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# Analysis of changes in brain morphological structure of taekwondo athletes by diffusion tensor imaging

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ABSTRACT

*Objective:* Taekwondo, which is the most preferred sport among the martial arts, is known to improve individuals physically, spiritually and mentally. The aim of this study is to reveal the effect of teakwondo sport on the brain and brain structures.
*Design;:* 30 taekwondo athletes and 15 control groups were included in this study. Diffusion tensor MR images of each participant were taken. The information was obtained by the self-declaration of the athletes, whether they were sports years, amateur or elite.
*Method:* Total brain volume and volumes of white matter, gray matter, frontal lobe, precentral gyrus, corticospinal tract, basal nuclei, postcentral gyrus, hippocampus and amigdala and the ratio of these volumes to total brain volume were evaluated statistically between the groups using MriCloud software and ROIEditor program.
*Results:* An increase in total brain volume, gray matter, frontal lobe and precentral gyrus volume in athletes was associated with taekwondo training. When the ratio of brain parts to total brain volume was examined, it was determined that there was a difference in the ratio of gray matter, white matter volumes in amateur athletes, right frontal lobe, left corticospinal tract, right postcentral gyrus volumes in elite athletes, and left postcentral gyrus volumes of both athletes compared to sedentary individuals.
*Conclusions:* The increase in the volume of gray matter, frontal lobe, postcentral gyrus and corticospinal tract together with the brain volume shows that taekwondo exercise contributes to physical, spiritual and mental development.

## 1. Introduction

Taekwondo, which is the most preferred sport among the martial arts, contributes to the physical, spiritual and mental development of individuals by teaching them to be respectful, self-confident and patient, as well as concepts such as courage, perseverance, determination, sudden decision-making, and staying vigorous (Kim et al., 1999, 2015). Changes in brain parts due to trauma, dehydration or hyponatremia have been investigated in different sports branches including taekwondo (Bernick et al., 2015). However, as far as we know, there are no studies on how taekwondo sports affect the brain and brain structures. In this context, in the presented study, it was aimed to determine the differences between the brain and brain parts of the groups in taekwondo, which is a sport that includes attention, posture, thinking, quick decision making and acting, and developing coping methods by remembering the difficulties encountered before. In line with this purpose, taekwondo sport is practiced in the frontal lobe that governs the psychic world of the person, nuclei basales responsible for the planning, initiation and maintenance of motor movements, the precentral gyrus known as the motor cortex, and the corticospinal tract that carries the motor senses originating from here, the hippocampus and amygdala, the parts of the brain responsible for learning and memory. It is aimed to determine the

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changes created in the volumes of the postcental gyrus of the sensory center, which is the place where all the events in our outer world are processed in the brain as sense**.** Against the notion that neurons are not renewed and reduced after brain development is complete, recent studies have shown that brain cells can repair themselves for life and that new neuron formation continues (Yücel et al., 2020). It is known that learning leads to structural changes in the brain, thanks to neuroplasticity, which is defined as the changes that occur in neurons due to different stimuli from the environment and in the synapses that neurons make with each other, reorganization ability and the power required for the adaptation of the organism to the environment (Li et al.,2014; Sagi et al., 2012). The structural effects of learning a sport that people of all ages are interested in or its continuous practice on brain neuroplasticity attract the attention of different disciplines such as neurology, neuropsychology, cognitive neuroscience, psychiatry, and physiology (Hernández-Mendo et al., 2019; Voelcker-Rehage and Niemann, 2013). Magnetic resonance imaging (MRI), which is widely used among routine radiological examinations in which studies and researches are carried out all over the world, allows determining the changes in the brain caused by sports activities (Özdurak et al., 2021). With MRI, volumetric analysis, shape analysis, voxel-based morphometry (VBM) calculations, cortical thickness measurement and tissue analysis, diffusion tensor imaging (DTG) and fMRI technique can be used to evaluate both structural and functional of the human brain (Smith et al., 2007; Özdurak et al., 2021).

## 2. Method

### 2.1. Volunteer selection

This study consists of participants between the ages of 18–31 who agreed to participate in the study after reading the voluntary consent forms in which it was stated that their identity information would not be used or found through MR images or in different ways. The study consists of sedentary, amateur and professional groups of 15 people each. In order to ensure the homogeneity of the created group, only male volunteers were included in our study. In order for the dominant brain hemispheres to be on the same side and the asymmetries between the hemispheres do not interfere with the detection of differences that may occur between the brain structures, only volunteers using their right limbs were included in our study.

The sedentary group included in the study, who did not participate in any sports activities, with a mean age of 26.20 ± 4.14 years were included. In addition, those with any neurological, psychiatric and neurodegenerative disorders that would affect the anatomy and physiology of the nervous system, and those with a history of using any addictive substance or drug such as heroin were not included in the study.

The amateur group consists of athletes with an average age of 22.80 ± 3.28 who have been practicing taekwondo 3 days a week for at least three years. The professional group consists of taekwondo athletes between 7 and 12 years of age, who train at least 6 days a week and received the title of national athlete, with an average age of 23.27 ± 1.67.

As in sedentary individuals, individuals who had any neurological, psychiatric and neurodegenerative disorders that would affect the anatomy and physiology of the nervous system, and those with a history of using any addictive substance and drug such as smoking, alcohol, heroin were excluded from the study.

### 2.2. Image acquisition

Images were obtained in Kayseri City Education and Research Hospital Radiology department with a 3 T MRI device (Siemens Magnetom Skyra, Netherlands). DTI sequence was a twice-refocused spin-echo sequence based on single-shot echo-planar acquisition. Diffusion sensitizing gradients were applied along 20 orthogonal directions using two b values (0 and 1000 s/mm2) and other DTI parameters were: TR= 4900 ms, TE= 95 ms, Number-of-Slice= 36, Flip Angle= 90$^{o}$, FOV= 230 × 230 mm2, matrix= 128 × 128 and slice thickness= 3.5 mm (voxel size 1.8 × 1.8 × 3.5 mm). The acquisition time per dataset was approximately 6 min. The original raw data were anonymized and transferred from the scanner to the DICOM format.

The data in our study were obtained using a cloud-based software MriCloud (http://www.braingps.mricloud.org) and an image processing program ROIEditor (https://MriStudio.org) using MRI taken in DICOM format.

### 2.3. What is parcellation?

From the past to the present, the division of the cerebral cortex into sections (plots) first began in 1786 when Vicq D′Azry tried to reveal the folds in the human brain by comparing the folds of the animal brain (Pearce, 2005). In the 20th century, Korbinian Broadman divided the cortex into 52 different anatomical and functional regions, with an important landmark discovery in the subdivision processes, which is still valid today (Zilles and Palomero-Gallagher, 2001). From the middle of the 20th century, with the development of neuroimaging techniques, various brain atlases began to be created and a three-dimensional coordinate field was first developed by Talariach in 1967, which was aimed to assist neurosurgery operations (Talairach et al., 1967). He later developed this area and created a brain atlas (Talairach and Tournoux, 1988). In the following years, an alternative to the MNI (Montreal Neurological Institute) Talariach atlas was developed by referring to Talariach and Tournoux atlas from MR images of young healthy subjects (Evans et al., 1992). With the MNI atlas developed by many similar studies, the brain MR image was divided into 142 sub-regions and each region was named (Aubert-Broche et al., 2006). Tzourio-Mazoyer et al. (2002) created an AAL (Automatic Anatomical Labeling) atlas by configuring 45 segments in a hemisphere with an MR image mapped to the MNI152 space. The data in our study were obtained using the current MNI atlas (Fig. 2).

### 2.4. Data processing

In order to download and use the ROIEditor program on the computer, it is necessary to log in (registration) with a username and password from the “https://MriStudio.org” site. With the account created, the ROIeditor program is downloaded according to the system type of the computer, which is 32 or 64 bits. In order to use the MriCloud software, you must first create a registration on the site and log in. In order to download and use the ROIEditor program on the computer, it is necessary to log in (registration) with a username and password from the "https://MriStudio.org" site and download the 32 or 64 bit appropriate one according to the system type of the computer.

### 2.5. Parceling process

“DTI processing” was selected by clicking the “DTI” tab in the MriCloud software. On the page that opens, the “DwiDcm2DpfRaw” program was installed according to the operating system of the computer in order to automatically convert the DICOM format files to the “.dpf” format. Images converted to “.dpf” format were converted to “.zip” format and uploaded to MriCloud software. After the steps that the software performs automatically, the data from the process is downloaded in “.zip” format. The “DtiSeg” part of the “4DtiSeg” file in the downloaded “.zip” format “result” file has been changed to “S” in order to bring it into a suitable form for the ROIEditor program. After these processes, “DTI Multi-Atlas” was selected by clicking the “DTI” tab in the MriCloud software, and the “4DtiSeg.zip” file was uploaded to the specified area and sent to the server that created the software.

The result file of DTI Multi-Atlas operation in “.zip” format was

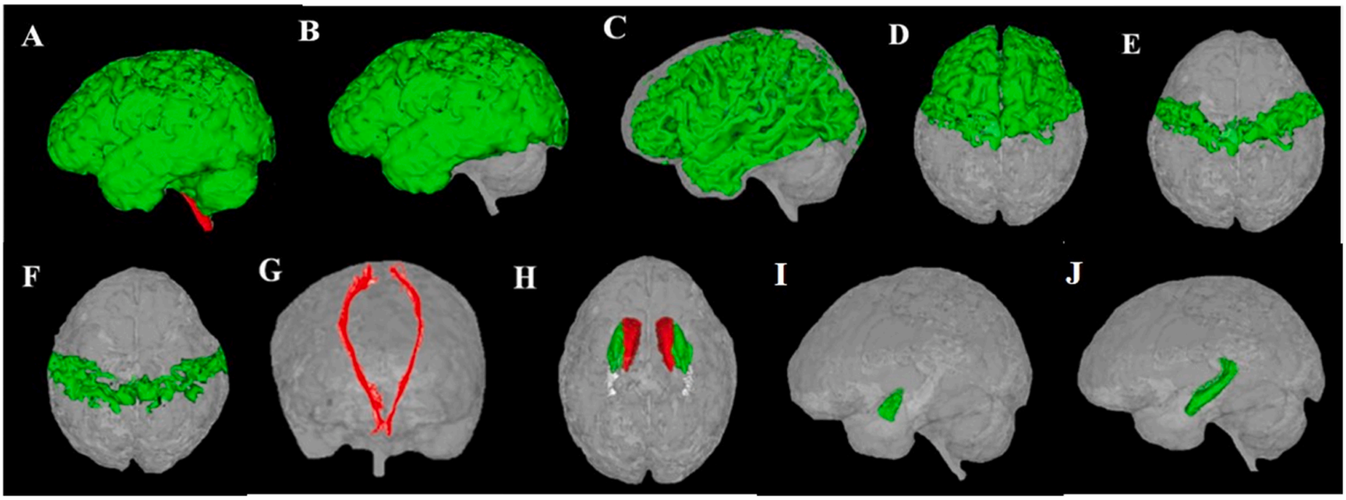


**Fig. 1.** 3D representation of the evaluated anatomical structures **A:** Side view of the Whole Brain, **B:** Side view of the Gray Matter, **C:** Side view of the White Matter, **D:** Top view of the Frontal Lobe, **E:** Top view of the Precentral Gyrus, **F:** Top view of the Postcentral Gyrus, **G:** Front view of the Corticospinal Tract, **H:** Top view of the Basal Nuclei, **I:** Side view of the Amygdala, **J: S**ide view of the Hippocampus.

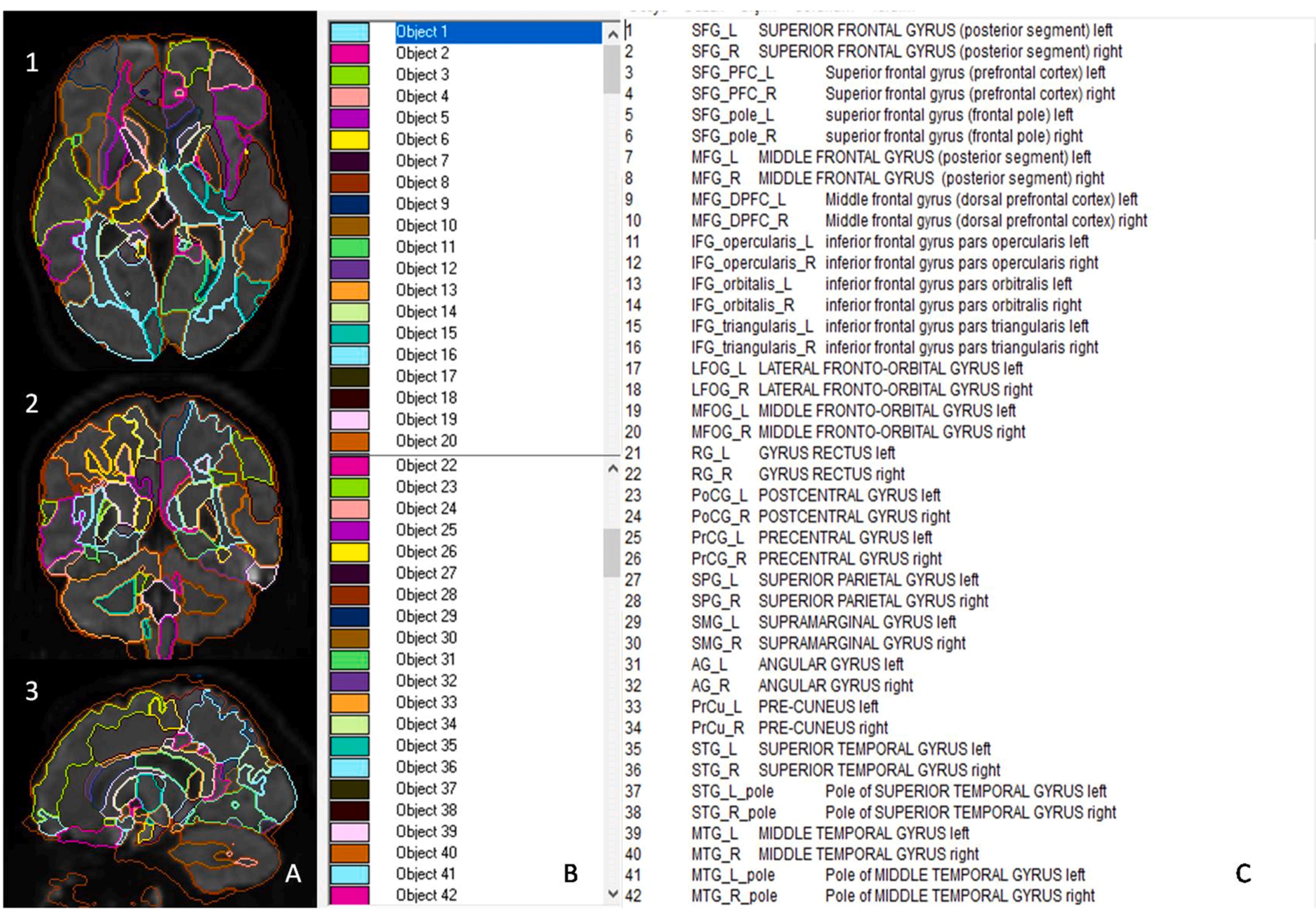


**Fig. 2.** An image from the brain parcellation process **1:** An image on the axial plane from the partitioned brain. **2:** An image on the coronal plane from the partitioned brain. **3:** An image on the sagittal plane from the partitioned brain **A:** An image in the axial, coronal and sagittal planes from the brain that has been partitioned **B:** After the brain parcellation process, the section colors and numbers corresponding to the brain substructures. **C:** A list of the numbers corresponding to the brain parts to which part of the brain they belong.

"unzip". The "DtiSeg_dwi_MNI_.hdr" or "DtiSeg_dwi_MNI_.img" file from the "tensor_native" file in the expanded file was opened in the ROIEditor software and the parcellation process was performed.

## 2.6. Statistical Analysis

In this study, statistical analysis of the data was evaluated in the IBM SPSS (version 25.0, Armonk, NY) statistical package program. Evaluation of the normal distribution of the data was tested with the Shapiro-Wilks test. Since the data in our study showed normal distribution, in-group and between-group comparisons were made with the ANOVA test. Homogeneity of variances was evaluated with Levene's test to determine the difference between groups. Variables with homogeneous distribution were analyzed by Benferonni, and variables without homogeneous distribution were analyzed by Games-Howell post-hoc tests. Continuous variables were expressed as mean±standard deviation ($\bar{x} \pm$ sd). Statistical significance level was accepted as $p < 0.05$.

## 3. Results

With the data we obtained, it was determined that both groups of athletes had higher grey matter (GM) (Fig. 1-B) and total brain volume (TBV) (Fig. 1-A) compared to sedentary individuals (Table 1). In addition, when the GM and white matter (WM) (Fig. 1-C) volumes were compared to TBV, it was determined that there was a significant difference in amateur athletes compared to sedentary individuals (Table 1). In addition, it was determined that frontal lobe (FL) (Fig. 1-D) volume and right postcentral gyrus (PoCG) (Fig. 1-F) volume in professional taekwondo athletes were higher than in sedentary individuals (Table 2, Fig. 3). It was found that FL, left corticospinal tract (CST) (Fig. 1-G) and right PoCG in the ratio of brain parts to TBV were different in professional taekwondo athletes compared to sedentary individuals and in left PoCG, there was a difference between both athlete groups and sedentary individuals (Table 2, Fig. 4).

## 4. Discussion

Studies conducted in different sports branches have reported that sports can affect brain volume and GM volume (Jacini et al., 2009; Mortimer et al., 2012; Bernick et al., 2020). Santiago Ramón y Cajal suggested that there may be morphological changes in brain structure with increased mental activity. Later neuroimaging studies reported experience-dependent increases in regional estimates of human brain volume and cortical thickness in adulthood. For example, a study of taxi drivers in London found increased hippocampus volume to help store a mental map of the city they had to navigate (Maguire et al.,2000). However, an endless shot cannot be imagined with lifelong learning and it has been reported that the volumetric expansions in the brain or brain structures are normalized in the later processes of learning (Fu and Zuo, 2011; Kilgard, 2012; Makino et al. 2016). The data obtained in the presented study showed that taekwondo sport, which includes planning and controlling complex motor movements, is associated with higher brain and GM volume. This shows that taekwondo athletes have higher neural activation compared to sedentary individuals. However, in our study, it is seen that the data on WM volume between the athlete groups and the sedentary group also support studies conducted in similar and different sports branches (Bernick et al., 2015; Özdurak et al., 2021). These data suggest that although there is a similarity in nerve conduction compared to sedentary individuals, the reactions of these stimuli in the cortex are different and may be due to the connections between neurons. Physical activity is defined as any bodily movement that causes energy expenditure and has been reported to affect mental health (Chekroud et al., 2018; Biddle and Vergeer, 2019). In the literature, it has been shown that children's participation in physical activity and higher aerobic activities positively affect their cognitive functions and brain health (Chaddock-Heyman et al., 2014; Donnelly et al., 2016). This situation has been associated with the FL volume, which undertakes premotor and supplementary motor areas, working memory processes, self-knowledge, personality perception, and social cognition (Chaddock-Heyman et al., 2014). In this study we conducted with individuals who are taekwondo players, a sport that teaches to be respectful, self-confident and patient as well as concepts such as courage, perseverance, determination, snap decision, and staying vigorous, it was determined that there was an increase in the volume of FL, which is the primary area in the brain responsible for these tasks. In addition, it was determined that the ratio of left CST volume to TBV was higher in professional taekwondo athletes. While these data cause an increase in the data processing of the part of the athletes where motor functions are performed, it shows that there may be an increase in the pathways where motor transmission is provided in people who do more intense sports. However, although the precentral gyrus (PrCG) (Fig. 1-E) volume was higher in the athlete groups, it was found to be statistically similar. This shows that taekwondo sports affect not only motor functions, but also functions related to the prefrontal area.

In their study on the dance and sports group created by Rehfeld et al., they stated that there was an increase in the PoCG cortex (Rehfeld et al., 2018). However, in the presented study, it was determined that the volume of PoCG was higher in the sedentary group than in the athlete groups. This situation suggests that the stimuli coming from the environment may be suppressed by inhibition mechanisms in the brain due to the fact that the athletes focus on the moves from the opponent. In order to clarify this situation, there is a need for detailed studies involving professionalized participants in different fields.

It is thought that exercise is effective in the regulation of nerve conduction in the basal nuclei, which plays a role in cognitive functions through dopaminergic projection, and therefore the cognitive process improves after exercise (Crosson et al., 2007; Petzinger et al., 2007). However, the data we obtained support the studies performed in martial arts sports, as the nuclei basales (NB) (Fig. 1-H) volume was similar between groups (Smith et al., 2007). This shows that there may be other reasons besides exercise that affects the brain volume.

It is known that exercise affects not only physical health but also spiritual and mental health positively (Greer et al., 2016; Aylett et al., 2018). Some of these effects are coping with stress and anxiety disorders, an increase in focusing and learning skills (Kandola et al., 2020). Studies have reported that physical activity prevents attention deficit, strengthens perception ability, and increases learning capacity (Greer et al., 2016; Aylett et al., 2018; Kandola et al., 2020). The parts of the brain called the amygdala (Fig. 1-I) and hippocampus (Fig. 1-J) are associated with learning and memory, and incoming stimuli, events or information are processed and stored (Boyer et al., 2007; Usui et al., 2018). In the current study, it was determined that the data we obtained in the amygdala and hippocampus volumes of athletes with higher physical activity compared to normal individuals were similar as in the literature (Lee et al., 2019; Bernick et al., 2020; Bobholz et al., 2021). This may be due to the fact that the participants could not be isolated

**Table 1**
Total brain volume, gray matter and white matter volumes and the mean of the ratio of these volumes to the total brain volume.

| Group | TBV ($cm^3$) ( $\bar{x}$±SD) | GM ($cm^3$) ( $\bar{x}$±SD) | GM/TBV (%)( $\bar{x}$±SD) | WM ($cm^3$) ( $\bar{x}$±SD) | WM/TBV (%)( $\bar{x}$±SD) |
|---|---|---|---|---|---|
| **sedentary** | 1585.804 ±29.774[b,c] | 1016.371± 29.776[b,c] | 64.08±0.96 [b] | 569.432± 10.587 | 35.91±0.86 [b] |
| **amateur** | 1641.844 ±39.081[a] | 1079.881±44.941[a] | 65.75±1.41[a] | 561.963±16.983 | 34.25±1.41 [a] |
| **elite** | 1630.094 ±45.413[a] | 1057.254± 39.674[a] | 64.85±0.96 | 572.839±15.812 | 35.15±0.96 |

a: It shows a statistically significant difference when compared with the sedentary group. (p<0.05).
b: It shows a statistically significant difference when compared with the amateur group. (p<0.05).
c: It shows a statistically significant difference when compared with the elite group. (p<0.05).
$\bar{x}$: Arithmetic Mean, SD: Standard Deviation

**Table 2**
Average volume values of brain sections by groups and ratios of mean brain segment volume to total brain volume by groups.

| Group | Frontal Lobe ($cm^3$) ($\bar{x} \pm SD$) | Precentral Gyrus ($cm^3$) ($\bar{x} \pm SD$) | Corticospinal Tract ($cm^3$) ($\bar{x} \pm SD$) | Basal Nuclei ($cm^3$) ($\bar{x} \pm SD$) | Postcentral Gyrus ($cm^3$) ($\bar{x} \pm SD$) | Amygdala ($cm^3$) ($\bar{x} \pm SD$) | Hippocampus ($cm^3$) ($\bar{x} \pm SD$) |
|---|---|---|---|---|---|---|---|
| Right Hemisphere | | | | | | | |
| sedentary | **159.872 ±6.004b,c** | 25.735 ± 1.923 | 1.667 ± 0.313 | 8.717 ± 0.659 | **26.934±1.818[c]** | 2.673 ± 0.383 | 5.810 ± 0.437 |
| amateur | **170.682 ±10.047**a | 26.748 ± 4.169 | 1.755 ± 0.328 | 9.436 ± 1.016 | 26.855±1.619 | 2.671 ± 0.216 | 5.768 ± 0.694 |
| elite | **168.754±6.662[a]** | 26.882 ± 2.570 | 1.891 ± 0.325 | 9.235 ± 0.919 | **24.821±1.766[a]** | 2.731 ± 0.319 | 5.894 ± 0.553 |
| Left Hemisphere | | | | | | | |
| sedentary | **159.470±6.218[b,c]** | 24.725 ± 1.885 | 1.574 ± 0.269 | 9.142 ± 0.614 | 28.982 ± 1.014 | 2.445 ± 0.382 | 7.134 ± 0.524 |
| amateur | **169.992±7.420[a]** | 25.297 ± 2.839 | 1.694 ± 0.269 | 9.736 ± 0.843 | 28.296 ± 1.672 | 2.482 ± 0.365 | 7.268 ± 0.978 |
| elite | **169.691±8.390[a]** | 27.109 ± 3.033 | 1.797 ± 0.254 | 9.104 ± 0.852 | 28.037 ± 2.406 | 2.710 ± 0.246 | 7.127 ± 0.488 |
| | **Frontal Lobe / TBV(%)($\bar{x}$±SD)** | **Precentral Gyrus/ TBV(%)($\bar{x}$±SD)** | **Corticospinal Tract/ TBV(%)($\bar{x}$±SD)** | **Basal Nuclei/ TBV(%)($\bar{x}$±SD)** | **Postcentral Gyrus / TBV(%)($\bar{x}$±SD)** | **Amygdala/ TBV (%)($\bar{x}$±SD)** | **Hippocampus/ TBV (%)($\bar{x}$±SD)** |
| Right Hemisphere | | | | | | | |
| sedentary | **10.08±0.39[c]** | 1.62 ± 0.14 | 0.102 ± 0.018 | 0.55 ± 0.04 | **1.69±0.11[c]** | 0.17 ± 0.02 | 0.37 ± 0.03 |
| amateur | 10.40 ± 0.72 | 1.63 ± 0.28 | 0.106 ± 0.019 | 0.57 ± 0.06 | 1.63 ± 0.08 | 0.16 ± 0.01 | 0.35 ± 0.04 |
| elite | **10.35±0.38[a]** | 1.65 ± 0.18 | 0.119 ± 0.021 | 0.57 ± 0.05 | **1.52±0.11[a]** | 0.17 ± 0.02 | 0.36 ± 0.03 |
| Left Hemisphere | | | | | | | |
| sedentary | 10.05 ± 0.39 | 1.56 ± 0.12 | **0.096±0.015[c]** | 0.58 ± 0.04 | **1.82±0.06[b,c]** | 0.15 ± 0.02 | 0.45 ± 0.03 |
| amateur | 10.36 ± 0.59 | 1.54 ± 0.20 | 0.103 ± 0.015 | 0.59 ± 0.04 | **1.72±0.11[a]** | 0.15 ± 0.02 | 0.44 ± 0.05 |
| elite | 10.40 ± 0.40 | 1.66 ± 0.20 | **0.113±0.017[a]** | 0.56 ± 0.05 | **1.72±0.14[a]** | 0.17 ± 0.02 | 0.44 ± 0.02 |

a: It shows a statistically significant difference when compared with the sedentary group. ($p < 0.05$).
b: It shows a statistically significant difference when compared with the amateur group. ($p < 0.05$).
c: It shows a statistically significant difference when compared with the elite group. ($p < 0.05$).
$\bar{x}$: Arithmetic Mean, SD: Standard Deviation.

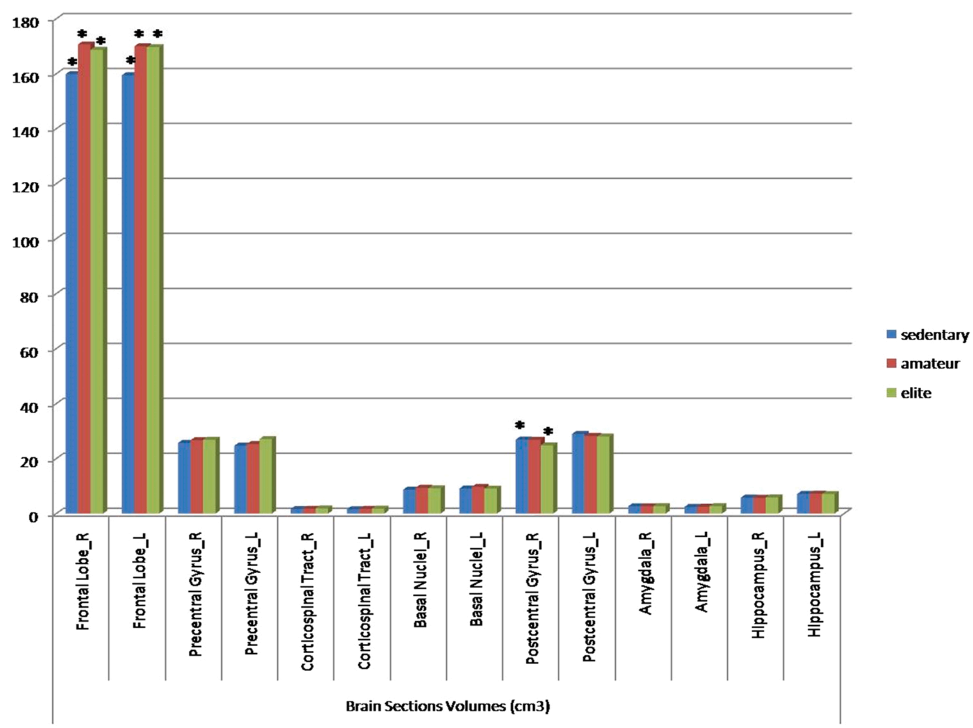


**Fig. 3.** Graph showing volumes of brain sections ('*' it shows a statistically significant difference between groups, R= Right, L= Left).

from factors other than exercise that would affect memory and learning.

Wenger et al. (2017) In their study on 15 right-handed people, they stated that they practiced writing and drawing with the left hand for 7 weeks, and they took T1-weighted MR images 18 times during this process. When they analyzed the obtained images with voxel-based morphometry, they stated that the gray matter increase in the primary motor cortex continued for the first 4 weeks, but in the following weeks, especially the right hemisphere motor cortex returned to its normal volume. Quallo et al. (2009) in their study in which they taught 3 adult macaque monkeys to use a rake to get food, they stated that they obtained and analyzed before, during and after learning. As a result of the analysis, they stated that the volume of the brain part related to learning increased, but at the end of the 2-week training period, the volume of the relevant region was higher than before learning and lower than the data during learning. This situation can be likened to the casting of a movie. In a process in which a large number of candidates (i.e., computational

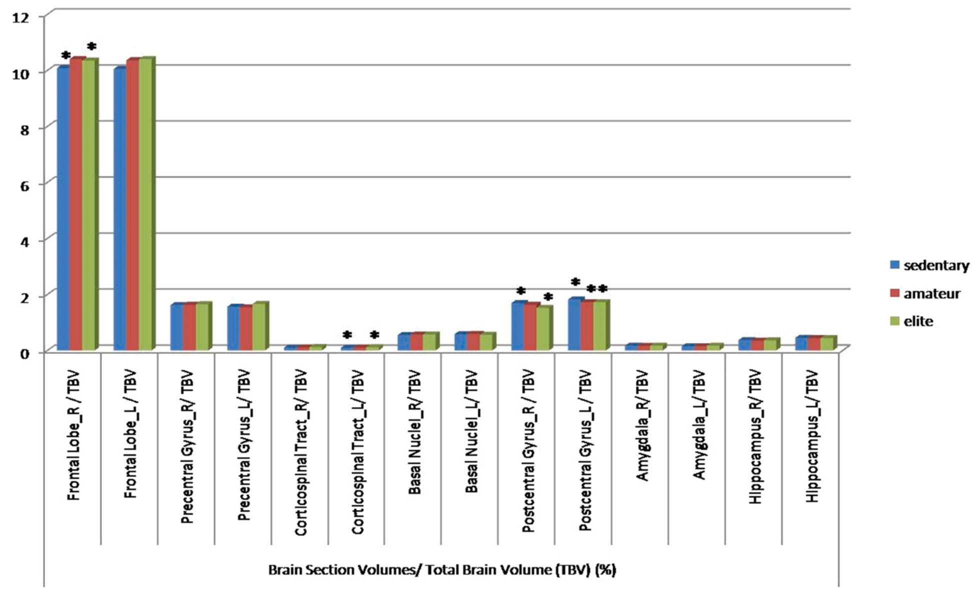


**Fig. 4.** Graph showing volumes of brain sections / total brain volume (TBV) ('*' it shows a statistically significant difference between groups, R= Right, L= Left).

circuits or ensembles of neurons, synapses, astrocytes, and glia cells) are called in the first place in casting (overall tissue expansion), candidates are tested for role fit (i.e. functional efficiency) and the best candidates (i.e., circuits) are selected (selection), the rest are sent home (i.e. pruned; leads to renormalisation) (Fu and Zuo, 2011; Kilgard, 2012; Makino et al. 2016). Thus, morphological re-normalization can occur in the relevant brain area. It is known that morphological volume increases in brain structures and cellular changes during their renormalization include adult neurogenesis, synaptic changes, and changes in the number and morphology of glial cells (Zatorre et al., 2012). In our current study, the increase in the volume of gray matter, basal nuclei and postcentral gyrus was greater in the amateur group than in both the professional and sedentary groups, suggesting that the volume increase at the beginning of learning re-normalizes the morphological changes in areas related to the generation of functional neuronal activity in the professional group with further training. At the same time, as stated in the studies in the literature (Crosson et al., 2007; Petzinger et al., 2007; Boyer et al., 2007; Chaddock-Heyman et al., 2014; Donnelly et al., 2016; Greer et al., 2016; Aylett et al., 2018; Usui et al., 2018; Kandola et al., 2020), the increase in frontal lobe, nuclei basales, amygdala and hippocampus volumes and subsequent normalization and the formation of more effective neural activity suggest that taekwondo sport has a positive effect on mental and mental health as well as physical health. We think that this situation will be supported by more comprehensive studies to be carried out.

## 5. Conclusion

As a result, the changes in brain morphology shown in the present study are associated with taekwondo sports. Our study will contribute to the studies to be carried out among the participants who investigate the subject-specific changes in the brain volume and who are interested in sports branches that include physical exercise.

## 6. Limitations

The limitations of our study can be listed as follows. First, although all the volunteers included in our study did not have habits such as smoking and alcohol that would affect their brain health, and they did not have any neurodegenerative diseases, no evaluation was made for stress and anxiety disorders, which are known to affect brain structures. Second, the participants were not given any assessment of cognitive memory or learning. Failure to isolate factors other than exercise in evaluations regarding memory and learning may suppress the discovery of the benefits of physical activity in this regard. Third, since the evaluation of its effect on the brain and brain parts in taekwondo athletes was sporadic, our results were compared with the existing literature on other sports branches. In both, it is insufficient to reveal the underlying mechanisms.

## Confirmation of ethical compliance

Permissions to complete the study were granted by the relevant ethics committee in Turkey (Erciyes University Clinical Research Ethics Committee; Non-interventional Clinical Trials, date, 15/01/2020 no. 36).

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## CRediT authorship contribution statement

**Erdal KURTOĞLU**, drafting and creating the study, making and following up the necessary applications for financial support and ethical approval, identifying sedentary individuals, explaining the study to all participants and obtaining voluntary consent, ensuring coordination of MRI procedures, processing MRI images and obtaining results, generating statistical data. **Ahmet PAYAS**, Processing MR images and obtaining results.**Serkan DÜZ**, determination and coordination of athletes, statistical analysis.**Mustafa ARIK**, Evaluation of participants in terms of suitability for the study and coordination of MRI procedures.**İlyas UÇAR**, interpretation and critical review of data, article spelling. **Turgut Tursem TOKMAK**, performing MRI of the participants and evaluating them in terms of suitability for the study.**Mehmet Fatih ERBAY**, performing MRI of the participants and evaluating them in terms of suitability for the study.**Niyazi ACER**, Supervision of the programs used in MRI processing and the results obtained.**Erdoğan UNUR**, final approval of the version to be published.

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