Gait & Posture 68 (2019) 258–263

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

The relationship between trunk position sense and postural control in ataxic individuals

Özge Onursal Kılınç[a,*], Ender Ayvat[a], Fatma Ayvat[a], Gülşah Sütçü[a], Muhammed Kılınç[a], Songül Aksoy[b], Sibel Aksu Yıldırım[a]

[a] Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Hacettepe University, Ankara, Turkey
[b] Department of Audiology, Faculty of Health Sciences, Hacettepe University, Ankara, Turkey

ARTICLE INFO

Keywords:
Trunk position sense
Ataxia
Postural control
Posturography

ABSTRACT

Background: The proprioceptive system plays a role in the maintenance of postural control more than the visual and vestibular systems in ataxic patients with postural control disorders, but the relationship between trunk proprioception and postural control has not been sufficiently investigated yet. This relationship can provide a different perspective to the ataxia rehabilitation.

Research question: This study aimed to examine the relationship between trunk position sense and postural control in ataxic individuals by comparing them to healthy individuals.

Methods: Twenty ataxic and 20 healthy individuals were included. The Sensory Organization Test, Limits of Stability Test, and Unilateral Stance Test in the Computerized Dynamic Posturography and Berg Balance Scale were used to evaluate postural control. The Baseline Digital Inclinometer (Norwalk, CA, USA) measured trunk position sense.

Results: It was found that repositioning error degree of the trunk position sense was higher in ataxic individuals than in healthy individuals, including scores of clinical and objective tests in postural control evaluation: they were lower in ataxic individuals ($p < 0.05$). As a result, trunk position sense was associated with almost all evaluated parameters, including sensory integration, postural sway, limits of stability, and functional balance ($p < 0.05$).

Significance: The impairment of postural control, which is the most important cause of activity and participation limitations in ataxic patients, is not only affected by motor disorders, but by sensory disturbances. Our study demonstrated that impairment of the trunk position sense in ataxic individuals was higher than that of healthy individuals, and affected the different components of postural control.

1. Introduction

Ataxia is a clinical syndrome that emerges due to lesions of the cerebellum and its neural connections, muscular coordination problems and postural disorders are the main symptoms as well [1]. Postural disorders are the major cause of poor balance in ataxia [2]. Various postural control disorders are seen in ataxia, such as increased postural oscillation, difficulty in controlling balance during movement of different body parts in which the gravity center undergoes a change, difficulty in adjusting the magnitude of postural responses to perturbations, and abnormal oscillations especially in the trunk [3]. The instability occurs in the anterior-posterior and medio-lateral directions, with a tendency developing to fall in every direction. Increased trunk movement in daily activities such as walking or climbing stairs, is a strategy to compensate for the balance disorder and to reduce backward falls [4].

Postural control is a complex process formed by the integration of numerous sensory-motor processes, and maintains the stabilization and orientation of the body in a standing position [5]. A critical sensory component of postural control is the proprioceptive system. Although it is not known to be related to many cerebral cortical areas, the relationship to the cerebellum has been of interest in recent years. It is known that the cerebellum is associated with some pathways that reflect positions of the joint and extremities, with importance for movement control [6]. Recent studies show that proprioceptive deficits are present in patients with cerebellar damage [7,8]. It is largely during sensory-motor tasks, the ability of patients with cerebellar damage to use proprioceptive input was shown to decrease [9]. It has been

* Corresponding author at: Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Hacettepe University, 06100 Ankara, Turkey.
E-mail address: ozgeonursal@hotmail.com (Ö. Onursal Kılınç).

https://doi.org/10.1016/j.gaitpost.2018.12.007
Received 13 August 2018; Received in revised form 20 November 2018; Accepted 5 December 2018

emphasized that when these patients need to control a movement by anticipating the amplitude of their movement rather than the direction, the proprioceptive deficiency occurs [7].

In previous studies, the effect of proprioception on postural control has been examined - e.g., in those with stroke, neuropathies, and older adults, where trunk position sense is a basic requirement for the formation of smooth limb movements and the maintenance of balance [10–12]. It has been seen that weight transfer is asymmetric, postural oscillations are increased, and the center of gravity shifts abnormally in patients with impaired trunk position sense [12]. After defining this relationship, it has been understood that postural control cannot be improved with only motor rehabilitation approaches. Thus, the idea that proprioceptive training should be an integral part of treatment has become popular in the last decade.

In ataxic patients, the proprioceptive system plays a role in the maintenance of postural control more than the visual and vestibular systems, but the relationship between them has not been sufficiently investigated yet. The sensorimotor ability of the trunk must be complete for trunk control to perform distal limb movements and selective movements [13]. However, in the literature the trunk is generally considered as motor aspect. In addition, trunk proprioception has not been studied in ataxic patients. This relationship can yield a different perspective to the ataxia rehabilitation with motor-focused rehabilitation approaches. As such, our study defines the relationship between postural control and trunk position sense in ataxic individuals and is recently being compared to that of healthy individuals.

2. Material and methods

2.1. Study design

The cross-sectional study was carried out at Hacettepe University, Department of Physiotherapy and Rehabilitation, Neurological Rehabilitation Unit. The permission and approval were obtained from Hacettepe University Non-Interventional Clinical Researches Ethics Board. (Approval No: GO 15/691)

2.2. Participants

Twenty-two ataxic individuals diagnosed by the neurologist and 20 healthy volunteers were included. The flow chart is shown in Fig. 1.

Inclusion criteria:

- Individuals with a diagnosis of ataxia;
- Individuals whose ages were between 18–50;
- Individuals who had a Mini Mental Test Score of 24 points and over;
- Individuals who were able to walk independently were included in the study.

Exclusion criteria:

- Individuals with another orthopedic or neurological disease that affects walking and balance were excluded from the study;
- Individuals with vestibular ataxia.

The evaluations were explained in detail to ataxic and healthy individuals. The informed consent form approved by Hacettepe University Ethics Committee was signed and approved.

2.3. Outcome measures

Individuals were asked about their age, gender, height, weight, history and duration of the disease, current complaints, and information about their medications.

2.3.1. Trunk position sense measurements

The trunk position sense was assessed with the Baseline Digital Inclinometer, which is a device that can be used to measure joint range of motion and position sense; it is calibrated with a 1° margin of error in measuring both range of motion and position sense. Measurements of trunk position sense were made with open-closed eye positions with trunk flexion and trunk right-left rotation movements. The reposition error method measured position sense. As such, the individual was in the position he/she was supposed to be in with the physiotherapist, and waited 5 s in that position; the therapist then wanted the individual to remember this position, as it was repeated 3 times for each move.

For trunk flexion movement, the inclinometer was fixed on the T4 spinous process while sitting and a 30-degree motion was requested [10]. The inclinometer was fixed between T1-T2 processes, so the individual was in the crawling position on the forearms and one side of the hand was on the neck of the other side to measure right-left rotation movements; individuals were asked to rotate their trunk 30 ° [14]. After 3 repetitions, the reposition degree of each one was determined as an absolute value. The average of these differences was taken, so the reposition error of the position sense for each movement was similarly assessed.

2.3.2. Functional balance measure

The Berg Balance Scale evaluates postural control in functional movements. It is a test of 14 items, scored from 0 to 4 for each one. The maximum score is 56 [15]. A score of 45 or higher indicates a lower risk of falling [16].

2.3.3. Postural control measures

The Neurocom Balance Master Computerized Dynamic Posturography device objectively evaluated postural control in the study.

2.3.3.1. Sensory organization test (SOT). It is considered the gold standard to assess postural control. It primarily identifies abnormalities in the patient's use of visual, somatosensory, and vestibular systems, plus sensory integration of these systems in the formation of postural control. Postural oscillations were measured in six different test conditions, where the eyes were both open and closed. A balance score for each condition and a composite equilibrium score were calculated by taking averages of the three repetitions [17].

2.3.3.2. Limits of stability (LOS) test. During LOS, each individual must move to the center of gravity from the middle starting point to 8 different targets, located at the 45-degree angle seen on the computer screen. The reaction time, directional control, end-point excursion, movement velocity, and maximum excursion parameters were evaluated for accuracy of movement during weight transfer at each target [18].

2.3.3.3. Unilateral stance test (UST). During UST, subjects were asked to repeat the 10-s trials while their eyes were both open and closed; this included standing on both the right and left leg. The velocity of postural oscillation was measured at four positions. The increase in the velocity of postural oscillation shows that the instability increases [19].

2.4. Statistical analysis

Statistical analyses of data were made using the IBM SPSS 20.0 statistical package (Armonk, NY, USA). The Mann-Whitney U test was used to determine the difference between groups and, the Spearman correlation test was used to evaluate the relationships between the variables in both groups. Trunk repositioning error for trunk flexion was the prime outcome measure used for calculating sample size. The power of the study found 99.2% for all 20 individuals by Gpower 3.0.10 analysis program. The data of volunteers who could not continue to

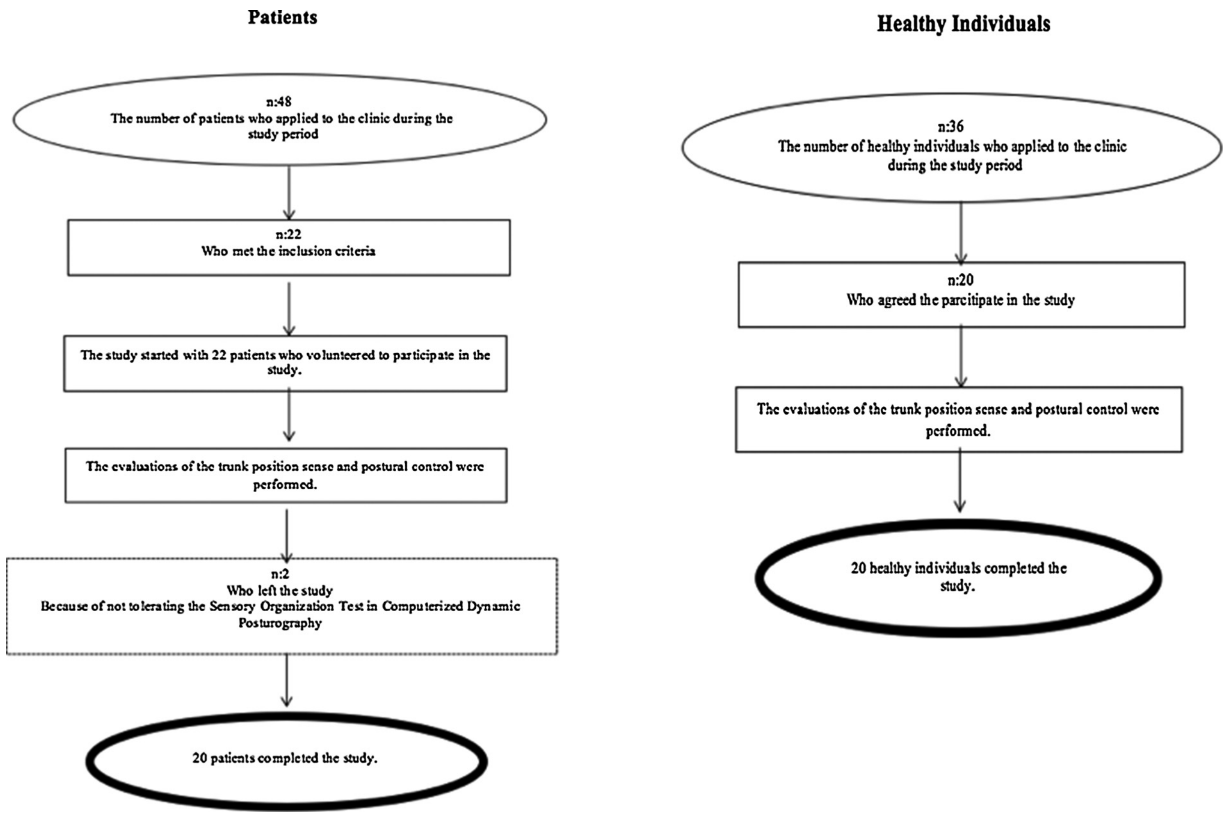

Fig. 1. The flow chart of the study participants.

study were not included in the statistical analysis.

3. Results

Twenty ataxic (13 females and 7 males) and 20 healthy individuals (8 females and 12 males) were included. The descriptive data are shown in Table 1. When the distribution of the diagnoses causing ataxia was examined, it was found that 55% had Multiple Sclerosis (11 individuals), 15% had Spinoserebellar Degeneration (3 individuals), 20% had cerebellar atrophy (4 individuals), and 10% had other diseases (2 individuals). Trunk position sense errors in ataxic individuals were significantly higher in all trunk positions compared to healthy individuals ($p < 0.05$). A comparison of the means of trunk position sense errors between the groups is in Table 2.

3.1. The differences in postural control parameters

When composite equilibrium scores and balance scores were examined in SOT - it was found that in ataxic individuals, the balance scores at the 1 st, 2nd, and 3rd conditions were significantly lower than those of healthy individuals ($p < 0.05$). In UST, it was found that the velocity of postural oscillation was significantly higher in ataxic individuals in all positions ($p < 0.05$). The SOT and UST results are shown in Table 2.

When the LOS test results were examined, it was found that there were differences at end-point excursion parameters in front, left, and left-front directions, and at maximum excursion parameters in front and left directions, with directional controls in front, back, and right directions, and at the reaction time parameter in the left-back direction between the groups. It was observed that healthy individuals were more successful in these parameters ($p < 0.05$). The different parameters of LOS are shown in Fig. 2A.

3.2. The relationship between trunk position sense and functional balance

There was a moderate negative correlation (r = -0.493) ($p < 0.05$) between the trunk right rotation position sense and the Berg Balance Scale score in the closed eye position in ataxic individuals; no relationship was observed in healthy individuals ($p > 0.05$).

3.3. The relationship between trunk position sense and postural control

The relationships between trunk position sense and UST and SOT results are shown in Table 3.

When the relationship between trunk position sense and LOS findings were examined; no correlation was found between trunk flexion position sense and findings of the LOS test in ataxic individuals ($p > 0.05$). The parameters of LOS and directions related to trunk rotation position sense in ataxic and healthy individuals are shown in Fig. 2B.

Table 1
Patients' demographic and physical characteristics.

	Patients X ± SD (n = 20)	Control X ± SD (n = 20)	Z	p
Age (years)	34.75 ± 8.83	31.25 ± 6.33	−1.466	0.143
Height (cm)	167.70 ± 11.71	172.45 ± 8.38	−1.558	0.119
Weight (kg)	66.45 ± 14.76	74.60 ± 14.70	−1.678	0.093
Gender (Female/Male)	13/7	8/12		
Dominant side (right/left)	20/0	20/0		
Disease Duration (years)	9.35 ± 5.11			

Mann-Whitney *U* test.

4. Discussion

The results of the present study have shown that ataxic individuals had more impairments in both position sense and postural control compared to healthy individuals. It was also demonstrated that the

Table 2
Trunk repositioning error degree, Sensory Organization Test and Unilateral Stance Test Scores, between groups comparisons.

		Patients X ± SD (n = 20)	Control X ± SD (n = 20)	Z	p
TRE	Trunk Flexion - EO	5.30 ± 3.41	2.50 ± 0.90	−2.678	**0.007***
	Trunk Flexion - EC	5.01 ± 2.85	1.81 ± 2.25	−3.909	**0.000***
	Right Rotation - EO	4.37 ± 2.33	2.60 ± 1.39	−2.759	**0.006***
	Left Rotation - EO	5.06 ± 2.39	2.82 ± 1.62	−3.030	**0.002***
	Right Rotation - EC	4.22 ± 1.93	2.57 ± 1.45	−2.530	**0.011***
	Left Rotation - EC	4.49 ± 2.02	3.07 ± 1.68	−2.286	**0.022***
SOT	CES (0-100)	73.75 ± 9.05	78.90 ± 7.42	−2.033	**0.042***
	C1 (somatosensory) (0-100)	91.48 ± 3.65	95.60 ± 1.79	−4.184	**0.000***
	C2 (somatosensory) (0-100)	88.85 ± 4.83	93.61 ± 1.62	−3.917	**0.000***
	C3 (somatosensory) (0-100)	88.94 ± 3.97	93.15 ± 2.31	−3.588	**0.000***
	C4 (visual) (0-100)	79.72 ± 9.13	82.36 ± 11.76	−1.746	0.081
	C5 (vestibular) (0-100)	57.05 ± 22.75	66.24 ± 11.46	−1.272	0.204
	C6 (vestibular) (0-100)	58.19 ± 15.58	63.61 ± 15.48	−1.312	0.189
UST	Left - EO	6.44 ± 4.94	0.53 ± 0.11	−5.077	**0.000***
	Left - EC	11.11 ± 2.54	3.48 ± 3.03	−4.967	**0.000***
	Right - EO	6.16 ± 4.93	0.53 ± 0.17	−5.296	**0.000***
	Right - EC	10.56 ± 3.20	3.24 ± 3.00	−4.575	**0.000***

Mann Whitney *U* test.
*$p < 0.05$; EO: eyes open; EC: eyes closed; TRE: Trunk Repositioning Error; SOT: Sensory Organization Test; CES: Composite equilibrium score; C: Condition; UST: Unilateral Stance Test; C: Condition.

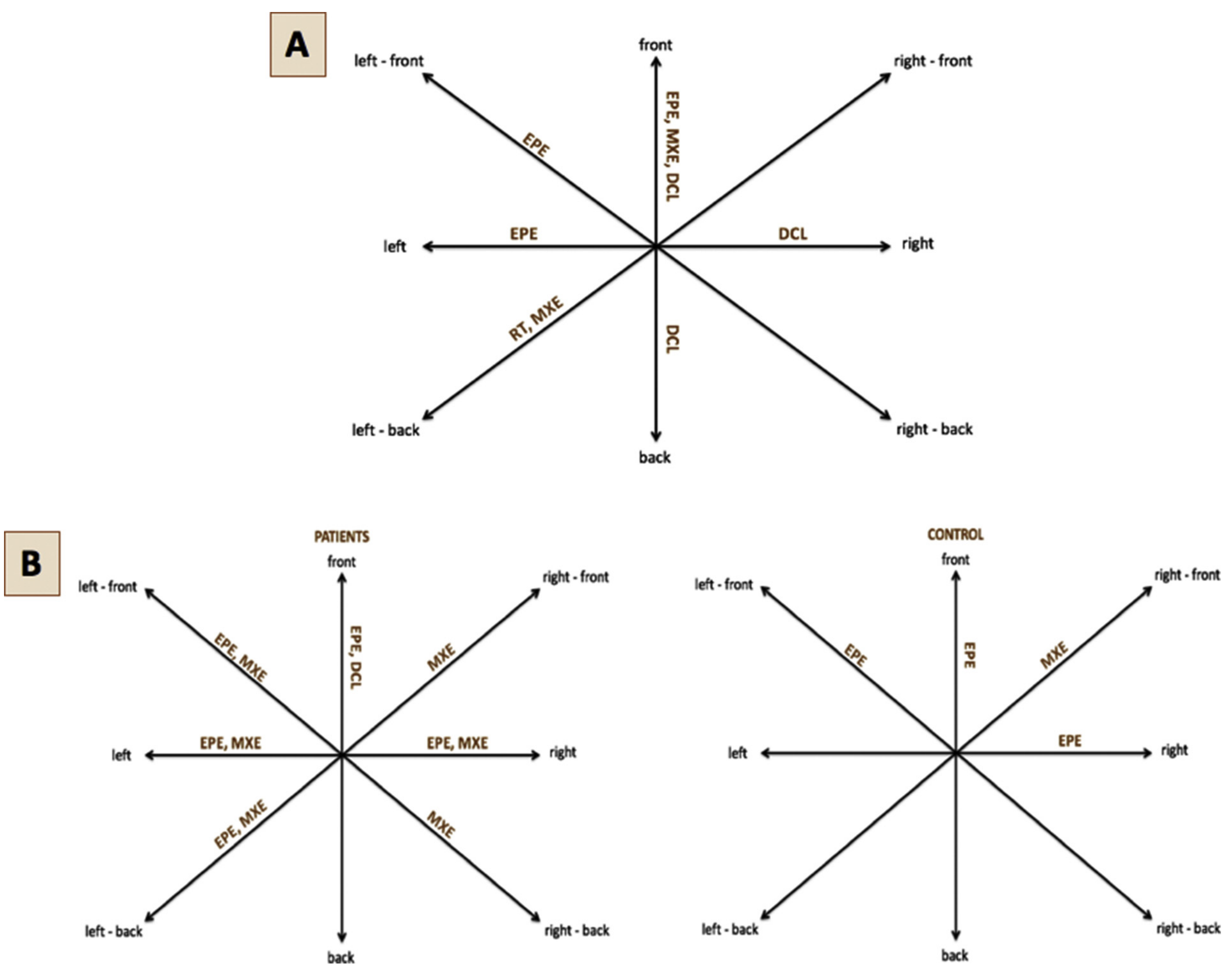

Fig. 2. Limits of Stability Test Results.
A: Differences parameters and locations in Limits of Stability Test between groups, Mann Whitney U test
B: The parameters and locations in Limits Of Stability Test related to trunk position sense in groups, Spearman Test
EPE: End Point Excursion; MXE: Maximum Excursion; DCL: Directional Control; RT: Reaction Time

Table 3
The correlation between trunk position sense and Sensory Organization Test and Unilateral Stance Test scores related to trunk position sense in groups.

		Patients (n = 20)						Control (n = 20)					
		Eyes Open			Eyes Closed			Eyes Open			Eyes Closed		
		Trunk Flexion	Trunk Right Rotation	Trunk Left Rotation	Trunk Flexion	Trunk Right Rotation	Trunk Left Rotation	Trunk Flexion	Trunk Right Rotation	Trunk Left Rotation	Trunk Flexion	Trunk Right Rotation	Trunk Left Rotation
SOT-CES	r	−0.097	0.434	0.072	−0.105	−0.288	−0.725	0.116	−0.371	−0.313	−0.212	−0.208	−0.695
	p	0.684	0.056	0.762	0.661	0.218	**0.000***	0.625	0.107	0.179	0.370	0.378	**0.001***
SOT-C1	r	−0.207	0.140	−0.193	0.104	−0.068	−0.317	0.295	−0.049	0.275	0.102	0.047	0.020
	p	0.381	0.556	0.414	0.663	0.774	0.173	0.207	0.837	0.241	0.668	0.845	0.933
SOT-C2	r	−0.128	−0.411	−0.542	0.060	−0.200	0.007	0.337	−0.343	−0.300	0.232	0.266	0.025
	p	0.590	0.072	**0.014***	0.801	0.397	0.977	0.146	0.139	0.198	0.324	0.258	0.918
SOT-C3	r	−0.097	−0.195	−0.355	0.165	−0.256	−0.222	0.097	−0.253	0.091	−0.009	−0.003	−0.324
	p	0.684	0.410	0.125	0.487	0.276	0.347	0.684	0.282	0.704	0.968	0.990	0.164
SOT-C4	r	−0.193	0.424	0.056	−0.204	−0.098	−0.662	0.062	−0.316	−0.542	−0.277	−0.044	−0.715
	p	0.416	0.062	0.813	0.389	0.682	**0.001***	0.795	0.175	**0.013***	0.238	0.853	**0.000***
SOT-C5	r	0.038	0.390	0.131	0.140	−0.468	−0.471	−0.088	−0.497	−0.304	−0.371	−0.309	−0.636
	p	0.875	0.089	0.582	0.556	**0.038***	**0.036***	0.711	**0.026***	0.192	0.107	0.186	**0.003***
SOT-C6	r	0.023	0.408	0.002	−0.038	−0.058	−0.777	0.140	−0.253	−0.180	−0.166	−0.322	−0.586
	p	0.925	0.074	0.995	0.875	0.808	**0.000***	0.556	0.283	0.448	0.483	0.166	**0.007***
UST-L-EO	r	0.357	−0.312	0.260	−0.378	0.560	0.535	0.197	0.026	0.333	0.057	0.138	0.169
	p	0.122	0.180	0.269	0.100	**0.010***	**0.015***	0.684	0.914	0.151	0.811	0.561	0.477
UST-L-EC	r	0.227	−0.065	0.085	−0.123	0.339	0.172	−0.102	0.273	0.138	0.070	−0.057	0.194
	p	0.335	0.784	0.723	0.604	0.144	0.469	0.669	0.243	0.562	0.769	0.810	0.412
UST-R-EO	r	0.188	−0.031	−0.140	−0.231	0.507	0.072	−0.198	−0.151	−0.022	−0.348	0.350	0.101
	p	0.428	0.898	0.556	0.326	**0.022***	0.762	0.402	0.525	0.928	0.133	0.131	0.671
UST-R-EC	r	0.224	0.321	0.372	−0.127	0.275	−0.037	0.270	0.183	0.011	−0.088	−0.006	0.398
	p	0.343	0.168	0.106	0.594	0.240	0.878	0.249	0.441	0.965	0.712	0.980	0.082

Spearman Test.
*$p < 0.05$; SOT: Sensory Organization Test; CES: Composite equilibrium score; C: Condition; UST: Unilateral Stance Test; L: Left, R: Right; EO: eyes open; EC: eyes closed.

trunk position sense is effective in many aspects of postural control in ataxic individuals. These results are thought to contribute to the selection of methods to be used in evaluating ataxic individuals and in determining priorities of the treatment program.

It is suggested that postural control disorders, which are considered to be the main cause of activity and participation limitations of ataxic individuals, should be evaluated to include all components of postural control and appropriate approaches for patients' needs [5]. In previous studies, investigating the relationship between position sense and balance, it was found that the impaired position sense was one of the main issues in postural control disorders. Moreover, it was emphasized that the response to treatment became difficult when motor problems were combined with sensory disorders. As a result, it has been suggested that the proprioceptive system should be assissted by more comprehensive approaches, such as body awareness as well as routine treatments. Although it is assumed to be clinically practical, there has been no study to date describing the properties of the relationship between position sense and postural control in ataxic individuals. As such, this study is the first original one to investigate the relationship between position sense and postural control in ataxic individuals as compared to healthy individuals, using clinical and objective measurements, and describing the role of the trunk position sense in terms of postural control.

In our study, postural control was assessed with a Computerized Dynamic Posturography, as it is a system that allows for evaluation of many components of postural control; it is accepted to be the gold standard and provides objective data about postural control [20,21]. Given our study, when the relationship between trunk position sense and SOT components in ataxic individuals were examined, the composite equilibrium score of SOT decreased, while the reposition error of trunk position sense increased. It was also important that test positions separately assessed the roles of somatosensory, visual, and vestibular systems in ataxic individuals, which were negatively affected in the reposition error of trunk position sense. This reinforces results of previous studies and suggests that trunk position sense is effective with postural control: it is also necessary to focus on the trunk during the development of sensory strategies.

Bart et al. found that the postural oscillations of ataxic individuals were higher and faster than those of healthy individuals, while evaluating the postural oscillations of individuals in 11 different tasks for standing and walking. It was emphasized that these oscillations were not in one direction but all directions, especially in patients with lesions in the spinocerebellum region, so the oscillations in the sagittal plane were more often seen than in the transverse plane [22]. As in other studies in the literature, the results of the present study have shown that in both ataxic and healthy individuals, the postural oscillations increased with the eyes closed, where the effects of the proprioceptive system is assessed without visual compensation [19,23]. It has been also shown that the velocities of postural oscillations of ataxic individuals were higher than those of healthy individuals under 4 different test conditions. When we investigated the relationship between postural oscillation and trunk position sense, it was observed that the velocity of postural oscillations increased while increasing the reposition error of trunk position sense; this was not observed in healthy individuals.

The LOS in Computerized Dynamic Posturography is a test that assesses the biomechanical constraint component of postural control [24]. In a case-control study in which the balance of the individual with Spinocerebellar Ataxia and healthy individuals were evaluated with LOS; it was concluded that the individual with Spinocerebellar Ataxia failed the test in all 8 directions, vs. the healthy individual. It was found that the success of the healthy individual was more prominent when transferring weight to the front and right side, compared to the ataxic individual. Despite being a case study, these results emphasize that LOS is a sensitive test in evaluating balance disorders of ataxic patients [25]. Similar to in our results, ataxic individuals were found to have failed the LOS parameters compared to healthy individuals. When we examine the relationship with trunk position sense, it was seen that endpoint excursion and maximum excursion parameters were related to trunk position sense in 7 directions, except for a backward direction. In healthy individuals, the trunk position sense was related to end-point excursion in 3 directions and maximum excursion in one direction.

Among the LOS parameters, especially end-point excursion and maximum excursion, the parameters seemed related to the position sense. When the relationship between the trunk position sense and the limits of stability is compared to that of healthy subjects, it is concluded that the trunk position sense can change limits of stability in both ataxic and healthy individuals, and thus can affect the biomechanical constraints component of postural control. For this reason, we suggest that a good trunk position sense and trunk control are required for weight transference, and that trunk position sense should be evaluated and included in any treatment program for patients having problems in limits of stability. Cameron et al. demonstrated that the limits of stability of Multiple Sclerosis patients were inadequate compared to healthy individuals and; they began to investigate the cause of falls in Multiple Sclerosis patients. They emphasized that approaches increasing somatosensory input would correct these disorders and reduce patients' risk of falls [26].

Marquer et al. reported in their systematic review that balance and ataxia scales were primarily used to assess postural disorders in ataxic patients [2]. However, the methods evaluating sensory system which is one of the important components of postural control were not included in these studies. The present study also contributed to the literature in this regard.

There is a limitation in the study – as we did not assess clinical evaluations in the protocol to evaluate the dynamics of postural control, such as walking and climbing up and down stairs. Although there is no gold standard method in the evaluation of proprioception, the failure of not using more objective methods to measure position sense as seen in the literature is another limitation. Also, the insufficient sample size in our study is another limitation.

5. Conclusions

Postural control impairments, the leading cause of activity and participation limitation of ataxic individuals, are under the influence of motor disorders as well as sensory disturbances. The results of the present study show that the trunk position sense of ataxic individuals is more affected than healthy individuals, and the impairment of trunk position sense affected different components of postural control. The trunk position sense was found to be related to limits of stability, postural oscillation, functional balance, and most importantly, sensory integration required to maintain postural control.

In light of this evidence, as witnessed by the rehabilitation of ataxic individuals, it has been concluded that in treatment programs, the creation of different sensory environments may affect the trunk position sense, as well as approaches to affect the sensory system: these should occur according to patient needs. We think that the present study will make a significant contribution to ataxia rehabilitation, which is generally approached by motor perspective.

In future studies, it is believed that evaluating the position sense with more objective methods and increasing the sample size will strengthen the evidence. Comparing the effects of different treatment approaches on postural control by treating trunk position sense will also contribute to this field.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

We acknowledge all the ataxic participants and healthy volunteers.

References

[1] T. Klockgether, H. Paulson, Milestones in ataxia, Mov. Disord. 26 (2011) 1134–1141.
[2] A. Marquer, G. Barbieri, D. Pérennou, The assessment and treatment of postural disorders in cerebellar ataxia: a systematic review, Ann. Phys. Rehabil. Med. 57 (2014) 67–78.
[3] S.M. Morton, A.J. Bastian, Cerebellar control of balance and locomotion, Neuroscientist 10 (2004) 247–259.
[4] M. Bakker, J.H. Allum, J.E. Visser, C. Grüneberg, B.P. van de Warrenburg, B.H. Kremer, et al., Postural responses to multidirectional stance perturbations in cerebellar ataxia, Exp. Neurol. 202 (2006) 21–35.
[5] F.B. Horak, Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? Age Ageing 35 (2006) ii7–ii11.
[6] W.T. Thach, H. Goodkin, J. Keating, The cerebellum and the adaptive coordination of movement, Annu. Rev. Neurosci. 15 (1992) 403–442.
[7] N.H. Bhanpuri, A.M. Okamura, A.J. Bastian, Predictive modeling by the cerebellum improves proprioception, J. Neurosci. 33 (2013) 14301–14306.
[8] N.H. Bhanpuri, A.M. Okamura, A.J. Bastian, Active force perception depends on cerebellar function, J. Neurophysiol. 107 (2011) 1612–1620.
[9] H.J. Block, A.J. Bastian, Cerebellar involvement in motor but not sensory adaptation, Neuropsychologia 50 (2012) 1766–1775.
[10] A. Goldberg, M.E. Hernandez, N.B. Alexander, Trunk repositioning errors are increased in balance-impaired older adults, J. Gerontol. A Biol. Sci. Med. Sci. 60 (2005) 1310–1314.
[11] A. Goldberg, J.W. Russell, N.B. Alexander, Standing balance and trunk position sense in impaired glucose tolerance (IGT)-related peripheral neuropathy, J. Neurol. Sci. 270 (2008) 165–171.
[12] S. Ryerson, N.N. Byl, D.A. Brown, R.A. Wong, J.M. Hidler, Altered trunk position sense and its relation to balance functions in people post-stroke, J. Neurol. Phys. Ther. 32 (2008) 14–20.
[13] G. Verheyden, A. Nieuwboer, J. Mertin, R. Preger, C. Kiekens, W. De Weerdt, The trunk impairment scale: a new tool to measure motor impairment of the trunk after stroke, Clin. Rehabil. 18 (2004) 326–334.
[14] K.D. Johnson, T.L. Grindstaff, Thoracic rotation measurement techniques: clinical commentary, N. Am. J. Sports Phys. Ther. 5 (2010) 252.
[15] K.O. Berg, S.L. Wood-Dauphinee, J.I. Williams, B. Maki, Measuring balance in the elderly: validation of an instrument, Canadian Journal of Public Health = Revue canadienne de sante publique 83 (1992) S7–11.
[16] L.D. Bogle Thorbahn, R.A. Newton, Use of the Berg Balance Test to predict falls in elderly persons, Phys. Ther. 76 (1996) 576–583.
[17] R. Ortiz-Gutiérrez, R. Cano-de-la-Cuerda, F. Galán-del-Río, I.M. Alguacil-Diego, D. Palacios-Ceña, J.C. Miangolarra-Page, A telerehabilitation program improves postural control in multiple sclerosis patients: a Spanish preliminary study, Int. J. Environ. Res. Public Health 10 (2013) 5697–5710.
[18] F. Melillo, A. Di Sapio, S. Martire, M. Malentacchi, M. Matta, A. Bertolotto, Computerized posturography is more sensitive than clinical Romberg Test in detecting postural control impairment in minimally impaired multiple sclerosis patients, Mult. Scler. Relat. Disord. 14 (2017) 51–55.
[19] K. Bouche, V. Stevens, D. Cambier, J. Caemaert, L. Danneels, Comparison of postural control in unilateral stance between healthy controls and lumbar discectomy patients with and without pain, Eur. Spine J. 15 (2006) 423–432.
[20] A. Üneri, Bilgisayarlı dinamik posturografi, Vertigo (2005) 97–108.
[21] R. Barona de Guzmán, Interés de la posturografía en el diagnóstico y tratamiento del vértigo y el desequilibrio en especialidades médico-quirúrgicas, Rev Biomech. 1 (2003) 11–14.
[22] B.P. Van de Warrenburg, M. Bakker, B.P. Kremer, B.R. Bloem, J.H. Allum, Trunk sway in patients with spinocerebellar ataxia, Mov Disord. 20 (2005) 1006–1013.
[23] F.A. Hazime, P. Allard, M.R. Ide, C.M. Siqueira, C.F. Amorim, C. Tanaka, Postural control under visual and proprioceptive perturbations during double and single limb stances: insights for balance training, J. Bodyw. Mov. Ther. 16 (2012) 224–229.
[24] G. Juras, K. Słomka, A. Fredyk, G. Sobota, B. Bacik, Evaluation of the limits of stability (LOS) balance test, J. Hum. Kinet. 19 (2008) 39–52.
[25] G. Mohan, P.K. Pal, K.R. Sendhil, K. Thennarasu, B. Usha, Quantitative evaluation of balance in patients with spinocerebellar ataxia type 1: a case control study, Parkinsonism Relat. Disord. 15 (2009) 435–439.
[26] M.H. Cameron, S. Lord, Postural control in multiple sclerosis: implications for fall prevention, Curr. Neurol. Neurosci. Rep. 10 (2010) 407–412.