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RESEARCH ARTICLE

Trunk sway in mildly disabled multiple sclerosis patients with and without balance impairment

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Abstract Multiple sclerosis (MS) causes a broad range of neurological symptoms. Most common is poor balance control. However, knowledge of deficient balance control in mildly affected MS patients who are complaining of balance impairment but have normal clinical balance tests (CBT) is limited. This knowledge might provide insights into the normal and pathophysiological mechanisms underlying stance and gait. We analysed differences in trunk sway between mildly disabled MS patients with and without subjective balance impairment (SBI), all with normal CBT. The sway was measured for a battery of stance and gait balance tests (static and dynamic posturography) and compared to that of age- and sex-matched healthy subjects. Eight of 21 patients (38%) with an Expanded Disability Status Scale of 1.0–3.0 complained of SBI during daily activities. For standing on both legs with eyes closed on a normal and on a foam surface, patients in the no SBI group showed significant differences in the range of trunk roll (lateral) sway angle and velocity, compared to normal persons. Patients in the SBI group had significantly greater lateral sway than the no SBI group, and sway was also greater than normal in the pitch (anterior–posterior) direction. Sway for one-legged stance on foam was also greater in the SBI group compared to the no SBI and normal groups. We found a specific laterally directed impairment of balance in all patients, consistent with a deficit in proprioceptive processing, which was greater in the SBI group than in the no SBI group. This finding most likely explains the subjective symptoms of imbalance in patients with MS with normal CBT.

Keywords Multiple sclerosis · Posturography · Balance · Rehabilitation

Oliver Findling and Johann Sellner equally contributed to this work.

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Introduction

Multiple sclerosis (MS) is the major cause of non-traumatic disability in young adults (Compston and Coles 2008). The prevalence of this chronic immune-mediated central nervous system (CNS) disorder ranges between 2 and 150 per 100,000 and differs between countries and regions (Sellner et al. 2011; Beer and Kesselring 1994). Women are affected 2–3 times more often as men, and the first diagnosis is mostly between the ages of 20 and 40 years (Pugliatti et al. 2006). Regarding the pathogenesis of the disease, an autoimmune response directed against the myelin sheats surrounding axons in the CNS is assumed. A broad spectrum of neurological symptoms is observed on recurrent episodes of CNS inflammation and includes diminished balance, coordination, muscle strength and sensory function (Compston and Coles 2008). In early stages of the disease, functional recovery can be complete; however, residuals develop over time, and a chronic progressive phase evolves in a subgroup of patients (Sellner et al. 2010).

Intact balance control results from a continuous interaction between the contributions of visual, vestibular and somato-sensory inputs to CNS command centres activating motor corrections. Especially the somato-sensory system with long fibres in the spinal cord is crucially dependent on intact myelinated nerves in the CNS for fast signal processing. The timely receipt of somato-sensory inputs from the legs is considered highly important for adequate control of balance (Bloem et al. 2002). In MS, the distribution of demyelinating lesions is highly variable and frequently leads to impaired balance control with slowed spinal somato-sensory conduction (Cameron et al. 2008; Wurdeman et al. 2011; Diener et al. 1984).

Impaired balance is one of the most disabling MS symptoms and affects about 75% of patients during the course of the disease (McDonald and Compston 2005; Missaoui and Thoumie 2009).

Neurological examination of mildly disabled MS patients complaining of poor balance control is often normal or does not show any unequivocal clinical signs of imbalance during standard clinical balance tests (CBT) such as the Romberg, Unterberger and tandem gait tests. Nonetheless, subjective balance problems can significantly impair the quality of life of such patients (Karatas 2008). Fear of falling, especially when the subjective signs of imbalance do not show a clinical correlate, can aggravate the problem to an incapacitating phobia (Goretti et al. 2010; Nilsagard et al. 2009).

None of the previously published studies assessed postural stability in mildly impaired patients with MS and normal clinical balance tests but subjective symptoms of balance impairment. A procedure to assess early signs of balance dysfunction in MS patients consistent with their complaints would therefore be useful (Sacco et al. 2011). It could confirm the patients' subjective symptoms and prompt earlier initiation of appropriate balance training and medication (Motl et al. 2010; Smedal et al. 2006; Lo and Triche 2008). As proprioceptive deficits in the lower legs lead to excessive roll sway of the trunk during quiet stance (Horlings et al. 2009a), we expected to find similar excessive roll rather than pitch sway in MS patients, with a gradation based on the presence of subjective impairment. The goal of this study was to examine differences in trunk sway in MS patients with and without subjective impairment with this concept in mind.

Materials and methods

Measurement system

Trunk sway was measured during several balance tasks using a SwayStar™-System (Balance International Innovations GmbH, Switzerland). The equipment used for the study is CE certified which in Europe is equivalent to FDA approval in the USA. The device provided an accurate measure of patients' stance and gait capabilities in prior studies (Gill et al. 2001; Sjostrom et al. 2003; Van de Warrenburg et al. 2005; Horlings et al. 2009b). Reliability of the SwayStar™ system has been previously demonstrated in several studies (Allum and Adkin 2003; Hegeman et al. 2007; Horlings et al. 2009b). The system is strapped around the waist at the level of the lumbar spine (L3) close to the body's centre of mass (see Fig. 1). Angular velocity and angular displacement deviations in the roll (medial–lateral) and in the pitch (anterior–posterior) plane are measured by two angular velocity transducers. A wireless Bluetooth™ connection to a personal computer (PC) allows unlimited mobility during stance and gait tests. Trapezoid integration of angular velocities is used to calculate angular deviations. Angular velocities are sampled in the range of ±327°/s at 100 Hz. The angular velocity values are transferred to a PC with 16 bit resolution (1 bit equivalent to 0.005°/s) and used directly without filtering. The baseline drift of the transducers is less than 0.01°/s (<6°/h), according to the manufacturer's specification. No post hoc filtering or smoothing was applied to the data.

Clinical balance testing

For clinical balance testing, we used a number of standard clinical protocols: The Berg Balance Scale, Dynamic Gait Index, Performance Oriented Mobility Assessment and Functional Reach. (Tinetti 1986; Duncan et al. 1990; Berg et al. 1992; Shumway-Cook and Woollacott 1995; Whitney et al. 1998). The Dizziness Handicap Inventory was used to evaluate the subjective impact of poor balance control in everyday life (Jacobson and Newman 1990).

The Berg Balance Scale (BBS) is a well-established clinical tool for measuring balance (Berg et al. 1992). Its high reliability and validity has been shown in several studies (Schädler et al. 2006). The test is composed of 14 items and has a maximum score of 56 points. There is a cut-off level at 45 points above which persons have no increased risk of falling. The Dynamic Gait Index (DGI) was developed by Shumway-Cook and Woollacott (1995) as a tool for examining dynamic posture control, specifically for patients with vestibular disorders. The protocol has also been used to assess balance control in MS patients

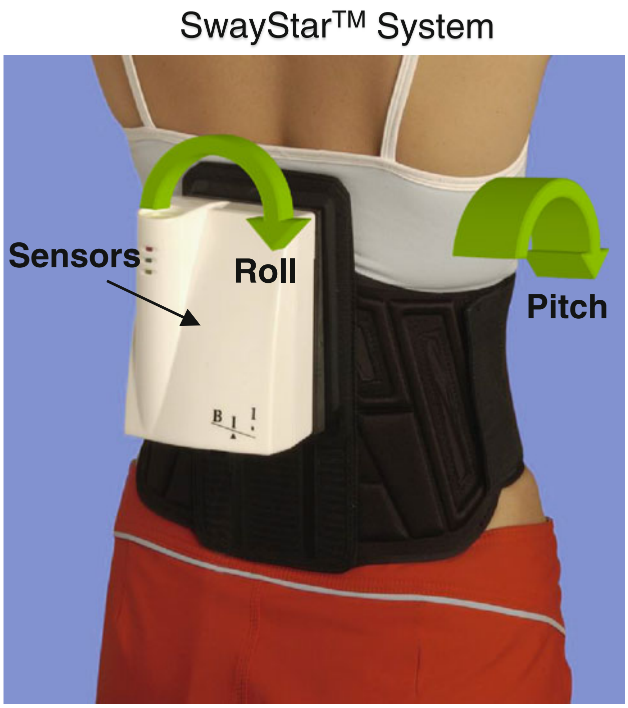

Fig. 1 SwayStar measurement system. For the measurements, the unit is strapped around the waist at the level of the lumbar spine. Its sensors register angular velocities of the trunk in the directions indicated near the body's centre of mass

(McConvey and Bennett 2005) and in the elderly prone to fall (Shumway-Cook et al. 1997). The Performance Oriented Mobility (POMA) or "Tinetti-Test" consists of two subscales, "balance" and "gait" developed to evaluate the risk of falling in elderly people (Tinetti 1986). The POMA has a maximum score of 28 points. Those who did not reach a cut-off score of 21 points have a high risk for recurrent falls (Shumway-Cook et al. 1997).

The Functional Reach (FR) test is similar to item 8 of the BBS (Duncan et al. 1990). The test measures the maximum distance a person is able to reach forward whilst standing without falling and has a high reliability and validity (Schädler et al. 2006). A FR greater than 25 cm is considered normal. Persons with a FR of 15–25 cm have a twofold risk of falling compared to healthy control persons with a normal FR (Duncan et al. 1990). The FR was shown to be a useful test for identifying frail elderly persons who have a high risk for falls (Duncan et al. 1990). In MS patients, marked differences compared to healthy controls were shown for the FR; however, these differences were not associated with a higher risk of falls in MS patients (Frzovic et al. 2000).

The Dizziness Handicap Inventory (DHI) of Jacobson and Newman (1990), one of the most commonly used "standardized questionnaires", was used to quantify subjective symptoms of dizziness or imbalance. It consists of 9 emotional items, 9 functional items and 7 physical items used to determine the level of impairment felt by the patient. A score of 0 points is equivalent to no subjective impairment. The maximum score is 100.

Patients, inclusion criteria and clinical examination

Consecutive patients ($N = 21$) with MS scheduled for their regular clinical visit were evaluated with the Sway Star system as part of the routine clinical examination. Inclusion criteria were an Expanded Disability Status Scale (EDSS) between 0 and 3.0 (Kurtzke 1983) and lack of overt signs of imbalance, ataxic gait or spasticity during normal walking. Patients were excluded from the study if they showed pathological balance performance during the neurological examination (Romberg and Unterberger tests) or during clinical balance testing (Romberg's sign, BBS, POMA and FR). Furthermore, patients with new relapses or those who reported signs of a change in balance control during the 4 weeks prior to testing were also excluded. In addition, patients with evidence for polyneuropathy or reasons for balance impairment other than MS were excluded. Patients were divided into two groups based on their assessment of balance problems during daily activities: One group consisted of patients with subjective balance impairment (SBI), and another group was formed from patients without subjective balance impairment (no SBI). Posturographic measurements of trunk sway were recorded with the SwayStar™-system during a series of stance and gait tests as described below. For comparison purposes, we selected 98 healthy controls from a reference database who were age- and sex-matched (mean 40.8 years, range 27–51) to the MS patients. Data of the healthy controls were collected during previous studies using the same equipment (Gill et al. 2001; Hegeman et al. 2007).

Posturography test protocol

The protocol consisted of 11 different tasks performed barefoot, all described in detail in the previous studies (Allum and Adkin 2003; Hegeman et al. 2007; Adkin et al. 2005; Grimbergen et al. 2008; Sjostrom et al. 2003). For two-legged stance tasks, the subject stood with open and closed eyes on a normal hard surface and on a foam surface for 20 s (4 tasks). One-legged stance tasks were performed with eyes open only with and without the foam surface (2 tasks). The maximum duration of these stance tasks was 20 s or until the non-supporting leg touched the ground. The trial was repeated once if the non-weight-bearing leg touched the ground before 20 s. Then, the trial of longest duration was used for analysis. Walking eight tandem steps whilst looking at the feet was performed on normal and on a foam surface (2 tasks). For these tasks, no maximum time was defined. Simple gait trials consisted of either, walking three metres with closed eyes or with eyes open, rotating the head horizontally or pitching the head in rhythm with the steps (3 tasks).

The tasks were those of protocols used in prior studies (Gill et al. 2001; Allum and Adkin 2003; Allum and Carpenter 2005): The protocols were also part of one or more of the above-mentioned clinical balance tests previously shown to be sensitive tools for detecting balance deficits in different clinical neurological disorders (Tinetti 1986; Dieruf et al. 1999; McConvey and Bennett 2005). Thus, in our experiments, the tests were quantified with measures of trunk sway. The two-legged stance on foam has been shown to be very sensitive to the detection of balance impairment due to neurological disorders (Allum and Carpenter 2005). Furthermore, multidirectional difficulties with tandem gait or gait incorporating head movements have been shown to be efficient in detecting balance deficits caused by cerebellar lesions (Van de Warrenburg et al. 2005).

Data analysis

Peak-to-peak excursions of trunk sway in the roll and pitch directions for both angular displacement and angular velocity were calculated. Because the distribution of measurements was more Poisson-like than Gaussian, we performed a non-parametric statistic analysis using the Mann–Whitney test. The significance level was set at $P < 0.05$.

Table 1 Clinical characteristics of patients with (SBI) and without (no SBI) subjective balance impairment

Patient	Age	EDSS	Duration since first symptoms in years	Group
1	38.6	1.5	6.4	No SBI
2	40.5	2	2.9	No SBI
3	49.0	1.5	3.4	No SBI
4	35.0	1.5	5.5	No SBI
5	47.1	2	0.6	No SBI
6	32.5	1.5	2.3	No SBI
7	27.4	1	5.9	No SBI
8	47.5	2	20.9	No SBI
9	44.9	1.5	8.7	No SBI
10	30.2	1.5	5.7	No SBI
11	35.3	2	9.7	No SBI
12	48.9	3	11.0	No SBI
13	29.7	2	4.3	No SBI
Median	38.9	1.5	6.7	
14	50.9	3	0.8	SBI
15	45.8	2.5	4.7	SBI
16	41.2	1.5	11.6	SBI
17	42.2	1	1.7	SBI
18	31.1	2.5	11.0	SBI
19	51.8	2.5	10.2	SBI
20	41.7	2	3.5	SBI
21	33.0	2.5	7.8	SBI
Median	42.0	2.5	6.7	

Results

Over a period of 3 months, twenty-five patients without overt signs of imbalance, gait ataxia or spasticity during normal gait were screened during their visit to our outpatient clinic. Four were excluded because of pathological balance performance in one or more of the clinical balance tests. Twenty-one patients met the inclusion criteria. Eight of them (38%; median EDSS 2.5 (range 1–3), mean age 42 years) complained of impaired balance in daily activities (SBI). Thirteen patients (62%; median EDSS 1.5 (range 1–3), mean age 38.9) did not report subjective balance problems (no SBI). The clinical characteristics of both groups are shown in Table 1. The mean DHI of the SBI group was 22.8 points (SD 13.6), whereas the no SBI group had a much lower mean, 4.2 points (SD 5.3) ($P = 0.001$).

The trunk sway of both groups was significantly greater than in healthy controls for stance tests, especially the stance tasks with closed eyes. Figure 2 provides examples of sway for standing on two legs, eyes closed, on a normal surface. For the SBI group, we found significant changes in MS patients compared to healthy controls on a normal surface for angular range in the pitch (anterior–posterior) and roll (medial–lateral) direction whilst standing on 2 legs, even with eyes open. Angular velocity and angular displacement in roll and also in the pitch direction were significantly different for standing on 2 legs with eyes closed on a normal surface. A similar pattern of increasing instability with eye closure was noted in MS patients, particularly in the roll direction (see Table 2) for stance on the foam surface. During standing on a foam surface on 2 legs with open eyes, we found significant differences for angular range and angular velocity in the roll direction. With closed eyes on the foam surface, significant changes were also noted for angular range and angular velocity in the roll and pitch directions. For standing on one leg on a foam surface, and during walking 8 tandem steps, significant differences were found for angular range in the roll and pitch direction. All differences with respect to controls are listed in Table 2.

In the no SBI group, significant differences compared to the normal control subjects were only observed during stance tasks with eyes closed and then only in the roll direction (Table 2). As illustrated in Figs. 2 and 3, roll trunk sway whilst standing on a normal surface with closed eyes was greater than in controls for angle and angular velocity ranges (Table 3).

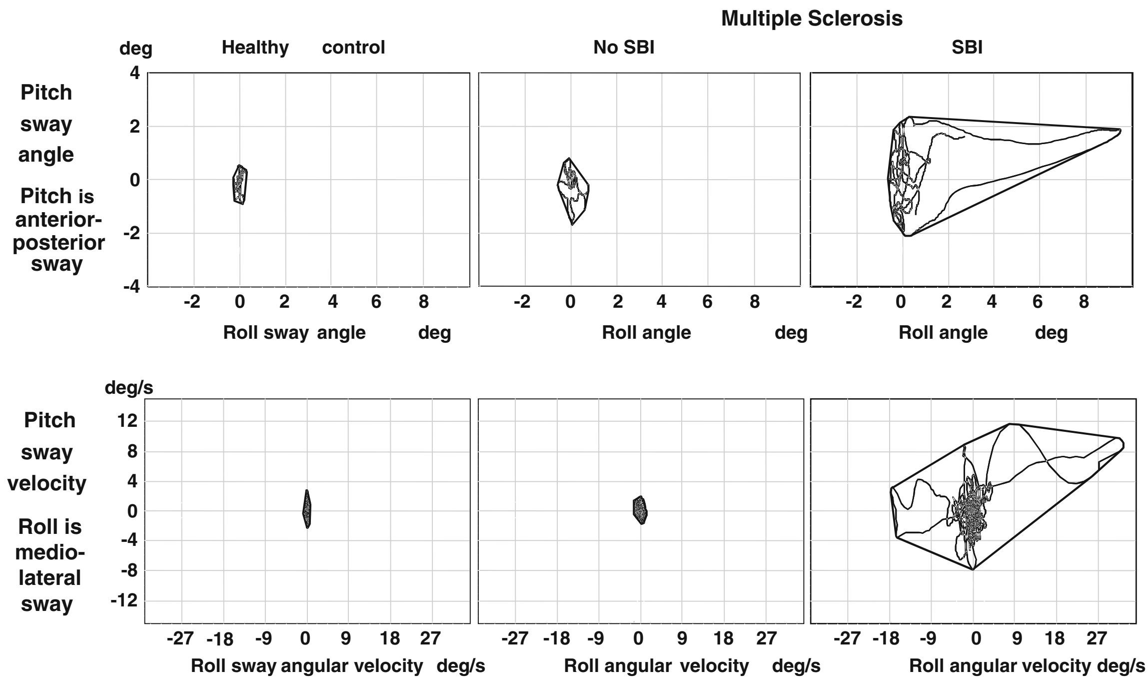

Fig. 2 Typical examples of trunk sway recorded over 20 s as *x*–*y* plots. The subjects were standing on 2 legs with eyes closed on a normal surface. The *upper row* displays sway angle and the *lower row* sway velocity. The *x*-axis represents roll (angle or angular velocity changes in the medio-lateral direction), the *y*-axis pitch (angle or angular velocity changes in the anterior–posterior direction). The *left* series of plots were recorded from a healthy control subject. The *middle* set shows an MS patient without subjective balance impairment (no SBI). The *right* set of plots shows a MS patient with the subjective balance impairment (SBI) and considerable instability in the lateral direction

Table 2 Significant differences in sway ranges between MS patients with subjective balance impairment and healthy controls

	Roll angle	Roll velocity	Pitch angle	Pitch velocity
Stand 2 legs EO	$P < 0.001$	n.s	$P = 0.029$	n.s
Stand 2 legs EC	$P < 0.001$	$P < 0.001$	$P = 0.001$	$P < 0.001$
Stand 2 legs EO on foam	$P = 0.002$	$P = 0.011$	n.s	n.s
Stand 2 legs EC on foam	$P < 0.001$	$P < 0.001$	$P = 0.002$	$P < 0.001$
Stand 1 leg EO on foam	$P < 0.001$	$P < 0.001$	$P = 0.001$	$P = 0.012$
Walking 8 tandem steps on foam	$P = 0.018$	n.s	$P = 0.048$	n.s

n.s. not significant

Comparisons between the SBI and the no SBI groups showed that the SBI patients had significantly increased sway when standing eyes closed on 2 legs on both the normal and the foam surface. However, the differences were greater on a normal surface. Roll angular displacement was also significantly increased whilst standing with 2 legs on a normal surface with eyes open (Table 4). In addition, increased angular sway was observed standing on one leg on foam with eyes open.

No significant changes were found during simple gait trials (data are not shown).

Discussion

In this study, we measured trunk sway during stance and gait balance tests in mildly affected multiple sclerosis patients with and without subjective balance impairment (SBI) and normal clinical balance tests. For stance tests, we found that both groups had increased roll sway with the SBI group having the greatest roll sway. In addition, the MS patients with SBI had greater sway than normal in the pitch direction. Earlier studies (Daley and Swank 1981; Corradini et al. 1997; Karst et al. 2005) demonstrated balance impairment in mildly impaired MS patients but did not subdivide the patients according to SBI. No significant changes were found in the current study in both patient groups compared to the healthy controls during simple gait tasks.

Data describing the frequency and characteristics of impaired balance in mildly affected MS patients are scarce (Kalron et al. 2010), and current clinical assessment tools do not appear to be sensitive enough to detect and quantify the patients' subtle imbalance. Most balance studies of MS

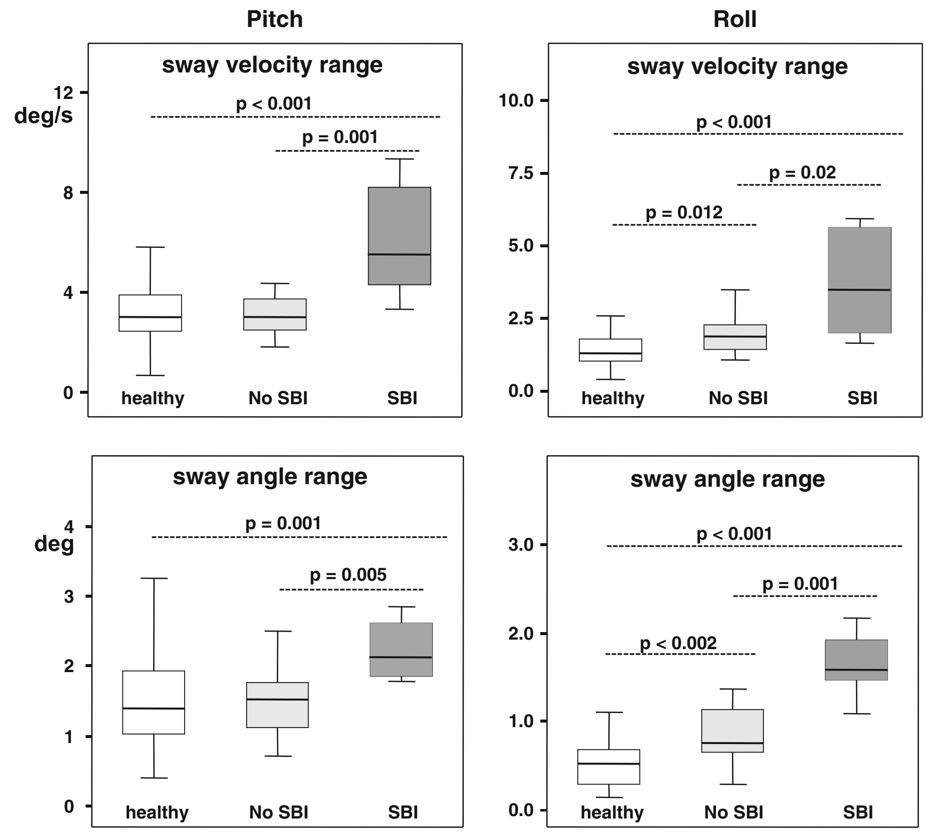

Fig. 3 Sway angle range and angular velocity ranges for the task of standing on two legs with closed eyes on a normal surface for MS patients with subjective symptoms of impaired balance (SBI) compared to MS patients without symptoms (no SBI) and to healthy controls. The *box-whisker* plots represent the 5th and the 25th percentile, the median, and the 75th and 95th percentile values

Table 3 Differences in sway ranges between MS patients with no subjective balance impairment (no SBI) and healthy controls

	Roll angle	Roll velocity	Pitch angle	Pitch velocity
Stand 2 legs EO	n.s.	n.s.	n.s.	n.s.
Stand 2 legs EC	$P = 0.002$	$P = 0.012$	n.s.	n.s.
Stand 2 legs EO on foam	n.s.	n.s.	n.s.	n.s.
Stand 2 legs EC on foam	$P < 0.001$	$P < 0.001$	n.s.	n.s.
Stand 1 leg EO on foam	n.s.	n.s.	n.s.	n.s.
Walking 8 tandem steps on foam	n.s.	n.s.	n.s.	n.s.

n.s. not significant

Table 4 Differences in sway angles between MS patients with (SBI) and without subjective balance impairment (no SBI)

	Roll angle	Roll velocity	Pitch angle	Pitch velocity
Stand 2 leg EO	$P = 0.016$	n.s.	n.s.	n.s.
Stand 2 leg EC	$P = 0.001$	$P = 0.02$	$P = 0.005$	$P = 0.001$
Stand 2 leg EO on foam	n.s.	n.s.	n.s.	n.s.
Stand 2 leg EC on foam	n.s.	$P = 0.045$	$P = 0.02$	$P = 0.013$
Stand 1 leg EO on foam	$P = 0.003$	$P = 0.005$	$P = 0.013$	$P = 0.03$
Walking 8 tandem steps on foam	n.s.	n.s.	n.s.	n.s.

n.s. not significant

patients were performed on patients with overt clinical disabilities. Furthermore, signs of subtle beginning gait disturbances may be missed in standard neurological examinations (Martin et al. 2006). There is, however, evidence for balance impairment even in mildly impaired MS patients (Karst et al. 2005; Van Emmerik et al. 2010; Chung et al. 2008). Indeed, an early study detected abnormal sway in MS patients without functional impairment during stance tests with open and closed eyes (Daley and Swank 1981). Our findings show that when subjective balance impairment is present in mildly disabled MS patients a correlate can be found using precise measurements of trunk sway during stance. The 8 patients who complained of balance impairment during daily activities were also those identified by the DHI questionnaire. However, the use of widely used clinical balance protocols (BBS, POMA, FR, DGI) did not identify any balance abnormalities. In contrast, direct measurement of trunk sway velocity with gyroscopes detected balance deficits and provided a quantification of differences when compared to normal controls. The trunk sway measurements showed that a specific laterally directed impairment of balance was present in all patients with MS, even if they did not complain of any balance problems. The roll instability was greater in patients with subjective symptoms. Because the distribution of demyelinating lesions in MS is variable, it is not possible to attribute our findings only to a single CNS lesion. Interestingly however, peripheral vestibular lesions tend to increase anterior–posterior sway and lesions of the somato-sensory system from the legs, lateral sway (Allum and Adkin 2003; Horlings et al. 2009a). Based on these authors' research, our results are suggestive of transmission problems with roll proprioceptive contributions to balance control. There are additional reasons to believe that transmission problems with somato-sensory inputs were responsible for the patients' increased roll sway. Firstly, the differences were observed in non-SBI patients under eyes closed conditions when only proprioceptive and vestibular contributions can be present. Secondly, the deficits in balance control were prominent also with eyes closed on a firm support surface when proprioceptive inputs from the lower legs have a major contribution to balance control. In this respect, it would be interesting to know whether a similar directional deficit is present in the balance control of MS patients to support surface perturbations in different directions.

Apart from the possibilities of studying the effect of spinal cord lesions on balance control using MS patients, these findings suggest that screening MS patients with trunk sway measurements recorded during stance tests provides diagnostic information on their balance problems that cannot be obtained by traditional balance tests. Furthermore, this study confirms that patients are knowledgeable about their balance impairment. Objective confirmation of subjectively felt balance problems could be reassuring to MS patients.

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Conflict of interest JHJ Allum works as a consultant for the company (Balance Int. Innovations GmbH) supplying the equipment used in this study. All other authors have no conflicts of interest regarding this work.

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