J CLIN PRACT RES

Original Article

Official Journal of Erciyes University Faculty of Medicine

DOI: 10.14744/cpr.2024.93419
J Clin Pract Res 2024;46(3):242–250

The Role of Conscious and Unconscious Proprioceptive Sensation in Unstable Postural Balance: A Cross-Sectional Study

Ahmet Payas,[1] Erdal Kurtoğlu,[2] Büşra Kepenek Varol,[3] Sabri Batın,[4] Caner Karartı,[5] Ali Koç,[6] İlyas Uçar[7]

[1]Department of Anatomy, Amasya University Faculty of Medicine, Amasya, Türkiye
[2]Department of Anatomy, Erciyes University Faculty of Medicine, Kayseri, Türkiye
[3]Department of Physiotherapy and Rehabilitation, Nuh Naci Yazgan University, Faculty of Health Sciences, Kayseri, Türkiye
[4]Department of Orthopedics and Traumatology, Kayseri City Training and Research Hospital, Kayseri, Türkiye
[5]Ahi Evran University, School of Physicaltherapy and Rehabilitation, Kırşehir, Türkiye
[6]Department of Radiology, Kayseri City Training and Research Hospital, Kayseri, Türkiye
[7]Department of Anatomy, Erciyes University Faculty of Medicine, Kayseri, Türkiye

ABSTRACT

Objective: Proprioception is the capacity to perceive the position of any body part, either consciously or unconsciously. This sense, in conjunction with the visual and vestibular senses, helps maintain postural balance. This study explores the relationship between postural balance analysis outcomes and proprioceptive sense tractography data.

Materials and Methods: Sixty-two healthy individuals were categorized into two groups based on postural balance analysis: the unstable posture group and the stable posture group. Postural sway test measurements, such as sway area, track length, velocity, Romberg quotient, lateral sway, and anteroposterior sway, were recorded for both groups on fixed and moving surfaces over 20 seconds. Using the DSI Studio program, tractography of the proprioceptive sensory pathways was conducted on participants using brain diffusion tensor images (DTI). IBM Statistical Package for the Social Sciences (SPSS) 23.0 software was employed for statistical analysis, with a p-value <0.05 considered statistically significant.

Results: Tractography of the unstable posture group revealed increased mean diffusivity (MD) and radial diffusivity (RD) in the brain white matter, superior cerebellar peduncle, and middle cerebellar peduncle, while axial diffusivity (AD) values decreased (p<0.05). There was a notable correlation between the sway area in the unstable and eyes-open positions and the fiber count and fiber percentage in the right inferior cerebellar peduncle.

Conclusion: The data suggest impairments in the pathways responsible for carrying unconscious proprioceptive sensations in individuals with unstable posture.

Keywords: Tractography, proprioception, postural balance, unstable posture, diffusion tensor imaging.

Cite this article as:
Payas A, Kurtoğlu E, Kepenek Varol B, Batın S, Karartı C, Koç A, Uçar İ. The Role of Conscious and Unconscious Proprioceptive Sensation in Unstable Postural Balance: A Cross-Sectional Study. J Clin Pract Res 2024;46(3):242–250.

Address for correspondence:
Ahmet Payas.
Department of Anatomy, Amasya University Faculty of Medicine, Amasya, Türkiye
Phone: +90 358 211 50 05
E-mail: fizyopayass@gmail.com

Submitted: 27.02.2024
Revised: 05.04.2024
Accepted: 16.05.2024
Available Online: 06.06.2024

Erciyes University Faculty of Medicine Publications - Available online at www.jcpres.com

INTRODUCTION

Postural balance involves maintaining body alignment by countering the forces of gravity, both internal and external.[1] It is achieved through the evaluation of multiple sensory inputs in both cortical and subcortical regions, which are then integrated with the motor control system.[2] A continuous flow of information from the visual, proprioceptive, and vestibular systems is crucial for maintaining postural balance.[3] Disruptions in any of these systems can impair postural balance.[4] Proprioception refers to the awareness, whether conscious or unconscious, of the position of body parts in space.[5,6] This sense is detected by mechanoreceptors located in muscles, tendons, joints, ligaments, skin, and other soft tissues surrounding the joints.[7] The spinobulbar tract conveys conscious proprioceptive sensations to the postcentral gyrus of the cortex, while the posterior and anterior spinocerebellar tracts transmit unconscious proprioceptive sensations to the cerebellum. These sensory inputs are essential for maintaining body position by coordinating muscle contractions and tone.[8] After sensory information is processed in the gyrus postcentralis, it is assessed in the motor cortex, and the sensations reaching the cerebellum are evaluated and regulated through connections to the brainstem via the superior, medius, and inferior cerebellar peduncles.[8,9] A deficiency or malfunction in proprioceptive sensing can significantly compromise an individual's ability to reposition and move body parts,[10] potentially leading to a deterioration in upright posture and balance. Proprioceptive sensory evaluation can be conducted using balance tests or tractography. Currently, the objective assessment of postural balance is facilitated by computer-assisted force platforms, where evaluations are conducted on both hard and soft surfaces, with eyes both open and closed.[11] Tractography, utilizing diffusion tensor imaging (DTI), provides insights into the microarchitecture of brain white matter tissue.[12]

Although proprioceptive sense-related issues are known to affect postural balance, sufficient studies have not been conducted to determine which types of proprioceptive senses are impacted. Therefore, this study explores the relationship between postural balance analysis results and both conscious and unconscious proprioceptive sensory pathways.

MATERIALS AND METHODS

Ethical Approval

The study received ethical approval under decision number 023/818 from the Kayseri City Training and Research Hospital Local Ethics Committee. It was designed as a single-center, prospective, and cross-sectional cohort study and conducted in accordance with the criteria of the Helsinki Declaration. Participants were fully informed about the study and provided their consent prior to inclusion.

Participants and Study Groups

The G*Power program was utilized to determine the study's sample size. The error probability level was set at 0.05, and the statistical power was calculated to be 95%. The analysis indicated that each group should consist of at least 30 participants.

Unstable posture group (n=31): Comprising 20 females and 11 males, this group displayed postural instability as determined by postural balance analysis results.

Stable posture group (n=31): Consisting of 20 women and 11 men, this group exhibited optimal postural stability, according to postural balance analysis results.

Inclusion Criteria

Participants without neuromuscular, orthopedic, or neurological diseases that could affect the musculoskeletal system were included.

Exclusion Criteria

Individuals with brain lesions visible on magnetic resonance images (MRI), those with neuromuscular, neurological, or orthopedic conditions, any spinal deformities, or a history of spine surgery were excluded from the study.

Balance Analysis

Balance assessments were conducted using the HUR SmartBalance computer-aided strength platform. Analyses of postural balance were performed on both hard and soft surfaces, with participants' eyes open and closed. Metrics such as the duration of stance in test positions, movement strategies, and the extent of postural oscillations were analyzed. From these assessments, fixed and dynamic ground testing was carried out for 20 seconds per participant, from which stable Romberg, unstable Romberg, and stability limits were derived.

The analysis resulted in the identification of two groups: those with unstable posture and those with stable posture.

Acquisition of Brain Diffusion Magnetic Resonance Images

Imaging was performed using a Siemens Magnetom Skyra MRI device with a 3T (Tesla) feature from the Netherlands. The imaging parameters were set as follows: Field of View (FOV) = 230×230 mm^2, Echo Time (TE) = 95 ms, Repetition Time (TR) = 4900 ms, voxel size = 1.8×1.8×3.5 mm, slice thickness = 3.0 mm, flip angle = 90o, and number of slices = 36, with a matrix size of 128×128.

Tractography Process

Tractography of targeted pathways from brain diffusion MRI was performed using the DSI Studio programme. Settings

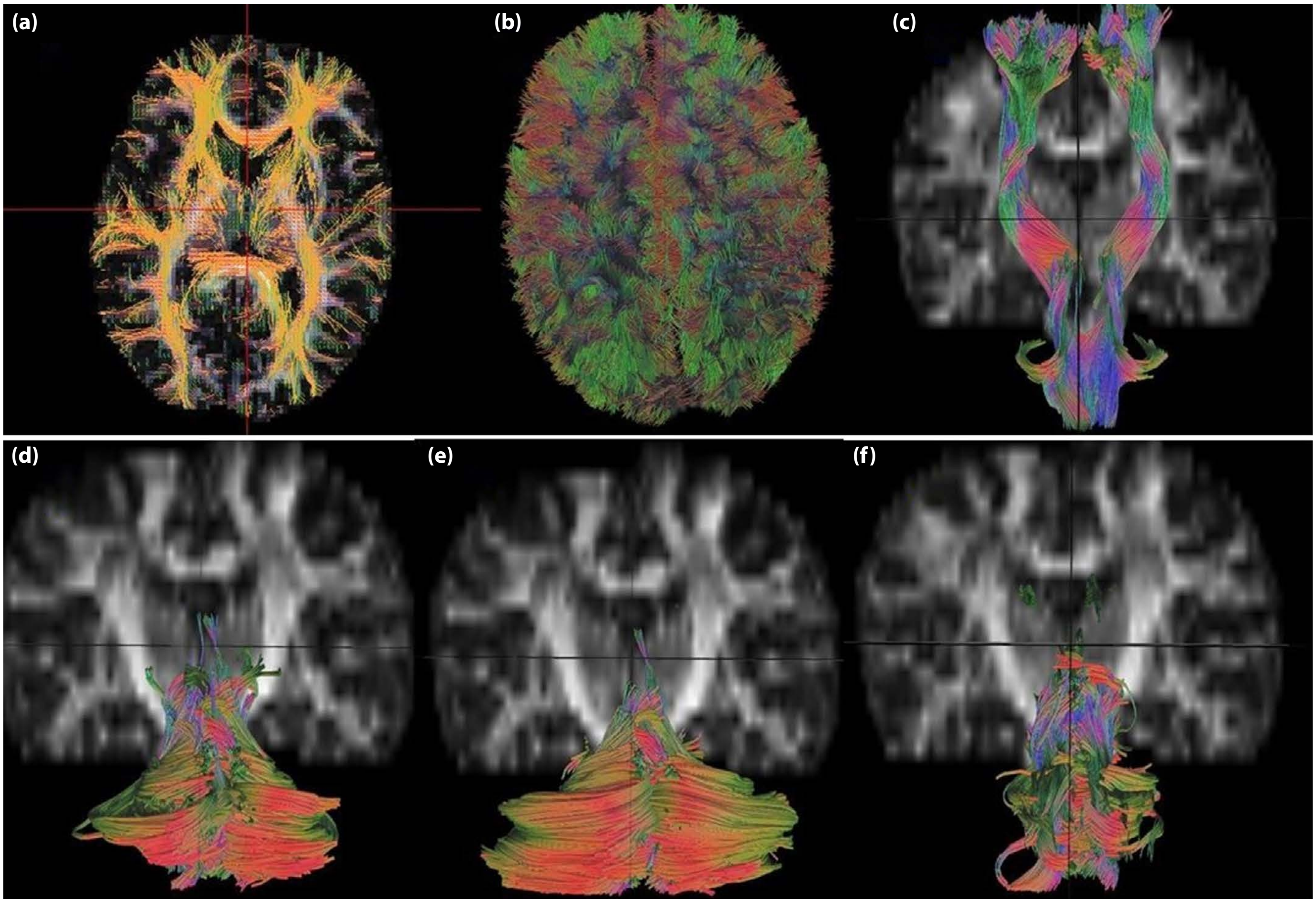

Figure 1. Visualization of pathway fibers using DSI Studio. **(a, b)** Visualization of all brain fibers with DSI Studio. **(c)** Visualization of all fibers in the lemniscus medialis with DSI Studio. **(d)** Visualization of all fibers in the inferior cerebellar peduncle with DSI Studio. **(e)** Visualization of all fibers in the medial cerebellar peduncle with DSI Studio. **(f)** Visualization of all fibers in the superior cerebellar peduncle with DSI Studio.

for the tractography included: Smoothing = 0.50, fiber termination = 100,000 fibers, Threshold = 0.20, Angular Threshold = 70 degrees, minimum fiber length = 10 mm, and maximum fiber length = 1000 mm. The study targeted the lemniscus medialis, which carries conscious proprioception, and the superior, medius, and inferior pedunculus cerebellaris pathways, linking the cerebellum—the center of unconscious proprioception—to the central nervous system. To quantify the fiber ratio in targeted pathways, all fiber data in the participants' brains were analyzed (Fig. 1). A "Tractography Atlas" was utilized to enhance the objectivity of the pathway tractography process. From this analysis, the following metrics were obtained for each participant's right and left conscious and unconscious proprioceptive sensory paths: total fiber number, average fiber length (in millimeters), the ratio of fibers in these pathways to the total number of fibers in the whole brain (fiber ratio = number of fibers in the pathway * 100 / number of fibers in the whole brain), axial diffusivity (AD), fractional anisotropy (FA), mean diffusivity (MD), and radial diffusivity (RD) values.

Statistical Analysis

The data were analyzed using SPSS (Statistical Package for the Social Sciences) version 22.0. The Kolmogorov-Smirnov/Shapiro-Wilk test was used to assess the normality and variability of the data, supplemented by histograms and probability graphs for visual inspection. Descriptive statistics were employed during the analysis phase. Baseline characteristics were compared using independent t-tests or χ^2 tests.

Table 1. Demographic and clinical characteristics of groups

Variable	Unstable posture group (n=31)	Stable posture group (n=31)	p
Age	25.90±1.16	26.19±1.19	0.72
Body mass index (kg/m^2)	20.70±1.44	21.01±1.85	0.46

Initially, an independent t-test was conducted to compare baseline tractography results between the groups. To evaluate changes in balance-related outcomes, a 2 x 2 [(groups) x (condition: eyes-open or closed)] repeated measures Analysis of Covariance (ANCOVA) was performed, with 'group' as a between-groups factor, 'condition' as a within-subjects factor, and demographic data as covariates. Significant F-ratios prompted the use of Bonferroni's post hoc test to identify mean differences. The effect size was reported as partial eta squared ($\eta^2 p$). Variables showing statistical differences in tractography and balance-related measurements proceeded to the second step of the analysis.

Pearson product-moment correlation coefficient analysis was used to explore the correlation between equilibrium data and tractography variables, which included: whole-brain (mean diffusivity, axial diffusivity, radial diffusivity), left pedunculus cerebellaris inferior (fiber count, fiber percentage), right pedunculus cerebellaris inferior (fiber count, fiber percentage), pedunculus cerebellaris medius (mean diffusivity, axial diffusivity, radial diffusivity), and pedunculus cerebellaris superior (mean diffusivity, radial diffusivity). Correlation coefficients >0.5 indicated strong correlation, 0.3 to 0.5 moderate correlation, and 0.2 to 0.3 weak correlation.[13] A p-value of <0.05 was considered statistically significant.

RESULTS

A total of 62 participants, 31 in each group, took part in the study. There was no difference in baseline characteristics between the groups (p>0.05) (Table 1). There was a statistically significant difference between the two groups in terms of whole-brain fiber tracts, including mean diffusivity (p=0.019), axial diffusivity (p=0.011), and radial diffusivity (p=0.042). The stable posture group exhibited higher axial diffusivity scores, while the other variables were higher in the unstable posture group (Table 2). There was also a significant difference between the two groups in left and right pedunculus cerebellaris inferior fibers, including fiber count and percentage, which were higher in the stable posture group (p=0.025-0.048) (Table 2). Axial diffusivity score was higher in the stable posture group (p=0.011) for pedunculus cerebellaris medius, whereas mean diffusivity (p=0.020) and radial diffusivity (p=0.026) were higher in the unstable posture group (Table 2). Similarly, mean diffusivity (p=0.024) and radial diffusivity (p=0.013) were higher in the unstable posture group for pedunculus cerebellaris superior (Table 2). ANCOVA revealed no significant group * condition interaction effects regarding stable- and unstable balance measurements in two conditions: eyes-open and closed (p=0.146-0.872) for both groups. However, significant differences were observed in within-condition measurements. Trace length in the stable and eyes-closed condition (p=0.049), sway area (p=0.002) and velocity (p=0.044) in the unstable and eyes-open condition, and lateral sway in the unstable and eyes-closed condition (p=0.004) all showed statistically significant differences.

Based on the student-t test (Table 2) and ANCOVA results (Table 3), trace length, sway area, velocity, and lateral sway under the aforementioned conditions, along with tractography results for whole-brain, left and right pedunculus cerebellaris inferior, medius, and superior, were entered into the correlation analysis. A significant correlation was found between the sway area in the unstable and eyes-open position and the right pedunculus cerebellaris inferior fiber count (r=-0.269, p=0.035) and fiber percentage (r=-0.275, p=0.031). As the fiber count and percentage decreased, sway area increased (Table 4).

DISCUSSION

In this study, we investigated potential relationships between postural balance analysis results and tractography data of pathways that carry proprioceptive sensations. According to our literature review, this is the first study to evaluate proprioceptive sensation using both postural balance analysis and tractography. In the unstable posture group, it was observed that fibers in the brain's white matter, specifically the pedunculus cerebellaris superior, medius, and inferior, are affected compared to those in the stable posture group. There appears to be a correlation between unstable posture and the number of fibers in the pedunculus cerebellaris inferior, which is responsible for the unconscious sense of proprioception.

Tractography allows for the assessment of axon structure, myelin structure, impulse conduction velocity, and fiber count of pathways involved in proprioception, which are believed to play a crucial role in maintaining postural balance. In the tractography process, metrics such as fiber number, average fiber length, fractional anisotropy, mean diffusivity, axial diffusivity, and radial diffusivity are calculated.[14] FA represents the fraction of directionally dependent (anisotropic) diffusion. Low FA values indicate damage to the myelin sheath surrounding axons. MD reflects the overall magnitude of mean directional diffusion and increases as white matter structure decreases. AD measures the magnitude of diffusion parallel to the fiber tracts. Low AD indicates axonal damage, reduced axonal diameter, or less uniform orientation of axons.

Table 2. Comparison of tractography data of brain and proprioceptive sensory pathways between groups

	Unstable posture (n=31) (Mean±SD)	Stable posture (n=31) (Mean±SD)	p
Whole-brain			
Fiber count	72,029.03±2,825.49	72,407.41±2,288.75	0.564
Mean fiber length	73.61±4.18	73.57±2.35	0.962
Fractional anisotropy	0.45±0.10	0.43±0.90	0.902
Mean diffusivity	0.82±0.03	0.80±0.02	0.019*
Axial diffusivity	1.23±0.03	1.26±0.03	0.011*
Radial diffusivity	0.60±0.03	0.58±0.02	0.042*
Left medial lemniscus			
Fiber count	2,176.87±1,164.99	2,490.70±1,167.19	0.294
Mean fiber length	125.69±7.82	126.79±7.07	0.562
Fractional anisotropy	0.48±0.02	0.48±0.01	0.524
Mean diffusivity	0.82±0.03	0.81±0.03	0.494
Axial diffusivity	1.30±0.05	1.29±0.04	0.248
Radial diffusivity	0.58±0.02	0.58±0.03	0.639
Fiber percentage	3.01±1.59	3.42±1.56	0.313
Right medial lemniscus			
Fiber count	2,889.45±1,266.47	3,406.87±1,515.57	0.150
Mean fiber length	125.45±7.70	125.86±6.13	0.817
Fractional anisotropy	0.51±0.01	0.50±0.01	0.188
Mean diffusivity	0.81±0.02	0.80±0.03	0.842
Axial diffusivity	1.31±0.04	1.30±0.05	0.602
Radial diffusivity	0.56±0.02	0.56±0.03	0.491
Fiber percentage	3.99±1.71	4.70±2.07	0.146
Left inferior cerebellar peduncle			
Fiber count	5,123.58±1,245.96	5,942.03±1,540.96	0.025*
Mean fiber length	41.55±3.79	40.76±3.92	0.422
Fractional anisotropy	0.39±0.01	0.38±0.01	0.523
Mean diffusivity	0.87±0.03	0.88±0.03	0.297
Axial diffusivity	1.26±0.05	1.25±0.05	0.489
Radial diffusivity	0.68±0.03	0.68±0.03	0.266
Fiber percentage	7.10±1.65	8.20±2.10	0.025*
Right inferior cerebellar peduncle			
Fiber count	6,147.32±1,301.82	6,981.16±1,791.32	0.040*
Mean fiber length	43.15±4.40	42.66±3.28	0.617
Fractional anisotropy	0.38±0.01	0.38±0.01	0.688
Mean diffusivity	0.87±0.02	0.86±0.03	0.211
Axial diffusivity	1.25±0.04	1.23±0.05	0.263
Radial diffusivity	0.68±0.02	0.68±0.03	0.333
Fiber percentage	8.53±1.80	9.65±2.49	0.048*

Table 2 (cont). Comparison of tractography data of brain and proprioceptive sensory pathways between groups

	Unstable posture (n=31) (Mean±SD)	Stable posture (n=31) (Mean±SD)	p
Middle cerebellar peduncle			
Fiber count	9,036.16±1,819.04	9,713.32±1,917.91	0.159
Mean fiber length	64.05±6.96	63.33±6.74	0.684
Fractional anisotropy	0.46±0.01	0.45±0.01	0.504
Mean diffusivity	0.87±0.03	0.85±0.03	0.020*
Axial diffusivity	1.30±0.03	1.33±0.04	0.011*
Radial diffusivity	0.64±0.03	0.62±0.02	0.026*
Fiber percentage	12.56±2.59	13.41±2.56	0.199
Superior cerebellar peduncle			
Fiber count	13,554.03±2,124.55	14,430.67±2,155.89	0.112
Mean fiber length	49.24±4.23	51.19±4.32	0.078
Fractional anisotropy	0.42±0.01	0.43±0.01	0.067
Mean diffusivity	1.04±0.03	1.02±0.04	0.024*
Axial diffusivity	1.51±0.04	1.49±0.05	0.131
Radial diffusivity	0.80±0.03	0.78±0.03	0.013*
Fiber percentage	18.79±2.74	19.93±2.96	0.118

SD: Standard deviation; *: Statistically significant data at p<0.05.

RD quantifies the diffusion perpendicular to the fiber paths, with an increase in RD suggesting loss of myelin or axons.[15,16] Proprioceptive sense facilitates the integrated functioning of the peripheral and central nervous systems, utilizing information from muscles, tendons, joint capsules, ligaments, skin, and other soft tissues around joints.[7] The spinocerebellar pathways, which carry the unconscious sense of proprioception, have the highest conduction speeds in the central nervous system. This rapid transmission allows environmental stimuli from muscles, skin, and joints to reach the cerebellum quickly. The resulting outputs play a crucial role in swiftly providing postural control through effective connections to the motor cortex, reticular formation, red nucleus, and vestibular nucleus.[5,9,17]

Studies have reported that a decrease in the number of brain fibers affects brain functions.[18,19] The fiber count of the pathways in the brain's white matter is crucial for quality communication within the brain and between the brain and lower centers.[20] Payas et al.[8] emphasized that the fiber number of pathways providing proprioceptive sensation and sensorimotor integration is closely related to postural balance.

As a result of the tractography procedure in the unstable posture group, it was observed that the MD and RD values of the brain's white matter, specifically in the pedunculus cerebellaris superior and medius, increased, while the AD value decreased. It appears that the unconscious proprioception in the unstable posture group is processed in the cerebellum, but the pathways that transmit this information to the cerebrum are compromised. Decreased fiber numbers in these pathways indicate that proprioceptive sensations are not effectively transmitted to the relevant parts of the central nervous system. In this study, both the fiber number and fiber ratio of all analyzed pathways, particularly in the pedunculus cerebellaris inferior, were reduced in the unstable posture group. This suggests that the conscious and unconscious proprioceptive senses may not be adequately reaching the relevant parts of the central nervous system in a healthy manner in the unstable posture group. Additionally, it was observed that the number of fibers in the pedunculus cerebellaris superior, medius, and inferior, which connect the cerebellum to other parts of the central nervous system, decreased, and the axon and myelin structure were compromised in the unstable posture group.

The sense of proprioception transmitted by the posterior and anterior spinocerebellar tracts is crucial for maintaining proper muscle tone and postural balance. The study found that the number and ratio of fibers in the inferior cerebellar peduncle, which connects the posterior and anterior spinocerebellar tracts to the cerebellum, were low. Concurrently, a reduction in the number and ratio of fibers in the inferior cerebellar peduncle was observed to increase the trunk swing area. This suggests that the fiber count in a pathway is critical for its functional efficiency.

Table 3. Comparison of outcome measurements related to balance between groups

Outcome measures	Eyes opened		p^1	Eyes closed		p^1	Condition p2 (η^2p)	Group* condition p2 (η^2p)
	Unstable posture group (n=31)	Stable posture group (n=31)		Unstable posture group (n=31)	Stable posture group (n=31)			
Stable position								
Sway area	130.73±90.96	118.18±101.60	0.539	240.47±232.64	200.35±115.18	0.079	<0.001 (0.254)	0.519 (0.007)
Trace length	174.79±63.71	170.15±60.63	0.355	293.96±155.40	267.19±80.25	**0.049**	<0.001 (0.592)	0.343 (0.015)
Velocity	3.95±1.84	3.61±1.45	0.064	6.46±3.80	5.70±2.06	0.148	<0.001 (0.490)	0.484 (0.008)
Romberg quotient	213.67±164.39	213.93±132.22	0.480	210.12±163.48	211.93±122.22	0.584	0.277 (0.020)	0.277 (0.020)
Lateral sway	2.86±1.46	2.57±1.03	0.160	3.33±2.15	3.19±1.34	0.127	0.012 (0.100)	0.734 (0.002)
Anteroposterior sway	3.24±1.43	3.25±1.54	0.653	4.65±1.75	4.37±1.22	0.150	<0.001 (0.449)	0.425 (0.011)
Unstable position								
Sway area	239.10±257.58	163.66±121.36	**0.002**	513.46±345.96	406.04±237.78	0.199	<0.001 (0.525)	0.616 (0.004)
Trace length	211.07±69.88	203.72±63.63	0.782	400.57±117.02	383.00±134.04	0.226	<0.001 (0.775)	0.692 (0.003)
Velocity	5.07±0.81	4.39±1.28	**0.044**	9.37±3.46	8.26±3.39	0.880	0.352 (0.014)	0.324 (0.016)
Romberg quotient	339.38±151.56	292.35±136.05	0.777	340.35±152.86	282.35±116.05	0.745	0.321 (0.016)	0.321 (0.016)
Lateral sway	3.44±1.98	3.19±1.26	0.052	5.46±2.38	4.57±1.32	**0.004**	<0.001 (0.507)	0.146 (0.035)
Anteroposterior sway	3.81±1.72	3.51±1.42	0.532	6.28±1.82	5.90±2.23	0.271	<0.001 (0.651)	0.872 (0.001)

p1: Independent samples t-test used for between-group comparisons; p2: Two-way repeated measures analysis of covariance with a mixed model. Values are expressed as mean±standard deviation. Effect sizes for p2 are reported as partial eta squared (η^2p).

Table 4. Correlations between tractography results and balance-related outcomes

	Whole-brain			Left inferior cerebellar peduncle		Right inferior cerebellar peduncle		Middle cerebellar peduncle			Superior cerebellar peduncle	
	MD	AD	RD	FC	FP	FC	FP	MD	AD	RD	MD	RD
Trace length												
Eyes-closed	r=-0.202	r=-0.187	r=-0.202	r=0.060	r=0.053	r=0.064	r=0.054	r=-0.148	r=-0.056	r=-0.206	r=-0.243	r=-0.237
stable	p=0.115	p=0.147	p=0.115	p=0.645	p=0.682	p=0.621	p=0.678	p=0.251	p=0.663	p=0.108	p=0.057	p=0.063
Sway area												
Eyes-opened	r=-0.083	r=-0.100	r=-0.021	r=0.003	r=0.005	r=-0.269	r=-0.275	r=0.072	r=0.147	r=0.021	r=-0.186	r=-0.216
unstable	p=0.520	p=0.439	p=0.873	p=0.979	p=0.971	p=0.035*	p=0.031*	p=0.578	p=0.255	p=0.869	p=0.147	p=0.091
Velocity												
Eyes-opened	r=-0.023	r=0.002	r=0.013	r=-0.053	r=-0.064	r=-0.057	r=-0.068	r=-0.048	r=-0.151	r=0.033	r=-0.071	r=0.018
unstable	p=0.860	p=0.985	p=0.923	p=0.680	p=0.622	p=0.657	p=0.602	p=0.713	p=0.241	p=0.798	p=0.585	p=0.887
Lateral sway												
Eyes-closed	r=-0.070	r=-0.078	r=-0.045	r=-0.078	r=-0.090	r=-0.092	r=-0.097	r=0.106	r=0.166	r=0.066	r=-0.067	r=-0.086
unstable	p=0.587	p=0.549	p=0.730	p=0.544	p=0.488	p=0.478	p=0.451	p=0.413	p=0.196	p=0.611	p=0.605	p=0.505

MD: Mean diffusivity; AD: Axial diffusivity; RD: Radial diffusivity; FC: Fiber count; FP: Fiber percentage.

The study's sample size could have been larger. The relatively small number of participants in the study groups may limit our findings. To mitigate this limitation, conducting more extensive research is advisable.

CONCLUSION

In the unstable posture group, it is evident that the fibers in the brain's white matter, including the superior, medial, and inferior cerebellar peduncles, are compromised compared to those in the stable posture group. There appears to be a correlation between unstable posture and a reduced number of fibers in the cerebellar peduncle, which transmits the unconscious sense of proprioception.

These findings underscore the importance of the unconscious sense of proprioception in maintaining postural balance. Therefore, clinicians should consider this factor a priority when assessing individuals with postural balance issues and in planning their treatment.

Ethics Committee Approval: The Kayseri City Training and Research Hospital Clinical Research Ethics Committee granted approval for this study (date: 04.04.2023, number: 818).

Author Contributions: Concept – AP, İU, CK; Design – AP, SB, İU; Supervision – AP, BKV, SB; Resource – AP, EK, İU; Materials – AP, EK, SB; Data Collection and/or Processing – SB, BKV, AP; Analysis and/or Interpretation – AP, EK, CK; Literature Search – AP, EK, BKV; Writing – AP, İU, CK; Critical Reviews – İU, AK.

Conflict of Interest: The authors have no conflict of interest to declare.

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Use of AI for Writing Assistance: Not declared.

Financial Disclosure: The authors declared that this study has received no financial support.

Peer-review: Externally peer-reviewed.

REFERENCES

1. Moon KM, Kim J, Seong Y, Suh BC, Kang K, Choe HK, et al. Proprioception, the regulator of motor function. BMB Rep 2021; 54(8): 393–402.
2. Assaiante C, Barlaam F, Cignetti F, Vaugoyeau M. Body schema building during childhood and adolescence: a neurosensory approach. Neurophysiol Clin 2014; 44(1): 3–12.
3. Picton LD, Bertuzzi M, Pallucchi I, Fontanel P, Dahlberg E, Björnfors ER, et al. A spinal organ of proprioception for integrated motor action feedback. Neuron 2021; 109(7): 1188–201.e7.
4. Wyart C. Taking a big step towards understanding locomotion. Trends Neurosci 2018; 41(12): 869–70.
5. Furmanek MP, Słomka K, Juras G. The effects of cryotherapy on proprioception system. Biomed Res Int 2014; 2014: 696397.
6. Kargin D, Emre Aycan O, Gönen Aydin C, Albayrak A, Atici Y, Balioğlu MB. The proprioception of the knee joint following tibia plateau fractures. Acta Orthop Belg 2018; 84(2): 213–22.
7. Relph N, Herrington L. Interexaminer, intraexaminer and test-retest reliability of clinical knee joint-position-sense measurements using an image-capture technique. J Sport Rehabil 2015: 24(2): 2013–134.
8. Payas A, Batin S, Kurtoğlu E, Arik M, Seber T, Uçar İ, et al. Is the integration problem in the sensoriomotor system the cause of adolescent idiopathic scoliosis?. J Pediatr Orthop 2023; 43(2): e111–9.
9. Proske U, Gandevia SC. Kinesthetic senses. Compr Physiol 2018; 8(3): 1157–83.
10. Hillier S, Immink M, Thewlis D. Assessing proprioception: a systematic review of possibilities. Neurorehabil Neural Repair 2015; 29(10): 933–49.
11. Farion-Navolska O, Mysula IR, Denefil OV, Zavidnyuk YV, Sverstyuk A, Sydliaruk N. Evaluation of postural balance indicators in healthy individuals. Wiad Lek 2023; 76(9): 2041–6.
12. Cheng H, Wang Y, Sheng J, Kronenberger WG, Mathews VP, Hummer TA, et al. Characteristics and variability of structural networks derived from diffusion tensor imaging. Neuroimage 2012; 61(4): 1153–64.
13. Uçar İ, Batın S, Arık M, Payas A, Kurtoğlu E, Karartı C, et al. Is scoliosis related to mastication muscle asymmetry and temporomandibular disorders? A cross-sectional study. Musculoskelet Sci Pract 2022; 58: 102533.
14. Mori S, Zhang J. Principles of diffusion tensor imaging and its applications to basic neuroscience research. Neuron 2016; 51(5): 527–39.
15. Nagai Y, Fujimoto A, Okanishi T, Motoi H, Kanai S, Yokota T, et al. Successful hemispherotomy for a patient with intractable epilepsy secondary to bilateral congenital brain malformation with lateralized pyramidal tract of diffusion tensor image tractography. Epilepsy Behav Case Rep 2016; 6: 30–2.
16. Pietrasik W, Cribben I, Olsen F, Huang Y, Malykhin NV. Diffusion tensor imaging of the corpus callosum in healthy aging: Investigating higher order polynomial regression modelling. Neuroimage 2020; 213: 116675.
17. Delhaye BP, Long KH, Bensmaia SJ. Neural basis of touch

and proprioception in primate cortex. Compr Physiol 2018;8(4):1575–602.

18. Noriega-Gonzalez DC, Crespo J, Ardura F, Calabia-Del Campo J, Alberola-Lopez C, de Luis-García R, et al. Cerebral white matter connectivity in adolescent idiopathic scoliosis: a diffusion magnetic resonance imaging study. Children (Basel) 2022; 9(7): 1023.
19. Kelley S, Plass J, Bender AR, Polk TA. Age-related differences in white matter: understanding tensor-based results using fixel-based analysis. Cereb Cortex 2021; 31(8): 3881–98.
20. He J, Zhong X, Cheng C, Dong D, Zhang B, Wang X, et al. Characteristics of white matter structural connectivity in healthy adults with childhood maltreatment. Eur J Psychotraumatol 2023; 14(1): 2179278.