Somatosensory evoked potentials and dynamic postural assessment in adolescent idiopathic scoliosis

Dalia Mohamed Ezz El Mikkawy[a], Eman Ahmed Tawfek[a], Mohja Ahmed El Badawy[a], Fathy Naeem[b]

Departments of [a]Physical Medicine, Rheumatology and Rehabilitation, [b]Ear, Nose and Throat, Ain Shams University Hospitals, Faculty of Medicine, Ain Shams University, Abbasia, Cairo, Egypt

Correspondence to Dalia M.E. El Mikkawy, MD, Lecturerin Physical Medicine, Rheumatology and Rehabilitation, 11 Abbass Zakzook Street, 7th District, Nasr City, Cairo, Egypt
Tel: +20 122 580 0199, +20 102 558 5779;
e-mail: drdaliaezz74@yahoo.com

Received 07 November 2015
Accepted 29 November 2015

Egyptian Rheumatology & Rehabilitation
2016, 43:67–72

Background
Dysfunction of the somatosensory pathways may cause an impaired postural balance when the somatosensory system is challenged, and this impaired balance may play a role in the etiology or development of scoliosis. Angle of scoliosis may affect the somatosensory evoked potentials (SSEPs) and dynamic balance control.

Purpose
The aim of this study was to investigate possible abnormalities and correlations in SSEPs and dynamic posturography in adolescent idiopathic scoliosis (AIS) patients.

Patients and methods
This study was conducted on 14 adolescents ranging in age from 10 to 16 years with AIS. Both sexes were included. Measurement of Cobb's angle, SSEPs of both posterior tibial nerves with cortical recording, dynamic postural assessment including sensory organization test, and motor control test were performed.

Results
There was a highly significant positive correlation between the angle of scoliosis and right and left SSEP. There was a highly significant negative correlation between the angle of scoliosis and equilibrium score-composite and ratio for sensory analysis-vestibular, and significant negative correlation with motor control-composite. There was a highly significant negative correlation between right SSEP and balance parameters. There was significant negative correlation between left SSEP and equilibrium score-composite and ratio for sensory analysis-vestibular.

Conclusion
The study demonstrates abnormal somatosensory and postural function in patients with AIS, and a significant inter-relationship between the scoliotic angle, the somatosensory system, and posture. Thus, optimum assessment and treatment of neurological pathway and balance are important in these patients.

Keywords:
adolescent, dynamic balance, evoked potentials, scoliosis

Egypt Rheumatol Rehabil 43:67–72

1110-161X

Introduction

Idiopathic scoliosis (IS) is the most common form of spinal deformity, and adolescent idiopathic scoliosis (AIS) occurs at or near the onset of puberty [1]. It is defined as structural lateral curvature of the spine, occurring in an otherwise healthy child, and for which no cause could be recognized [2]. Understanding the cause of AIS is important for elucidating its pathogenesis. Epidemiological investigations have demonstrated that the incidence of IS is ~2% in patients with a Cobb angle greater than 11° and is ~0.3–0.5% among those with a Cobb angle greater than 20°. The wide range of curve magnitudes in patients with IS suggests the presence of multiple factors [3].

Results in studies have shown that growing children and adolescents with disorders in the somatosensory pathway are more susceptible to the development of scoliosis than are healthy people [2]. This raises the possibility that a subclinical somatosensory neuropathologic process may be associated with AIS [1].

It was postulated that IS can result from a dysfunction in the central nervous system [4]. This hypothesis is supported by a study conducted by Machida *et al*. [4] in 1994 who found delayed latency of the somatosensory cortical potential of the tibial nerve in scoliosis patients compared with healthy individuals.

Dysfunction of the somatosensory pathways may cause an impaired postural balance mechanism when the somatosensory system is challenged, and this impaired balance may play a role in the etiology or development of scoliosis [5] as balance control requires

the contribution of information from somatosensory, visual, and vestibular systems, followed by central integration and motor response [6].

Herman *et al.* (1985) [7] and Byl and Gray (1993) [8] found that patients with AIS had similar balance responses and body sway parameters to healthy controls under normal static stable balance conditions, but body sway was significantly greater in AIS patients when visual feedback was removed and proprioception was challenged. Chen *et al.* (1998) [9] showed that AIS patients have a poorer static balance control characterized by increased sway area, lateral sway, sagittal sway, and sway radius compared with normal controls.

Nault and colleagues (2002) studied standing postural sway in children with IS by comparing the sway area of the center of pressure and center of movement between patients with AIS and normal controls. They found that children with scoliosis had a larger center of pressure-center of movement difference in both anterior–posterior and medial–lateral directions [10].

The aim of this study was to investigate possible abnormalities and correlations in somatosensory evoked potentials (SSEPs) and dynamic posturography in AIS patients.

Patients and methods

The methodology of this study was approved by the research ethical committee of Ain Shams Faculty of Medicine and all patients or their families provided written informed consent before participation. This study was conducted on 14 adolescents with IS. Their ages ranged from 10 to 16 years, and both sexes were included. All of them were recruited from the pediatric physical medicine and rehabilitation outpatient clinic at Ain Shams University Hospitals, Faculty of Medicine, Ain Shams University. The patient is diagnosed as having IS when there is a lateral curvature of the spine clinically, which is confirmed by radiographic measurement of Cobb's angle (include any angle range) and clinical exclusion of all possible medical causes of secondary scoliosis.

Exclusion criteria included individuals with scoliosis with signs and symptoms of sensory disturbance, muscle weakness in any limb, auditory or visual disturbance, other spinal deformities, and neurological diseases whether central or peripheral.

Patients were subjected to the following

(1) Detailed medical history including age, sex, family member with scoliosis, onset, course and duration of the condition, and any underlying medical conditions to exclude cases of secondary scoliosis.
(2) Physical examination including:
   (a) Postural assessment in the form of patient height, trunk asymmetry, head and neck position, shoulder height, scapular alignment, other spinal deformities, and pelvic symmetry; back examination with emphasis on inspection of scoliosis curve, its site, determining whether right or left, sacroiliac joints level, and paraspinal muscles; musculoskeletal assessment including range of motion of upper and lower limbs, other deformities, and true leg length.
   (b) Neurological assessment and skin and soft tissue assessment for any skin pigmentation or hair patches over the spine to exclude neurological conditions such as neurofibromatosis or myelodysplasia.
(3) Plain radiograph: Lateral and anteroposterior views to determine the type and site of the curve and Cobb's angle.
(4) Corrective back exercises, back extension exercises, and suspension exercise. A Boston brace was prescribed for two patients with Cobb's angle of 25 and 28°. One patient underwent surgery as she experienced rapid progress of scoliosis angle in 6 months.
(5) SSEPs of both posterior tibial nerves with cortical recording using an electrophysiological instrument (Schwarzer topas; NEC Multisystem, USA). The participants were asked to lie supine and remained awake but relaxed during the procedure during which a recording electrode was placed at Cz' point according to the international 10–20 system and a reference electrode was placed at the Fz point. A ground electrode was placed between recording and stimulating electrodes. Height of the patients was entered. The posterior tibial nerve was stimulated at the ankle behind and inferior to the medial malleolus with the cathode directed proximally. The stimulus strength used was the stimulus intensity that produced a muscle twitch. The stimulus rate was 3 Hz. Pulse duration used was 0.2 ms with amplifier bandpass 10–3000 Hz. Two trials were recorded using averaging 200 each time. The recorded SSEP-waveform was analyzed as regards absolute P1 latency (P37) and interside latency difference. Ten age-matched and sex-matched healthy children were taken as the control group for latency and interside latency difference of right and left sides (mean difference values were 1.66 ± 1.24).

Computerized dynamic posturography

Dynamic postural assessment was performed using the EquiTest System version 7.0+ (USA). The assessment

depended on standardized test protocols that exposed the patient to support surface and visual surround motions, during which the patient's postural stability and motor reactions are recorded. The test protocols used in this study included the following:

The sensory organization test

The first three conditions were followed on a fixed platform (C1) eyes opened, (C2) eyes closed, (C3) in a sway referenced visual enclosure. The other three conditions utilized a sway referenced platform with (C4) eyes opened, (C5) eyes closed, (C6) in a sway referenced visual enclosure. Three trials were conducted for each condition [11]. Analysis of the results included the equilibrium score (ES), which quantifies the center of gravity sway or postural stability under each of the three trials of the six sensory conditions.

Calculation of equilibrium score

The maximum peak-to-peak sway angle was calculated for each trial with respect to the maximum theoretic sway possible without falling. This ratio was referred to as ES. Increases in the ES reflected greater postural stability. An ES of 100 indicated no body sway, and a zero was recorded for falls or steps. The ES was calculated for each trial in each sensory condition. A composite ES was used initially to determine whether the overall pattern of balance was normal or abnormal for each patient. The composite score was the mean ES from condition 1 and condition 2 averaged with all the trials from condition 3 to condition 6. The composite scores were statistically analyzed for both the study and control groups.

We have also studied another parameter of sensory analysis, the ratio for sensory analysis-vestibular (unstable support/absent vision), which represents the ratio of anteroposterior sway from condition 5 to condition 1 and reflects the patient ability to use the input from the vestibular system to maintain balance.

The motor control test

Sequences of small, medium, and large platform translations in forward and backward directions were used to elicit automatic postural responses. Latency parameters were measured, which quantifies the time between translation onset and initiation of the patient's active response [11]. Matched control values for computerized dynamic posturography were used.

Statistical analysis

Continuous variables are expressed as mean and SD. Categorical variables are expressed as frequencies and percentages. The paired *t*-test was used to analyze an interside difference in latencies of PTN-SSEPs. The Student *t*-test was used for analysis of differences in latencies of PTN-SSEPs between healthy participants and patients with AIS. Pearson's correlation was used to assess the correlation between numerical data. A significance level of *P* value less than 0.05 was used in all tests. All statistical procedures were carried out using SPSS version 15 for Windows (SPSS Inc., Chicago, Illinois, USA).

Results

The mean age of the study group was 12.8 ± 1.8 years, with a minimum age of 10 and maximum age of 16 years. Girls represented the majority of cases [10 girls (71.4%) vs. four boys (28.6%)]. Their height ranged from 135 to 158 cm. The height of the control group ranged from 133 to 158 cm.

Description of disease characteristics among cases showed a mean angle of scoliosis of 12.7 ± 7.3° with minimum of 5° and maximum of 28°. Dorsal scoliosis presented in eight patients (57.1%), dorsolumbar scoliosis in five (35.7%), and cervicodorsal in one patient (7.1%). Regarding the side of scoliosis, there were nine patients (64.3%) with right-side scoliosis and five (35.7%) with left-side scoliosis. Description of the right and left posterior tibial-SSEPs (Pt-SSEPs) of patients is shown in Table 1.

There was one patient with right and left SSEP and one right and two left latencies within the average value of controls. An overall 85.7% of patients had right SSEP abnormality and 78.5% had left SSEP abnormality. Regarding the relation between right and left Pt-SSEP, P1 latencies with each of sex and scoliosis site showed no statistically significant relation between SSEP and the above parameters (Tables 2 and 3).

Comparison between right and left SSEP among controls showed a nonsignificant difference between the right and left SSEP, with a mean of 34.15 ± 1.133 on the right side and a mean of 35.54 ± 2.151 on the left side (Table 4).

P1 latencies among cases showed no significant difference ($P = 0.5$) with respect to the right and left Pt-

Table 1 Description of right and left posterior-tibial somatosensory evoked potential P1 latencies of patients

PT-SSEP P1 latencies (ms)	Mean±SD	Minimum	Maximum
Right SSEP	48.3±10.2	36.4*	66.6
Left SSEP	48.3±10.1	37.0*	70.2

PT-SSEP, posterior-tibial somatosensory evoked potential; SSEP, somatosensory evoked potential. *Student *t*-test.

Table 2 Relation between each of sex, scoliosis site, and right (posterior-tibial somatosensory evoked potential) P1 latency

	Right SSEP (ms) (mean±SD)	*P*	Significance
Sex			
Male	46.79±7.28	0.740	NS
Female	48.91±11.44		
Site of scoliosis			
Dorsal	48.91±10.52	0.808	NS
Dorsolumbar/cerviodorsal	47.49±10.64		

SSEP, somatosensory evoked potential.

Table 3 Relation between each of sex, scoliosis site, and left (posterior-tibial somatosensory evoked potential) P1 latency

	Left SSEP (mean±SD)	*P*	Significance
Sex			
Male	43.43±5.33	0.274*	NS
Female	50.22±11.16		
Site of scoliosis			
Dorsal	50.14±11.31	0.451*	NS
Dorsolumbar/cerviodorsal	45.80±8.71		

SSEP, somatosensory evoked potential. *Student *t*-test.

Table 4 Comparison between right and left somatosensory evoked potential among controls

	Mean	*N*±SD	*P*	Significance
SSEP Rt	34.15	10±1.133	0.084*	NS
SSEP Lt	35.54	10±2.151		

SSEP, somatosensory evoked potential. *Paired *t*-test.

Table 5 Comparison between right and left somatosensory evoked potential among cases

	Mean	*N*±SD	*P*	Significance
SSEP Rt	48.305	14±10.1876	0.993	NS
SSEP Lt	48.279	14±10.1486		

SSEP, somatosensory evoked potential.

Table 6 Comparison between cases and controls as regards right and left somatosensory evoked potentials, and difference between the two sides

	Group (mean±SD)		*P*	Significance
	Case	Control		
SSEP Rt	48.30±10.19	34.14±1.13	0.004[a]	HS
SSEP Lt	48.28±10.15	35.54±2.15	0.008[a]	HS
Difference in SSEP				
Mean±SD	7.90±7.29	1.66±1.24	0.012[b]	S
Median (IQR)	4.4 (3-14.2)	1.3 (0.5-3)		

IQR, interquartile range; SSEP, somatosensory evoked potential. [a]The values are calculated using the Student *t*-test. [b]The value is calculated using the Mann–Whitney test.

Table 7 Correlations between angle of scoliosis and each of right and left somatosensory evoked potentials

	Right SSEP	Left SSEP
Angle of scoliosis		
r	0.715	0.574
P	0.004	0.032
Significance	HS	S

SSEP, somatosensory evoked potential.

SSEPs, with mean of right side being 48.305 ± 10.1876 ms and mean of left side being 48.279 ± 10.1486 ms, using a paired *t*-test (Table 5).

Comparison between cases and controls as regards right and left SSEPs and comparison between the two sides showed highly statistically significant difference (P = 0.004 between right SSEP and controls and P = 0.008 between left SSEP and controls).

There was a statistically significant difference in mean values between cases and controls (P = 0.012) (Table 6).

There was a highly significant positive correlation between the angle of scoliosis and Pt-SSEP latencies recorded from both sides, as shown in Table 7. Description of the sensory organization test and its vestibular division among cases and matched controls is shown in Tables 8 and 9. There was a highly significant difference between cases and controls as regards ES-composite, ratio for sensory analysis-vestibular, and motor control latency-composite, as shown in Table 10.

There was a highly significant negative correlation between angle of scoliosis and ES-composite and ratio for sensory analysis-vestibular, and a significant negative correlation between angle of scoliosis and motor control-composite, as shown in Table 11.

There was a highly significant negative correlation between right Pt-SSEP latencies and ES-composite, ratio for sensory analysis-vestibular, and motor control latency-composite, as shown in Table 12. There was a significant negative correlation between left Pt-SSEP P1 latencies and ES-composite and motor control latency-composite, and a nonsignificant correlation between left Pt-SSEP P1 latencies and ratio for sensory analysis-vestibular, as shown in Table 13.

Discussion

The aim of this study was to investigate possible abnormalities and correlations in SSEPs and dynamic posturography in AIS patients. In this study on 14 patients with AIS, there was a highly statistically significant difference between right SSEP and controls (P = 0.004) and between left SSEP and controls (P = 0.008), and a statistically significant difference in mean values of cases and controls (P = 0.012).

In this study the mean angle of scoliosis was 12.7 ± 7.3° with minimum of 5° and maximum of 28°.

Table 8 Description of sensory organization test and its vestibular division among cases

	Mean±SD	Minimum	Maximum
SOT EQL-CMP	72.18±7.13	52.00	84.00
RAT-VEST	0.71±0.07	0.56	0.81
MC LAT-CMP	154.96±13.11	120.00	177.00

EQL-CMP, equilibrium score-composite; LAT-CMP, composite of all latencies (motor control test); MC, motor control; RAT-VEST, ratio for sensory analysis-vestibular; SOT, sensory organization test.

Table 9 Description of sensory organization test and its vestibular division among matched controls

	Mean±SD	Minimum	Maximum
SOT EQL-CMP	76.14±4.37	70.00	84.00
RAT-VEST	0.75±0.04	0.69	0.81
MC LAT-CMP	162.21±6.24	155.00	177.00

EQL-CMP, equilibrium score-composite; LAT-CMP, composite of all latencies (motor control test); MC, motor control; RAT-VEST, ratio for sensory analysis-vestibular; SOT, sensory organization test.

Table 10 Comparison between cases and matched controls as regards sensory organization test and its vestibular divisions

	Group (mean±SD)		*P*	Significance
	Cases	Controls		
SOT EQL-CMP	72.18±7.13	76.14±4.37	0.002*	HS
RAT-VEST	0.71±0.07	0.75±0.04	0.003*	HS
MC LAT-CMP	154.96±13.11	162.21±6.24	0.003*	HS

EQL-CMP, equilibrium score-composite; LAT-CMP, composite of all latencies (motor control test); MC, motor control; RAT-VEST, ratio for sensory analysis-vestibular; SOT, sensory organization test. Student *t*-test.

Table 11 Correlations between the angle of scoliosis and sensory organization test and its vestibular division

*Student *t*-test	SOT EQL-CMP	RAT-VEST	MC LAT-CMP
Angle of scoliosis			
r	−0.865	−0.692	−0.601
P	0.0001	0.006	0.023
Significance	HS	HS	S

EQL-CMP, equilibrium score-composite; LAT-CMP, composite of all latencies (motor control test); MC, motor control; RAT-VEST, ratio for sensory analysis-vestibular; SOT, sensory organization test.

Table 12 Correlations between right somatosensory evoked potential and sensory organization test and its vestibular division

	SOT EQL-CMP	RAT-VEST	MC LAT-CMP
Right SSEP			
r	−0.878	−0.784	−0.809
P	0.0001	0.001	0.0001
Significance	HS	HS	HS

EQL-CMP, equilibrium score-composite; LAT-CMP, composite of all latencies (motor control test); MC, motor control; RAT-VEST, ratio for sensory analysis-vestibular; SOT, sensory organization test; SSEP, somatosensory evoked potential.

Table 13 Correlations between left somatosensory evoked potential and sensory organization test and its vestibular division

	SOT EQL-CMP	RAT-VEST	MC LAT-CMP
Left SSEP			
r	−0.611	−0.390	−0.619
P	0.020	0.168	0.018
Significance	S	NS	S

EQL-CMP, equilibrium score-composite; LAT-CMP, composite of all latencies (motor control test); MC, motor control; RAT-VEST, ratio for sensory analysis-vestibular; SOT, sensory organization test; SSEP, somatosensory evoked potential.

There was a highly significant positive correlation between angle of scoliosis and Pt-SSEP P1 latencies recorded from both sides (right SSEP, $P = 0.004$; and left SSEP, $P = 0.032$), indicating the important effect of scoliosis angle on SSEPs.

Our results agree with those of previous studies regarding abnormal values of SSEP in AIS, but the percentage of abnormality in our study is higher, perhaps because of the smaller number of our patients (85.7% of patients with right SSEP abnormality and 78.5% with left SSEP abnormality).

Cheng *et al.* (1998) [1] studied 147 patients with AIS with a Cobb angle of 10–55° and showed a frequency of abnormal SSEPs of 17 patients (11.7%). In another study, Cheng *et al.* (1999) [2] found that the frequency was 11.4% in patients with a Cobb angle less than 45°, whereas it was 27.6% in patients with a Cobb angle greater than 45°.

Guo and colleagues (2006) found abnormal SSEPs (involving participants with a Cobb angle from 10 to 35°) in 14.3% of patients with AIS. This frequency of abnormal SSEPs is much higher in patients with AIS than the prevalence of 0.5% in the normal population [6]. In another study by Yong and colleagues (2010), abnormal SSEPs were found in 166 of 489 (33.9%) AIS patients. Among them, 17 (3.5%) showed absent wave forms, 50 (10.2%) had unilateral latency prolongation, 38 (7.8%) had bilateral latency prolongation, and 120 (24.5%) showed interside difference. Statistical analysis failed to show a correlation between abnormal SSEPs and curve severity [12].

In our study there was a highly significant negative correlation between the angle of scoliosis and ES-composite ($P = 0.0001$) and ratio for sensory analysis-vestibular ($P = 0.006$) and a significant negative correlation between the angle of scoliosis and motor control latency-composite ($P = 0.023$). This means that when the angle of scoliosis increased, the balance parameters and balance control were affected, including vestibular division, motor division, and composite ES.

In our study, there was a highly significant negative correlation between right SSEPs and ES-composite ($P=0.0001$), ratio for sensory analysis-vestibular ($P=0.001$),

and motor control latency-composite ($P = 0.0001$). There was a significant negative correlation between left SSEP and ES score-composite ($P = 0.020$) and motor control latency-composite ($P = 0.018$).

This agrees with the study of Guo and colleagues (2006) who found that sensory organization test showed a significantly increased anteroposterior center of pressure sway associated with abnormal SSEPs. This finding proves that the abnormal SSEPs can reflect the presence of disturbed standing balance control when the participant relies on the somatosensory input [6]. Gauchard *et al.* (2001) [13] also indicated that, whereas slow dynamic balance testing is used for the evaluation of balance inputs and their interactions, fast dynamic testing would assess more nerve conduction and proprioception.

McIlroy and colleagues (2003) have shown that proprioceptive inputs alter with balance tasks of varying difficulty, with the spinal reflex pathway being inhibited in favor of sensory input to the cortex as balance becomes increasingly challenged. Therefore, the role of the lower limb and spinal stretch reflexes may be sufficient to maintain balance during quiet unperturbed stance without the somatosensory pathways to the cortex becoming overly involved [14]. Lao and colleagues (2008) demonstrated that dynamic control parameters could reflect the somatosensory function, as the finding of significant asymmetries in the gait parameters associated with the direction of the scoliotic curve, which was found only in the AIS patients with abnormal Pt-SSEPs, suggested that impairment of the somatosensory pathways may lead to poorer balance control under dynamic situations [5].

Conclusion

The study demonstrates abnormal somatosensory and postural function in patients with AIS, and a significant inter-relationship between the scoliotic angle, the somatosensory system, and posture control. These findings may contribute to our understanding of the pathogenetic mechanisms of IS, and help us in providing the optimum assessment and treatment for these patients. Thus it is recommended to investigate patients with scoliosis especially with large angle for SSEP for postural assessment and postexercise programme or surgical correction.

Study limitations

The small number of patients is due to exclusion of congenital scoliosis and secondary scoliosis patients.

Acknowledgements

Authors' contributions: Dalia M.E. El Mikkawy: collection of patients from clinic, clinical assessment, share in SSEP assessment, prepare patients data for statistical analysis; E.A. Tawfek: SSEP assessment, SSEP writing in method; M. Ahmed: share in SSEP assessment; F. Naeem: postural assessment, dynamic posturography writing in *Patients and methods*.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Cheng JC, Guo X, Sher AH. Posterior tibial nerve somatosensory cortical evoked potentials in adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 1998; **23**:332–337.

2 Cheng JC, Guo X, Sher AH, Chan YL, Metreweli C. Correlation between curve severity, somatosensory evoked potentials, and magnetic resonance imaging in adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 1999; **24**:1679–1684.

3 Yagi M, Machida M, Azazuma T. Pathogenesis of adolescent idiopathic scoliosis. JBJS Rev 2014; **2**:1-7.

4 Machida M, Dubousset J, Imamura Y, Iwaya T, Yamada T, Kimura J, Toriyama S. Pathogenesis of idiopathic scoliosis: SEPs in chicken with experimentally induced scoliosis and in patients with idiopathic scoliosis. J Pediatr Orthop 1994; **14**:329–335.

5 Lao ML, Chow DH, Guo X, Cheng JC, Holmes AD. Impaired dynamic balance control in adolescents with idiopathic scoliosis and abnormal somatosensory evoked potentials. J Pediatr Orthop 2008; **28**:846–849.

6 Guo X, Chau WW, Hui-Chan CW, Cheung CS, Tsang WW, Cheng JC. Balance control in adolescents with idiopathic scoliosis and disturbed somatosensory function. Spine (Phila Pa 1976) 2006; **31**:437–440.

7 Herman R, Mixon J, Fisher A, Maulucci R, Stuyck J Idiopathic scoliosis and the central nervous system: a motor control problem. The Harrington lecture, 1983. Scoliosis Research Society. Spine (Phila Pa 1976) 1985; **10**:1–14.

8 Byl NN, Gray JM. Complex balance reactions in different sensory conditions: adolescents with and without idiopathic scoliosis. J Orthop Res 1993; **11**:215–227.

9 Chen PQ, Wang JL, Tsuang YH, Liao TL, Huang PI, Hang YS The postural stability control and gait pattern of idiopathic scoliosis adolescents. Clin Biomech (Bristol, Avon) 1998; **13**(Suppl 1):S52.

10 Nault ML, Allard P, Hinse S, Le Blanc R, Caron O, Labelle H, Sadeghi H. Relations between standing stability and body posture parameters in adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 2002; **27**:1911–1917.

11 Nashner L. Computerized dynamic posturography: clinical applications. In: Jacobson G, Newman C, Kartsh J (editors) Handbook of balance function testing. Chicago: Mosby-Year Book; 1993. p. 15-40.

12 Yong QIU, Zhi-jun C, Ze-Zhang ZHU, Bang-Ping Q, Bing W, Yong YU, *et al.* Study of somatosensory evoked potentials in adolescent idiopathic scoliosis with different curve magnitudes. Research into spinal deformities 7.2010; C-E Aubin *et al.*(Eds)0.245

13 Gauchard GC, Lascombes P, Kuhnast M, Perrin PP. Influence of different types of progressive idiopathic scoliosis on static and dynamic postural control. Spine (Phila Pa 1976) 2001; **26**:1052–1058.

14 McIlroy WE, Bishop DC, Staines WR, Nelson AJ, Maki BE, Brooke JD. Modulation of afferent inflow during the control of balancing tasks using the lower limbs. Brain Res 2003; **961**:73–80.