Original Article

The Relationship between Basal Ganglia Volume and Audiovisual Reaction Time in Turkish Elite Athletes

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Abstract

Background: In this study involving young adult elite athletes and healthy sedentary individuals, volumetric analyses were performed on basal ganglia (BG) involved in the coordination of motor movements. **Aims and Objectives:** In a group of athletes with high coordination speed, potential relationship between BG volumes and audiovisual reaction time of acquired-trained hand movements was explored by examining whether these individuals had significant differences in terms of BG volumes. **Materials and Methods:** Nineteen elite athletes aged between 19 and 25 years (9 male and 10 female) and 20 sedentary subjects (10 male, 10 female) were included. Gender, age, height, weight, and body-mass index (BMI) were recorded. In each group, audiovisual reaction time and stereological basal ganglia volumes were assessed and statistically analyzed. **Results:** Elite athletes react more rapidly to auditory stimuli than visual stimuli. As compared to sedentary individuals, elite athletes exhibited significantly shorter visual reaction time and only numerically shorter (statistically insignificant) visual reaction time. Left BG volume was higher in both groups, compared to right side). **Conclusion:** Our data may contribute to the construction of a database of normal BG morphology and provide useful information for clinicians and athletes.

Keywords: *Basal ganglia, elite athletes, nuclei basales, reaction time, stereology, volume*

Introduction

Classically, nuclei basales which are called basal ganglia (BG) have been intriguing anatomical structures due to their concealed location in between brain convolutions. BG or basal nuclei consist of five pairs of nuclei located deep in cranial hemispheres and are referred to as *nucleus caudatus, putamen, globus pallidus, substantia nigra*, and *nucleus subthalamicus*. Nucleus caudatus, putamen, and globus pallidus are collectively termed as "corpus striatum."[1,2]

BG has been shown to be involved in the coordination of motor movements as well as in mental and emotional functions. Their main functions include utilization of input coming from the sensory cortex, thalamus, and brainstem; conveyance of information from multiple nonspecific areas to somatomotor areas; regulation of impulses associated with muscle tone, posture, and movement; and regulation of muscular movements through effects on the activity of motor centers within the brainstem.[2] In addition, BG is known to be associated with mental and emotional functions such as comprehension and appraisal.[2-5]

The harmonious activity of the motor and sensory cortices to regulate movements during physical activity is referred to as sensory-motor integration. The primary motor cortex utilizes the sensory afferent input very efficiently to ensure a concerted activity between muscle groups.[6] An examination of the association between the sensory-motor system and BG in athletes indicates that this system has important roles in the integration of motor, sensory, and central systems as well as in the processes involved. Visual and auditory reaction input as well as the information obtained from muscles, skin, tendons, and joints are processed within this system. Therefore, the sensory-motor system has significant roles in the perception, planning, execution, and regulation of the movements during physical activity in athletes. Furthermore, it has an important role in the protection against injury and the level of sportive performance due to its complex structure and intricate connections.

Until now, although many studies have been published regarding the functional, volumetric, or pathological changes

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according to age and gender in disease processes involving BG, none have specifically looked at the association of BG volume with reaction times and gender in normal healthy individuals and elite athletes, and only scarce data have been made available recently, regarding the age-related effect of exercise on BG.[7,8] Similarly, gender-based comparisons among young adult elite athletes using different methodologies are few.[4,5] In addition, our literature search for BG volume studies using stereological methods did not yield any published data that assessed the association of BG volume with acquired-trained repetitive movements and audiovisual reaction time.[8-13]

In the present study involving young adult elite athletes and healthy sedentary individuals, volumetric analyses were performed in BG areas involved in the coordination of motor movements. For this purpose, significant volume differences in a group of sportsmen with high coordination speed were explored, in an effort to identify potential links between BG volumes and audiovisual reaction time in acquired-trained hand movements.

Materials and Methods

The study is a prospective comparative experimental study. Following approval from the Ethics Committee for Non-Interventional Studies of Dokuz Eylul University Medical Faculty, audiovisual reaction time and morphological (height, weight, and body mass index [BMI]) measurements of elite athletes and sedentary individuals were performed at the Department of Anatomy and Sport Academy. Then, each participant underwent a cranial magnetic resonance imaging (MRI) examination at the radiology department of Dokuz Eylul University Medical Faculty Hospital. Data were statistically assessed.

A total of 19 right-handed elite athletes (9 male and 10 female) aged between 19 and 25 years with no audiovisual impairment and 20 otherwise healthy sedentary individuals (10 male and 10 female) aged between 18 and 28 years were included in the study. Audiovisual reaction tests and MRI examinations could not be performed in some cases due to poor adherence. The number of cases (*n*) who underwent assessment for each parameter was indicated in tables.

Elite athletes included those who achieved a good performance level or a ranking in a team or individual sports activity at the national level, Olympic Games, or World Championships and who followed a consistent training program for at least 10 years.[14] Ten of the elite athletes were involved in a team sport such as basketball or volleyball, and 9 were involved in an individual sport activity, namely swimming. A total of 20 age- and sex-matched, right-handed, healthy, and sedentary individuals (10 male and 10 female) with no regular physical activity served as controls.

Radiological examination

BG measurements in both study groups were performed using T1–T2 weighed three-dimensional gradient echo images 3-Dimensional T1-Weighted Turbo Field Echo acquired with an MRI device 1.5-T unit (Integra, Philips, the Netherlands). Sedentary group images were obtained from healthy at the discretion of the radiologist right-handed individuals. Specifically, conventional spin echo (SE) T1A cross-sections (Repetition time [TR]: 500–700 ms; Echo time [TE]: 10–30 ms) were obtained in sagittal and axial planes, and T1-weighed sagittal images were recorded. No sedation or IV contrast enhancement was used. The image acquisition and recording of measurements were performed by the same operator to minimize the risk of error.

In both groups, manual stereological measurements were performed in sagittal 0.3 mm cross-sections in T1-weighed MRI images to determine BG (caudate and lentiform nuclei) volumes according to side (left vs. right) and gender. All BG structures other than the corpus striatum were excluded from measurements, due to their small size and technical inability to acquire image sections <0.3 cm in thickness.

Stereological volumetric method

Stereological assessment with a point counting method involves the use of a marked scale in randomly selected positions to assess cross sections. The counted points are summed and multiplied by the thickness of the cross-section to yield the volume. The following formula was used for the point counting method, $V = t \times ([(SU) \times d]/SL)\ 2\times \Sigma P$, where *t*, SU, *d*, SL, and p correspond to cross-section thickness, MRI scale unit, distance between two points in the grid, scale length, and the number of points counted, respectively.[4,15-19] In volumetric assessments, the sagittal and axial MRI cross-sections were measured to allow that the optimal plane corresponded to the smallest diameter of the anisotropic structure.

A stable and consecutive cross-section thickness of 0.3 cm was maintained to reduce the error of margin. For each participant, all cross-sections were separately evaluated for the left and right hemispheres, and the point counts were performed manually [Figure 1]. These mathematical processes are known as Cavalieri's principle.[4,5,15,17,20]

Audiovisual reaction time measurement method

Visual reaction time

A Lafayette Multi-Operational Apparatus for Reaction Time (MOART) Reaction Device (Lafayette, USA) was used. This device can record auditory and visual reaction time with 1/1000 s units. For visual reaction recording, the lights on the right and left buttons randomly flash without any visual stimuli to detect the visual reaction time. Before recording, each participant performed five repetitions of a practice test.

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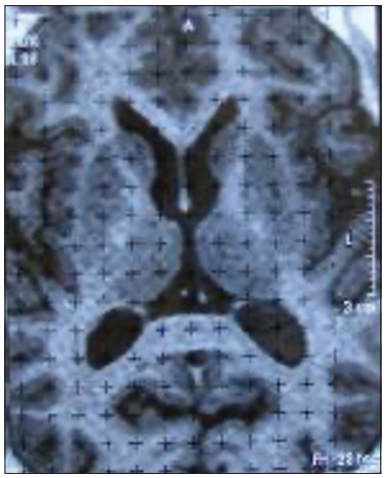


Figure 1: Stereological nucleus lentiformis and nucleus caudatus measurement on axial T1-weighted magnetic resonance imaging section

Auditory reaction time

A Lafayette MOART Reaction Device (Lafayette, USA) was used. This device can record auditory and visual reaction time with 1/1000 s units. During the test, the participant is asked to press a button in the middle of the device using his/her dominant hand upon being exposed to auditory stimuli given at random intervals. Before recording, each participant performed five repetitions of a practice test. Measurements were repeated at least 10 times in all participants, and the average value was recorded.

Subjects were excluded from the study if they had osteoarthritis, structural deformity, history of head or body trauma, active infection, or any health problem during the study period. Also excluded were the subjects with disability precluding MRI examination and those with claustrophobia and/or anxiety.

Statistical methods

The normality of the distribution of the continuous variables was checked with Shapiro–Wilk test, whereas Box's M statistics were performed for the homogeneity of the variance-covariance matrices. Since the assumptions of the parametric tests were met, dependent variables were used in a "variance analysis on repeated measures" with 3 factors with repetition of one factor to reduce the error. For variables without repeated measurements, a 2-factor variance analysis and independent two-group *t*-test were performed for variables meeting the assumptions of the parametric tests.

Mann–Whitney *U*-test was used for variables not meeting the parametric test assumptions. Association between variables was evaluated with Pearson and Spearman rho correlation coefficients. Results were expressed as mean ± standard deviation, median, and correlation coefficients. A $P < 0.05$ was considered statistically significant. SPSS 22.0 statistical software pack was used for analyses (SPSS Ver. 22.0, SSPS Inc., Chicago, IL, USA).

Results

Physical data for elite athletes and sedentary individuals

Age, gender, weight, height, and BMI data were recorded and compared between the two age- and gender-matched groups. In females, there were significant height and weight differences between athletes and sedentary subjects ($P = 0.05$, $P = 0.033$, respectively). In males, a significant BMI difference was found between athletes and sedentary subjects ($P = 0.041$) [Table 1].

Data for audiovisual reaction time

Audiovisual reaction time data were obtained from right-handed athletes and sedentary individuals for statistical analysis. Table 2 shows the reaction times in millisecond units in both groups. A significant difference was noted in auditory and visual reaction times between the two groups ($P_1 = 0.001$). This difference was found to vary according to the groups tested (P_2 interaction [auditory and visual × Group] = 0.001). The mean visual reaction time among athletes was higher as compared to the mean auditory reaction times, with no gender difference (P_3 interaction [visual and auditory × Gender] = 0.825, P_4 interaction [visual and auditory × Group × Gender] = 0.618). Thus, as compared to sedentary subjects, athletes have a shorter reaction time to auditory stimuli than visual stimuli.

In right-handed athletes with higher right BG volume, auditory reaction times were shorter, i.e., more rapid, than visual reaction times. As compared to sedentary individuals, athletes were significantly more rapid in terms of auditory reaction time. Although athletes had more rapid reactions to visual stimuli than sedentary individuals, the difference was not statistically significant. It was assumed that a larger sample size could have yielded more significant results. Although these data were recorded independent of gender, female and male athletes had more rapid reaction times to auditory stimuli than sedentary males and females, although the differences were not significant.

Stereological volume analysis data for basal ganglia

Caudate nucleus volume

Right and left caudate nucleus volumes were recorded in cubic centimeters in the two age- and gender-matched groups for statistical analysis [Table 3]. In general, there was a significant difference between right and left caudate nucleus volumes in athletes and sedentary subjects ($P < 0.05$), with higher left-sided volume measurements ($P_1 = 0.045$).

However, these differences between athletes and sedentary subjects ($P_2 = 0.925$) and differences regarding gender ($P_3 = 0.074$) were not significant. Thus, the right and left caudate nucleus volume did not differ significantly

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Table 1: Physical data for athletes and sedentary individuals

	Female			Male		
	Athlete, *n* Mean±SD Median	**Sedentary, *n* Mean±SD Median**	***P***	**Athlete, *n* Mean±SD Median**	**Sedentary, *n* Mean±SD Median**	***P***
Age	10	10	0.104	9	10	0.776
	20.900±1.286	22.700±3.093		22.555±1.943	22.200±3.190	
	20.000	21.500		22.000	21.000	
Height (cm)	9	9	0.050*	9	10	0.869
	1.718±0.064	1.660±0.030		1.767±0.065	1.762±0.082	
	1.7750	1.650		1.770	1.750	
Weight (kg)	9	9	0.033*	9	10	0.07*
	60.222±3.763	56.222±3.492		70.222±7.870	80.100±13.370	
	60.000	56.000		69.000	82.000	
BMI	9	9	0.873	9	10	0.041*
	20.388±1.060	20.481±1.333		22.500±2.330	25.843±4.223	
	20.500	20.569		23.000	26.524	

*$P \leq 0.05$. SD: Standard deviation, BMI: Body mass index

Table 2: Audiovisual reaction time data for athletes and sedentary individuals

Group	**Gender**	**Reaction time - auditory (ms), *n* Mean±SD Median**	**Reaction time - visual (ms), *n* Mean±SD Median**	***P***
Athlete	Female	9	9	P_1=0.001*
		471.333±59.902	224.777±15.417	P_2=0.001*
		464.000	223.000	P_3=0.825
	Male	9	9	P_4=0.618
		422.777±51.664	192.555±12.640	
		413.000	199.000	
Sedentary	Female	9	9	
		432.122±46.115	281.222±36.591	
		430.000	275.000	
	Male	10	10	
		446.000±60.929	288.800±63.308	
		457.500	262.000	

*$P \leq 0.05$. SD: Standard deviation

according to group and gender ($P_4 = 0.578$). Interestingly, left and right caudate nucleus volumes were smaller among athletes than sedentary individuals, although the difference was not significant.

Lentiform nucleus volume

Left and right nucleus lentiform volume data in the two age- and gender-matched groups were recorded in cubic centimeters and statistically analyzed [Table 4]. In both groups and genders, lentiform nucleus volume was higher on the left, although the difference was not significantly different ($P_1 = 0.903$). This result was independent of the group (i.e., athlete or sedentary) ($P_2 = 0.338$) and gender ($P_3 = 0.477$). Statistically, the left and right lentiform nucleus volumes did not differ according to group and gender ($P_4 = 0.863$).

Overall, left caudate nucleus and left lentiform nucleus volumes were higher as compared to the right in both elite athletes and sedentary individuals.

Discussion

Reaction time is a natural response reflecting the duration of time between a stimulus and the first moment of muscular response or movement and corresponds to the sum of time from the reception of an immediate and unpreceded signal and the response to that signal. Previous literature has reported higher auditory and visual reaction speed among elite athletes compared to lay individuals. Audiovisual reaction time is a significant and determining factor in many branches of sports and is known to be feasible to improve with regular training. Furthermore, shorter reactions to visual stimuli have been reported among well-trained athletes as compared to athletes with poorer training status. Furthermore, responses to auditory stimuli have been generally more rapid as compared to responses to visual stimuli,[21] similar to our observations where athletes responded to auditory stimuli faster than visual stimuli. Furthermore, in our study, athletes exhibited significantly more rapid auditory reactions than sedentary subjects. In contrast, elite athletes participating in our study also had shorter visual reaction times as compared to sedentary individuals, but the difference was insignificant. However, a larger sample size could have yielded significant differences. Similarly, these response times were shorter in male athletes as compared to sedentary males, although there were no significant differences. Interestingly, among female athletes, auditory reaction times were longer than their visual reaction times. Although the visual reaction time among female athletes was shorter than that of the

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Table 3: Nucleus caudatus volume data in cm³ for athletes and sedentary individuals

Group	Gender	Right nucleus caudatus, *n* Mean±SD Median	Left nucleus caudatus, *n* Mean±SD Median	*P*
Athlete	Female	10	10	P_1=0.045*
		3.548±0.734	3.588±0.522	P_2=0.925
		3.539	3.731	P_3=0.074
	Male	9	9	P_4=0.578
		3.365±0.556	3.551±0.409	
		3.380	3.635	
Sedentary	Female	10	10	
		3.754±0.606	3.741±0.602	
		3.641	3.881	
	Male	10	10	
		3.526±0.394	3.787±0.411	
		3.571	3.922	

*$P \leq 0.05$. SD: Standard deviation

Table 4: Nucleus lentiformis volume data in cm³ for athletes and sedentary individuals

Group	Gender	Right nucleus lentiformis, *n* Mean±SD Median	Left nucleus lentiformis, *n* Mean±SD Median	*P*
Athlete	Female	10	10	P_1=0.903
		4.684±0.662	4.498±0.510	P_2=0.338
		4.751	4.337	P_3=0.477
	Male	9	9	P_4=0.863
		5.303±1.148	5.308±1.375	
		5.56640600	4.980	
Sedentary	Female	10	10	
		5.476±0.666	5.535±0.448	
		5.485	5.612	
	Male	10	10	
		5.021±0.741	5.197±0.812	
		4.974	5.134	

$P \leq 0.05$. SD: Standard deviation

sedentary female subjects, the difference was insignificant. Based on gender, female and male athletes had shorter auditory response times than sedentary female and male subjects, again with no significant differences.

The motor performance among athletes is determined by several skills such as endurance, strength, and speed. Previous experimental studies showed that motor speed is coded in the BG, sensory-motor cortex, and cerebellum. Again, a previous study of motor speed difference between strength and endurance athletes showed neurofunctional and structural differences specific to motor speed in the peripheral and central nervous systems.[6] This has led to the question whether "strength athletes" had a unique structural attribute that allowed them to perform simple foot movements much more rapidly as compared to "endurance athletes."

Several studies have assessed the correlation between BG volume, gender, and age among healthy individuals.[4,15] In our study involving right-handed elite athletes and sedentary individuals, left BG volumes were larger than right BG volumes independent of age, gender, and physical activity status. Athletes with larger right BG were found to respond more rapidly to auditory stimuli than visual stimuli. However, the volume measurements were not associated with the reaction times in sedentary individuals.

It has been previously shown that automatic motor movements are modulated by BG, and regular exercise has beneficial effects on cortical activities responsible for attention and cognition through effects that facilitate neuronal transmisyon.[22-24] Human studies also showed that putamen and the caudate nucleus play fundamental roles in performance-related processes that involve cognitive control, motor integration, and motor reaction.[7]

In the study by Chaddock *et al*.,[24] no associations were observed between putamen and caudate nucleus volumes and sports performance in children participating in aerobic fitness activities, whereas a link was observed between globus pallidus volume and physical performance, which was explained in the basis of the association between globus pallidus and efferent stimuli conveying motor instructions. Our study bears some similarity to that study in assessing the lentiform and caudate nucleus volumes. In our study, the volume of the right and left caudate nucleus was smaller among athletes than in sedentary subjects, although the difference was insignificant. On the other hand, right-handed elite athletes with larger BG volumes had shorter auditory reaction times than visual reaction times, irrespective of gender. However, our study did not aim to assess the performance among athletes. In sportive activities where hearing is a contributory factor to performance, this attribute may have positive implications.

When BG was separately evaluated, significant differences in the volume of right and left caudate nuclei were found in both groups, with significantly higher left-sided volume measurements. Again, the volume of the lentiform nucleus was higher on the left side in both groups and genders. In both groups of participants, left-sided caudate nucleus and lentiform nucleus volumes were higher as compared to right-sided volumes.

Corpus striatum is involved in the acquisition and maintenance of motor skills. Several studies have shown that motor learning induces neuronal changes in striatum.[25,26] In Park *et al*.'s study,[25] examining basketball players and healthy controls using three-dimensional MRI volumetry, morphological volume expansion was found in the striatum of basketball players as compared to

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healthy controls.[25] According to the authors of that study, persistent repetition and execution of motor skills relevant to basketball as well as repeated motor performances may lead to plastic structural alterations in the human striatum. In sports such as basketball requiring double-handed coordination and visuomotor activity skills, it has been purported that putamen is responsible for the execution of complex movements such as ball driving, ball chasing, and ball throwing.[25] In the same line of thinking, we decided to compare MRI-based BG volume measurements in athletes and sedentary individuals due to their role in motor control of learned-acquired movements.

Previously, ballerinas have been reported to have lower left putamen volumes,[6] in addition to data indicating lower left caudate nucleus volumes in professional divers.[27] Furthermore, male javelin throwers and male long jumpers had higher ventral striatum volumes bilaterally as compared to controls.[28] In our study, we found statistically significant differences between right and left caudate nucleus volumes, with the latter exhibiting larger volumes. However, this difference was not statistically significant between sedentary individuals and athletes and between genders. A larger sample size could have yielded more meaningful results. The volumes of the right and left caudate nuclei were lower among athletes than in sedentary subjects, similar to the data reported in ballerinas and professional divers.

Hänggi *et al*.[26] measured age-corrected intracranial volume, right and left total gray matter volume, right and left total mid-sagittal cortical surface area, and mean cortical thickness in professional handball players versus controls and found higher BG volumes among handball players, although the difference could not reach statistical significance.[26] Furthermore, in another study assessing the association between BG volume, age, and professional training duration, no significant differences between athletes and controls could be detected for either variable. In contrast with that study, we were unable to evaluate the relation between training duration and performance, since all the elite athletes participating in our study were required to have a minimum regular training duration of 10 years. In that study, there was no information on the dominant hand. Although subjects had to use both of their hands during handball matches, information on the dominant hemisphere would have provided further insights into their findings. Due to such considerations, only elite athletes and controls with right-hand dominance were included in our study, which showed larger BG volumes on the left than on the right in both athletes and sedentary individuals, probably due to the fact that the left brain comprised the dominant hemisphere in our participants. However, there was no difference when compared with the sedentary group. In addition, the BG sizes of athletes were higher than sedentary individuals in our study, although the difference was not statistically significant. It is possible that similar studies with larger sample size may allow more meaningful conclusions on that matter.

Our results showed significantly shorter auditory reaction time than visual reaction time in athletes, suggesting a more rapid responsiveness to auditory stimuli in these individuals. Therefore, athletes might have developed concentration habits mainly for responding to auditory stimuli rather than visual stimuli during sportive activities.

Our study has several limitations. Our sample size was relatively limited due to a number of factors such as the low number of volunteering young adult elite athletes as well as the claustrophobic subjects who were unable to undergo MRI examination. Furthermore, several BG structures such as the subthalamic nucleus, nucleus accumbens, and substantia nigra were excluded from analyses due to their small size and poor image quality on MRI. Since the putamen and globus pallidus could not be readily discerned, they were collectively measured under the umbrella term of "lentiform nucleus." Furthermore, subjects who refused to perform 5 repetitions of preparatory tests and 10 consecutive repetitions of formal measurements were excluded.

Conclusion

Identification of differences between professional elite athletes and sedentary subjects is important using the volumetric evaluation technique through stereological analysis. The technique is unbiased, easy, and simple.[15,17,29-31] Assessment of the effect of motor coordination and motor movement control on BG volume changes may provide valuable information, not only for elite athletes but also for improving motor coordination in diseases affecting the neuromuscular system.[27,28] Establishing reference ranges for BG volumes and audiovisual reaction time among elite athletes may allow researchers to develop selection criteria in different fields of sports for the early identification of potential elite athletes. To the best of our knowledge, our study is the first of its kind in assessing the effect of exercise on BG volume as well as the correlation between BG volume and audiovisual reaction time.

Further cross-sectional, multidisciplinary studies comparing athletes from different branches of sports that also include volume measurements in other relevant brain structures affecting motor control (e.g., cerebellum) may shed further light on this subject. We believe that our results represent a valuable contribution to the knowledge on BG morphology in athletes and sedentary individuals and may prove to be important for sportspeople and clinicians alike.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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