelli et al. 2007; Hillman et al. 2008; Davis and Cooper 2011; Van Dusen et al. 2011; Han 2018).

In contrast, some studies reported that there was no relationship between physical activity and academic performance tests (Sallis et al. 1999; Tremblay et al. 2000; Coe et al. 2006). There was no significant correlation between VO_{2max} and academic performance in our study as well. The possible reasons for this result may be the presence of other factors that affect academic performance, such as IQ (intelligence quotient) level, systematic study and participation in classes. We could not question these factors in detail, as we subjected the participants to extensive testing and questioning, enough. This situation can be considered as one of the limitations of our study.

Other limitations in the study were as follows:

- Aerobic capacity measurement and cognitive performance tests were performed on different days since appointments were made with the students in the free time remaining from the classes.
- Computer usage skills and gaming experience affected cognitive performance scores. If there was an opportunity to take a larger study universe and standardized questions, the study could be generalized to a larger universe with a larger sample group.
- Functional brain imaging techniques combined with cognitive performance assessment could not be used due to financial limitations.
- Although we questioned caffeine habits, we may not have been able to standardize it enough as this is such a broad topic.
- The questions in the Volunteer Form were not from a valid scale and were subjective questions.
- As a confounding factor, the menstrual cycle in female was not controlled.

Conclusion

In this study done with medical students who are young individuals with high academic achievement, although we confirmed the existence of positive effect of high aerobic capacity on cognitive performance stated in the literature, we couldn't confirm this for all cognitive domains or academic performance. These results suggest that more comprehensive studies are needed on this subject.

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