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SITTING BALANCE AND EFFECTS OF KAYAK TRAINING IN PARAPLEGICS

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Objectives: **The objectives of this study were to evaluate biomechanical variables related to balance control in sitting, and the effects of kayak training, in individuals with spinal cord injury.**

Subjects: **Twelve individuals with spinal cord injury were investigated before and after an 8-week training period in open sea kayaking, and 12 able-bodied subjects, who did not train, served as controls.**

Methods: **Standard deviation and mean velocity of centre of pressure displacement, and median frequency of centre of pressure acceleration were measured in quiet sitting in a special chair mounted on a force plate.**

Results: **All variables differed between the group with spinal cord injury, before training, and the controls; standard deviation being higher and mean velocity and median frequency lower in individuals with spinal cord injury. A significant training effect was seen only as a lowering of median frequency.**

Conclusion: **The results indicate that individuals with spinal cord injury may have acquired and consolidated an alternative strategy for balance control in quiet sitting allowing for only limited further adaptation even with such a vigorous training stimulus as kayaking.**

Key words: spinal cord injury, sitting balance, adaptation, training, paraplegia.

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INTRODUCTION

Spinal cord injury (SCI) means an abrupt cessation of normal neuromuscular function. Both descending motor tracts and ascending sensory feedback pathways are interrupted. The degree of functional loss depends on the level and completeness of the spinal cord lesion. Lesions below cervical level cause paraplegia, i.e. a paralysis involving the lower extremities and the trunk. Individuals who have suffered an SCI are forced to spend most of their time in a wheelchair and thus to perform everyday activities from a sitting position. Therefore, studying balance control and its trainability in sitting becomes a highly relevant issue to obtain a better basis for improvement of rehabilitation programs and quality of life in general for paraplegics.

It has been proposed that the adaptation to a partial paralysis following an SCI would lead to reorganization of the individual's balance control system (1, 2). A gradual development of specific motor synergies for balance control in sitting, involving even non-postural muscles, has been demonstrated in individuals with SCI performing sit-and-reach tasks (3). However, to our knowledge, there is no information published describing balance in sitting and its trainability in fully rehabilitated persons with SCI.

Participation in sports activities may have benefits for individuals with SCI both from a social and physiological perspective (4). Kayaking is an outdoor activity that can be performed on equal terms by both physically able and disabled people. In addition, kayaking presents high metabolic demands and challenges to the balance control system. Maintaining the sitting posture requires continuous compensation for perturbations to the upper body by motion of the kayak and paddle in the water, as well as of the arms and paddle in the air.

The purpose of this study was to compare sitting balance in SCI and able-bodied individuals and to evaluate the effects of a period of open sea kayak training on sitting balance in a group of people with SCI.

MATERIAL AND METHODS

Spinal cord injured group

Persons with SCI were initially contacted mainly through the database of the Spinalis Clinic, Karolinska Hospital, Stockholm. Individuals with any cardiovascular, lung or mental impairment were excluded. Thirteen persons with SCI volunteered and 12 of those completed the study. One person dropped out due to recurrent shoulder pain. The 12 subjects with SCI (9 men and 3 women; 40 (SD 11) years, 1.77 (0.08) metres, 80.3 (11.4) kg) had injury levels ranging from T2 to T11 (Table I). The average sit height, defined as the vertical distance from the seat of the chair to the top of the head was 0.91 (0.04) metres.

The classification and the medical examination were performed at the Spinalis Clinic within a period of 18 months before the study began. A description of the subjects with SCI based on the ASIA (American Spinal Injury Association) impairment scale and sensory and motor scores (5) is presented in Table I. Ten subjects with SCI were traumatically injured, 1 had a non-progressive acquired spinal cord injury, and 1 an aneurysm, respectively. The time after the SCI varied from 4 to 32 years within the group (Table I). Four subjects were

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Table I. *Description of the subjects with spinal cord injury, in accordance with International Standards for Neurological and Functional Classification of Spinal Cord Injury, American Spinal Injury Association (ASIA)* (5)

Subject	Age	Years post-injury	Gender	Neurological lesion level	Sensory pin prick score (max. 112)	Sensory light touch score (max. 112)	Motor score (max. 100)	Impairment scale
I	29	13	M	T 2	112	112	50	B
II	22	5	M	T 3	42	42	50	A
III	39	19	M	T 4	48	48	50	A
IV	38	17	F	T 4	78	78	50	B
V	38	22	M	T 5	48	48	50	A
VI	57	4	M	T 6	52	52	50	A
VII	35	15	M	T 6	52	66	50	B
VIII	40	17	M	T 9	51	52	50	A
IX	47	27	F	T 9	90	88	52	B
X	47	23	F	T 9	88	90	71	C
XI	46	32	M	T 10	73	72	50	A
XII	33	13	M	T 11	78	83	50	B

negatively affected by spasticity (I, II, IV, XII) and 2 of those (IV, XII) were under medication during the whole study period.

Subjects with SCI were given both written and verbal information before the study started. They were free to withdraw at any point in the study. The Ethical Committee of the Karolinska Institutet approved the study and all subjects gave their written informed consent to participate before the start of the study.

Control group

The control group comprised 12 able-bodied subjects (9 men and 3 women; 32.8 (SD 8.3) years; 1.79 (0.07) metres; 75.9 (12.1) kg) free from any motor impairment. The average sit height was 0.94 (0.04) metres, which was not significantly different from that of the SCI group. The control group was retested for reproducibility of the measured balance parameters (see below) about 6 months after the first test occasion.

Kayak training and special equipment

A special chair (Slimskate, Sweden) (Fig. 1) mounted into a kayak and onto a kayak ergometer gave the persons with SCI the possibility to sit in a stable and secure position. Before the training period started, participants were acclimatized to the special kayaking equipment and introduced to the basic paddling technique. The paddling technique was taught on a kayak ergometer and then applied in a preliminary session on water in an indoor pool. In the pool, all subjects also practised capsizing the kayak and learned how to turn and get back into the kayak again. After an indoor session followed an introduction to outdoor technique. On the water, subjects were taught how to use an effective and efficient paddling technique.

Subjects were kayaking 2 or 3 times per week, in small groups, during an 8-week training period of supervised kayaking. Total number of sessions was 19–23 (Table II). Every session on water lasted approximately 60 minutes and included a warm up, interval or distance training, and a tapering off at the end. The interval sessions consisted of 2–4 medium to high intensity paddling intervals, between 2 and 7 minutes in duration, with a pause of approximately 1 to 3 minutes between the active phases. In the distance training there was a lower intensity but a longer duration, e.g. 2 sessions of 20 minutes paddling. The type of training performed, the weather and wind conditions were recorded in a training diary. For safety reasons kayak instructors with detailed knowledge of the special needs of persons with SCI participated in each kayak session.

The participants had the possibility to choose a kayak according to 4 different degrees of difficulty with respect to balance control: a single open water kayak (K1) (Lisa, VKV, Sweden) with or without pontoons, and 2 different types of double open water kayaks (K2). In the K1, the subject used a hand rudder to steer the kayak, and inflatable pontoons were attached to the kayak to increase the stability. In K2, an instructor sat in the back section and used a foot rudder to steer the kayak. Two different types of double kayak were offered, either an ordinary double kayak (Albatross XL, Kanotcenter Svima Sport, Sweden) or a more solid and secure kayak (Yoo-A-Kim, VKV, Sweden). Eight persons tried the K1 with inflatable pontoons during the training period. Two subjects (VIII, IX) completed the sessions kayaking mainly in a K1, 1 of them (IX) without pontoons under all conditions. Four of the subjects (I, II, VII, XII) were affected by illness during the training period and could not take part in all the ordinary kayak sessions on water. The missed sessions were later compensated by extra training on the kayak ergometer (3 to 7 sessions, Table II).

Experimental set-up and protocol

Tests of balance control in sitting were performed before and after the training period. Subjects were seated, with knees slightly bent, in a special chair mounted onto a force plate (Fig. 1). The subjects were asked to sit as still and relaxed as possible, with folded arms, and focus on a visual target on the wall, 2 metres in front of them. The type of chair was the same as that mounted into the kayaks and used during the training period. Ground reaction forces were registered with an AMTI (Advanced Medical Technology, USA) force plate (50 × 50 cm). The location for the point of application of the resultant ground reaction force vector, i.e. the centre of pressure (CoP) was measured. All data were collected and digitized at a sampling rate of 100 Hz using a 1401 Plus device (Cambridge Electronics Design, UK).

The data were obtained during 2 periods of 30 seconds while the subject was sitting quietly with eyes open. The standard deviation (SD)

Fig. 1. The experimental set-up for balance testing. The subject is sitting in a special chair which is also used in the kayak. The chair is firmly attached to a force plate. The subject's feet are resting on a support connected to the chair via steel rods.

Table II. *Number of training sessions with different types of kayak training and different degrees of difficulty with respect to balance control (type of kayak or ergometer)*

		Number of sessions with different types of training			Number of sessions in different types of kayaks or ergometer		
Subject	Total number of sessions	Technique	Interval	Distance	Single	Double	Ergometer*
I	21	5	10	6	1	11(A/Y)	9 (5)
II	19	5	11	3		9 (Y)	10 (7)
III	21	5	9	7		15 (Y)	6 (3)
IV	23	6	9	8		20 (A)	3
V	21	6	9	6	4	14 (Y)	3
VI	21	7	6	8	4	14 (A/Y)	3
VII	21	5	11	4	2	10 (A/Y)	9 (6)
VIII	21	6	11	4	14	3 (A)	4
IX	22	5	12	5	17	2 (A)	3
X	21	2	14	5	3	14 (A)	4
XI	23	7	11	5		20 (A)	3
XII	21	6	10	5	6	8 (A/Y)	7 (4)

* Including tests of submaximal and maximal oxygen uptake before and after the training period and 1–2 initial technique training sessions. Numbers within parentheses denote ergometer sessions replacing ordinary on water training sessions (see text).
(A = Albatross – ordinary double kayak, Y = Yoo-A-Kim – more solid and secure double kayak).

and mean velocity (v_{mean}) of the CoP displacement as well as the median frequency (f_{med}) of the acceleration of the CoP in the sagittal and frontal planes were calculated and averaged for the 2 30-second periods.

Questionnaire

A written questionnaire was distributed 1 year after the cessation of the training study to evaluate subjective experiences, to the best of their recollection, of short- and long-term effects of the kayak training upon balance control and ability to cope with everyday activities. The questionnaire included questions about effects on trunk stability, shoulder strength and spasticity. The subjects also had the possibility to express personal experiences from the kayak training in their own words. Registration of the answers was done anonymously.

Statistics

Shapiro-Wilks' W test was used to determine normality in the distribution of data. One-way ANOVA and Student's *t*-test were used to determine statistical significance of differences ($p < 0.05$) between the SCI and control groups as well as between values for the SCI group before and after training. Linear correlation coefficients were calculated between the balance variables and the ASIA sensory scores as well as between the initial performance and the training effects for the subjects with SCI. Test-retest reproducibility of results from identical tests performed 6 months apart by the control group was calculated as the standard deviation of the difference between the 2 tests.

RESULTS

Balance variables, reproducibility in the control group

The standard deviation for the test-retest difference, in the control group, were: in the sagittal plane: SD = 0.021 cm, v_{mean} = 0.119 m/s and f_{med} = 0.799 Hz and in the frontal plane: SD = 0.0086 cm, v_{mean} = 0.202 m/s and f_{med} = 0.762 Hz. These values were used as limits for defining changes with training in individuals within the SCI group.

Balance variables, SCI group vs controls

There was no difference in mean SD between the SCI group and controls in the sagittal plane (Fig. 2a). On the other hand, the frontal plane SD for the SCI group before training was significantly higher than that for controls (Fig. 2b). Large inter-individual variation in SD was present within the SCI group, in both planes (Fig. 2). The SCI group value of v_{mean} was significantly lower than that for the control group for sagittal as well as frontal displacement of CoP (Fig. 3). Significantly lower SCI values were also seen for f_{med} in both planes (Fig. 4).

Balance variables, correlation with impairment in the SCI group

Correlation analysis between balance variables and ASIA scores showed a tendency ($p < 0.07$) towards a negative correlation between the sagittal SD and the ASIA sensory scores for pin prick (r = –0.550) and light touch (r = –0.556). Frontal SD demonstrated significant negative correlations (r = –0.685 – 0.737) with both scores. There was no significant correlation between v_{mean} or f_{med} and ASIA sensory scores in any situation. No correlation analysis was performed on the ASIA motor scores since they showed a very limited differentiation (Table I). There was no significant correlation between the balance variables and the neurological lesion level or years post-injury. Neither did any difference appear when subgroups of SCI with high (T2–T6, $n = 7$) and low level (T9–T11, n = 5, cf. Table I) injuries were compared.

Balance variables, inter-correlations

For each of the 3 balance variables the measures in the sagittal and frontal planes tended to be positively correlated in both groups and in all test situations (Table III). The correlation coefficients reached statistical significance for v_{mean} in both the SCI and control groups (r = 0.847 and 0.663, respectively) (Table III).

As to the correlations between balance variables within each plane, there were significant positive correlations, in the control group, between SD and v_{mean} both in the sagittal and frontal planes, whereas the correlations between SD and $f_{med,}$ as well as between v_{mean} and f_{med}, were non-significant (Table III). No

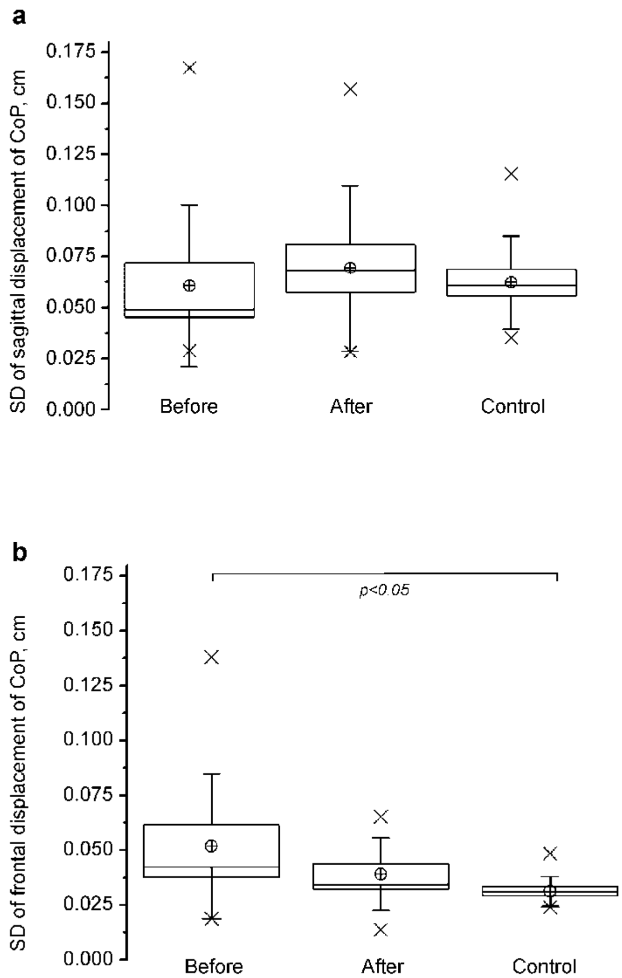

Fig. 2. Standard deviation (SD) of centre of pressure (CoP) displacement for the spinal cord injury (SCI) group before and after kayak training and for the control group; (a) in the sagittal and (b) in the frontal plane, respectively. The encircled plus-sign in the centre of the box represents the mean, and the horizontal line within the box indicates the median value; the long sides of the box represent ±1 standard error of the mean, and the vertical error bars denote ±1 SD; the crosses indicate the highest and the lowest value for each variable. The *p*-value and horizontal square bracket on top of (b) indicate a significant difference between the SCI group before training and the control group.

significant correlations between variables within each plane were present for the SCI group (Table III).

Balance variables, training effects

There was no significant effect of the kayak training on the SD of CoP displacement in the sagittal or frontal planes for the SCI as a group (Fig. 2). Individual values for changes in SD with training showed an increased sagittal SD in 4 subjects (I, II, VIII and XII). One subject (VI) showed a decrease, whereas the others had changes within ±1 standard deviation of the test-retest differences in the control group (cf. above). In the frontal plane, 3 subjects (III, V, IX) showed a decrease, and 1 (I) an increase after training.

The kayak training did not cause any significant change in sagittal or frontal v_{mean} of CoP displacement for the SCI group (Fig. 3). Individual values showed an increase in the sagittal plane for 1 subject (II), whereas in the frontal plane all individual changes were within the, rather large, ±1 standard deviation of the test-retest differences in the control group (cf. above).

There was a significant decrease in sagittal f_{med} of CoP acceleration after training (Fig. 4a), whereas frontal f_{med} remained unchanged (Fig. 4b). Individual values in the sagittal f_{med} demonstrated decreases for 2 subjects (III, IV) in excess of ±1 standard deviation of the test-retest differences in the control group (cf. above), whereas the rest of the subjects with SCI (except VII) had decreases of smaller magnitude. In the frontal plane, 3 subjects showed an increase (I, IV, XII) of f_{med} after kayak training.

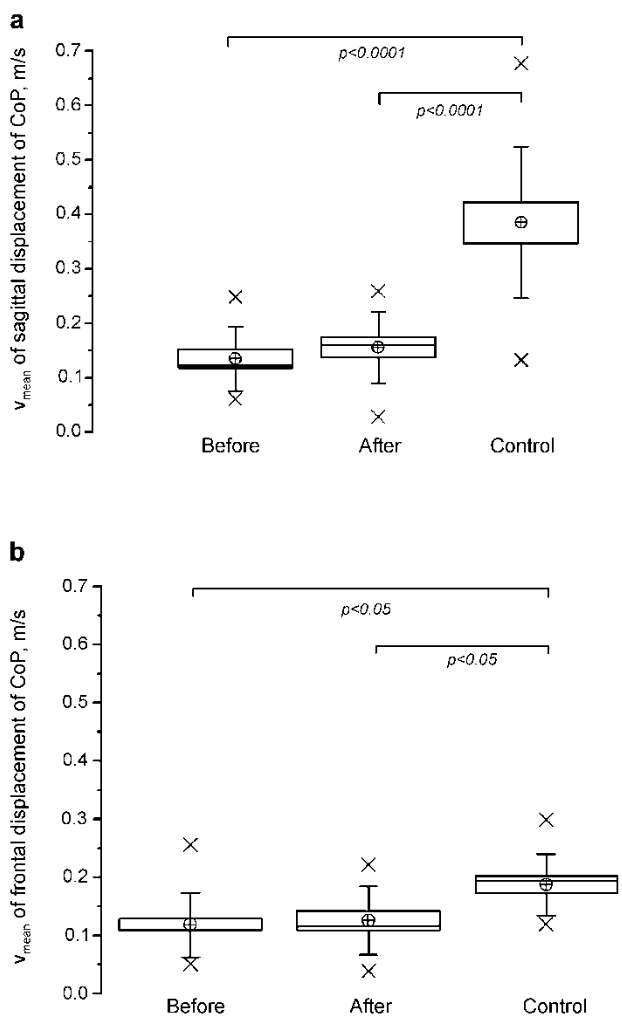

Fig. 3. Mean velocity (v_{mean}) of centre of pressure (CoP) displacement for the spinal cord injury group before and after kayak training and for the control group; (a) in the sagittal and (b) in the frontal plane, respectively. The layout is identical to that in Fig. 2. The *p*-values and horizontal square brackets on top indicate significant differences between means.

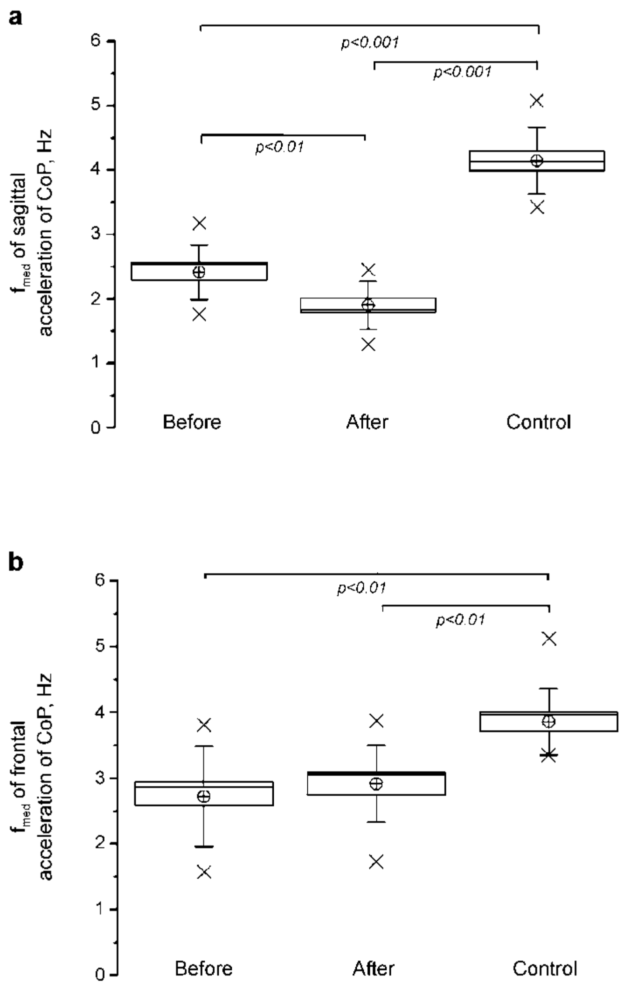

Fig. 4. Median frequency (f_{med}) of centre of pressure (CoP) acceleration for the spinal cord injury group before and after kayak training and for the control group; (a) in the sagittal and (b) in the frontal plane, respectively. The layout is identical to that in Fig. 3.

Balance variables, correlations between training effects, impairment and before training values

The magnitude of the decrease in sagittal f_{med} with training showed no significant correlation with number of years post-injury or neurological lesion level, and there was no significant difference between the subgroups with high and low level SCI (cf. above); neither were there any correlations with the ASIA sensory scores. However, there was a difference between subgroups A and B, classified according to the degree of impairment (A having the greatest impairment; Table I) in that the decrease in sagittal f_{med} with training was significant ($p < 0.05$) only in subgroup A.

Correlation analysis demonstrated that the largest decrease in sagittal f_{med} occurred in the subjects having the highest values before training, i.e. there was a significant positive correlation between the absolute size of the training effect and the starting value ($r = 0.717$, $p < 0.05$).

Questionnaire

Nine of 12 subjects with SCI stated that they had noted improvements of balance control when sitting in the wheelchair directly after the period of kayak training (Table IV). Three of those subjects reported remaining small [2] or moderate [1] positive effects 1 year after the training period.

Eleven subjects recalled having experienced an improvement of their general well being directly after the training period (Table IV). Eight persons reported an increase in shoulder muscle strength and stability of the upper body and 5 subjects stated that they had felt an improvement of their spasticity as a direct result of the kayak training (Table IV).

DISCUSSION

Balance control in sitting

Differences between the SCI group and the control group were present in all investigated balance variables during quiet sitting. This might be expected due to the impaired sensorimotor function of the legs and part of the trunk in the SCI. Evidently, a completed rehabilitation period and long-term experience of sitting in a wheelchair had not led to a full compensation for the initial injury-induced impairment of the balance function, as judged from the CoP characteristics measured during quiet sitting. New strategies for balance control may have developed utilizing also non-postural muscles, as indicated in earlier studies on persons with thoracic level spinal cord injury (1, 3).

Interestingly, the differences between subjects with SCI and controls were expressed differently depending on the variable studied. This may indicate that the three variables used to characterize displacement, velocity and acceleration of the CoP are indicative of different aspects of balance control in sitting. In line with that reasoning were the relatively low, or even absent correlations between these variables, particularly the f_{med}, within both groups.

Higher values for frontal SD were observed in the subjects with SCI than in the controls, which could indicate an impaired control causing a larger variation in sideways displacement of the CoP. Accordingly, higher frontal SD values were seen within the SCI for those with a high injury level and an ASIA score "A", i.e. having a more pronounced sensorimotor impairment. Frontal postural sway has earlier been noted as discriminative in conditions of decreased postural stability. For instance, frontal SD was used to describe differences in postural control in standing between elderly fallers and non-fallers (6), and to grade patients with peripheral neuropathy (7). In sitting, a gradually reduced stability induced by varying sitting conditions caused a more pronounced increase in the SD of frontal than of sagittal sway (8).

Our study did not reveal any difference in sagittal SD between subjects with SCI and controls. Although this may reflect a less affected balance control for the SCI in this plane, another possible contributing factor could be that the elevated back

Table III. *Linear correlation matrix for the balance variables, standard deviation (SD) and mean velocity (v_{mean}) of the displacement of centre of pressure (CoP) and the median frequency (f_{med}) of the acceleration of the CoP, obtained in the sagittal and frontal planes for the control group (C, n = 12; upper right half) and the group with spinal cord injury (SCI, n = 12; lower left half). Significant ($p < 0.05$) correlation coefficients are given with bold-faced numbers*

		Sagittal SD	Frontal SD	Sagittal v_{mean}	Frontal v_{mean}	Sagittal f_{med}	Frontal f_{med}
Sagittal	SD	C *SCI*	0.275	**0.873**	**0.609**	−0.034	0.165
Frontal	SD	0.435	C *SCI*	0.162	**0.601**	0.275	0.513
Sagittal	v_{mean}	0.192	0.133	C *SCI*	**0.663**	0.009	0.056
Frontal	v_{mean}	0.402	0.223	**0.847**	C *SCI*	0.434	0.447
Sagittal	f_{med}	0.145	**0.643**	−0.280	−0.075	C *SCI*	0.267
Frontal	f_{med}	0.086	0.324	0.255	0.372	0.360	C *SCI*

Marked correlations are significant at $p < 0.05$.

support of our experimental chair might have provided some assistance in the backward direction.

The differences between the SCI and control groups were relatively large for v_{mean}, the average SCI value was lower by 66% in the sagittal plane and 41% in the frontal plane. It seems reasonable to ascribe the lower v_{mean} in SCI to an impaired balance control function. Interestingly, in some studies the reversed, i.e. a high v_{mean} has been associated with decreased control, e.g. in persons with peripheral neuropathy (7) and rheumatoid arthritis (9). Our contradictory finding may be related to the possibility that spinal cord injury *per se* may induce a specific type of functional adaptation and reorganization of postural control in sitting. Also, support for a specific organization of balance control for individuals with SCI may be found in the absence of any correlations between v_{mean} and SD in the SCI as opposed to the control group.

Subjects with SCI had significantly lower values for f_{med} in both the sagittal and frontal planes; f_{med} was also the only variable that showed a significant change with training. Frequency analysis of CoP has been shown to be more discriminative than other measures in some earlier balance control studies, both in sitting (10) and standing (11, 12). The physiological correlate to the measure of f_{med} still remains unclear. However, the conspicuous lack of correlations between f_{med} and the other balance variables demonstrated here, indicates that f_{med} may represent a different aspect of balance control than SD and v_{mean}. It can also be speculated that differences in mechanical characteristics may be present between the SCI and control groups. A relative lack of muscle "tone" in certain critical trunk muscles could result in a reduced stiffness of the system and thus a slower switch in sway direction and thus a reduced f_{med}. However, an even further reduction of f_{med} in the sagittal plane with training speaks against such a mechanism. Notably, a similar finding was reported for children with myelomeningocele, who demonstrated a lower median frequency of sagittal horizontal ground reaction force in quiet sitting than healthy children (10).

Effects of kayak training

The kayak training performed by the subjects with SCI had relatively small effects on the balance variables measured during quiet sitting. The only significant training effect observed, i.e. a decrease in f_{med} in the sagittal plane, actually went in a direction opposite to becoming more "normal". This training effect was more pronounced for individuals with an ASIA A-impairment score than for the B-scored ones, which is suggesting that the more severe the degree of impairment the higher the probability to develop and/or strengthen a "novel" or specific strategy or reorganization of the balance control by training. Unfortunately, the ASIA motor scores did not allow for any similar analysis due to its very limited range of values. Furthermore, the scoring of motor function includes only the upper and lower extremities

Table IV. *Subjective experiences of direct effects of the kayak training as stated in a questionnaire presented to the individuals with spinal cord injury 1 year after the training period*

	General well being	Sitting balance in wheelchair	Shoulder strength	Upper body stability	Spasticity
No improvements	1	3	4	4	5
Small improvements	1	3		5	3
Moderate improvements	4	3	6		1
Large improvements	6	3	2	3	1
Don't know					2

and not the trunk muscles (5), which appear crucial for the control of sitting balance and trunk stabilization in persons with a thoracic SCI.

That training of similar, relatively short duration, can actually affect body sway has been demonstrated previously in studies on quiet standing. A decreased postural sway (perimeter of the sway area of CoP displacement) was reported for individuals with a traumatic brain injury after a period of specific balance training (13). A reduced frontal sway (amplitude, % of width of base and speed) was observed after balance training for elderly persons (14), and Messier et al. (15) also reported effects of training (aerobics, walking, and weight training) that were related to improved balance (shorter length of CoP displacement) in elderly people with osteoarthritis. There appears, however, to be paucity in data on the possible changes in balance variables during quiet sitting and standing that can be accomplished by training in a healthy young or middle-aged population.

Although a year had passed between the training period and the questionnaire, and thus the answers are hampered by limited remembrance, a clear majority of the trainees expressed subjective feelings of improved life quality and balance control in every day activities directly after the kayak training period, some effects even remaining. These subjective improvements were most likely experienced during motor tasks involving balancing the trunk when executing dynamic arm movements, of a similar nature as those performed in kayaking. Testing under such more demanding circumstances may, therefore, reveal more significant effects of the training protocol, than those reported here for quiet sitting.

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