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Original article

Changes in balance and strength parameters induced by training on a motorised rotating platform: A study on healthy subjects

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Abstract

Aim. – The aim of the present study was to analyse the effects of training performed on a rotating, motorised platform (the Huber®/SpineForce™ device from LPG Systems, Valence, France) intended to improve, postural control and muscle function.

Subjects. – Twelve healthy adults (divided into a sedentary group and an active group) took part in a two-month training programme (involving three sessions a week) on the SpineForce™ whole body rehabilitation device.

Method. – Instrumental assessment of postural control (on a Satel® platform) and muscle function (on a Cybex Norm®) was performed before and after training. Postural control in various conditions was measured using a position parameter (the mean anteroposterior position of the centre of foot pressure [CoP]) and two stability parameters (maximum CoP displacement and CoP sway area). Assessment of the muscle function was performed during knee and spine extension and featured maximum voluntary isometric contraction (MVIC), root mean square (RMS) and neuromuscular efficiency (MVIC/RMS) measurements.

Results. – For static postural control, we observed a more forward CoP position in the maximum backward inclination condition ($p < 0.01$) and a decrease in maximum CoP displacement in the ''eyes closed on foam'' and ''maximum anterior inclination'' conditions. In this latter condition, a lower CoP sway area was also noted ($p < 0.01$). In terms of muscle function, a greater MVIC for knee extension was observed in the sedentary group only ($p < 0.05$).

These changes were not correlated with each another ($p < 0.05$). However, the value of the pretraining maximum CoP displacement predicted its final value ($p < 0.05$).

Conclusion. – Our results suggest that static postural control responds to training on a Huber®/SpineForce™ rehabilitation device. It seems probable that a population with a low initial level of physical activity would benefit most from training on this type of device. This training could notably be applied to elderly or disabled people and especially those with sensorimotor disabilities.

Keywords: Balance; Muscular strength; Statokinesimetry; Rehabilitation

1. Introduction

Motor functions are less solicited during a reduction in physical activity – during a stay in microgravity or when someone wears a plaster cast, for example. Consequently, deconditioning occurs and leads to alterations in balance and muscle function. Training that addresses balance and muscle function has been found to be beneficial for health, quality of life and functional and physical capacities [3,9].

When the body is deprived of functional demand, balance is altered. For example, Liu et al. [15] reported in a study that after 21 days of bed confinement, the proprioceptive system became less efficient in maintaining dynamic balance. However, the system's effectiveness was maintained when exercises were performed during the period of bed rest. Many protocols (which incorporate balance exercises) are now available for soliciting and stimulating the physiological systems involved in postural control [9,12]. For example, the sport of Tai Chi develops balance capacities and provides efficient protection against the

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risk of falls in the elderly [8]. However, simpler physical activities provide the same benefits. For example, after performing exercises on a ball in a seated position or when lying down, postural oscillations in the frontal plane are reduced [21]. Moreover, after training on a rotating platform, postural oscillations decrease (as documented by a drop in the maximum centre of foot pressure [CoP] displacement) [11]. Even in more difficult balance conditions (such as standing on foam), postural stability is improved following the performance of physical exercises that require balance [13].

The effects of a reduction in functional charge on muscle function are well known [10,18,19]. Real or simulated microgravity is responsible for a decrease in muscle volume [5,14]. Correspondingly, atrophy leads to a decrease in strength. For instance, four to six weeks of bed rest lowers muscle strength by 6 to 40% [1]. However, amyotrophy can be limited with even quite low levels of physical activity [6]. When in training, quadriceps strength [25] and torso-extensor muscle strength are improved [20].

There is now a wide range of methods available to improve postural control (balance workshops, for instance). To improve muscle function, muscle-improvement devices (quadriceps chair, weights, etc.) have been designed to preferentially develop the function of a given muscle group. Ergometers (bench press machines, rowing machines, bicycles, stair climbers, etc.) are also used for more general stimulation of the locomotor system. In the present study, we investigated the Huber®/SpineForce™ device, which claims to stimulate both balance and muscle function. The objective of this study was therefore to quantify the effects of a training programme using this system on motor function. More specifically, we looked for potential improvements in postural control (the primary criterion) and knee and spine-muscle strength (the secondary criteria).

2. Method

2.1. Population

Six middle-aged men and six middle-aged women (mean age: 36 ± 6 years) gave their informed, written consent to participation in this three-month study. The study protocol had been approved by the Pitié–Salpêtrière Independent Ethics Committee (reference 6404-THO596). The study population's mean weight was 63 ± 13 kg and the mean height was 169 ± 11 cm.

The study's inclusion criteria were as follows:

- male or female subjects, aged 25 to 45;
- good general health;
- valid health insurance;
- living in the Paris area;
- willing to be monitored for at least three months;
- provision of informed, written consent.

The exclusion criteria were as follows:

- contra-indication to physical exercise;
- the performance of any sport at a high level;
- known cardiovascular disease;
- any pathology that could interfere with motor activity or posture;
- any neurological disease;
- any rheumatic disease;
- any recent incident (particularly surgery) that could interfere with the initial assessment and a regular follow-up of the subjects for at least three months;
- known respiratory problems;
- participation in the previous six months in a biomedical study.

A Bouchard questionnaire [2] was filled out by each subject at the beginning of the study in order to assess physical activity levels.

2.2. Assessment protocol

The assessment protocol used to evaluate the effects of training with the Huber®/SpineForce™ system included two types of criteria:

- primary criterion: assessment of balance (using a force platform) in static conditions;
- secondary criterion: assessment of maximum isometric muscle force on an ergometer; characteristics of the electromyographic (EMG) signals from the *vastus lateralis* and lumbar *erector spinae* muscles.

2.2.1. Balance

We used a Satel® platform (Blagnac, France) to assess balance under static conditions. This device enables measurement of the forces and moments applied to the platform by the subject. The signal was acquired at a frequency of 40 Hz. The subject was asked to stand barefoot on the platform and stay as still as possible, looking to the horizon and with the arms held in a natural position alongside the body. During the two trials, the following experimental conditions were applied at random, with the subject standing on two feet:

- eyes open or eyes closed for 25.6 s (Fig. 1);
- on foam, eyes open or eyes closed for 25.6 s;
- leaning as far forward or backward as possible, eyes open for 12.8 or 51.2 s.

The biomechanical parameters taken into consideration were as follows:

- the mean CoP coordinates in the sagittal plane, an index reflecting the subject's overall posture,
- the CoP displacement and sway area, which are indexes of the subject's postural stability (Fig. 2).

2.2.2. Muscle function

In order to assess muscle function under isometric conditions, we used an isokinetic dynamometer (Cybex Norm®, Cybex International, Medway, USA) coupled to a portable EMG data logger (ME 3000P8®, Mega Electronics Ltd, Kuopio, Finland) to measure the torque and EMG activity

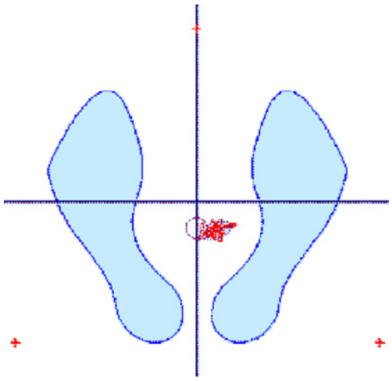

Fig. 1. Reference position given by SATEL® and a sample statokinesigram (sway-path measurement).

generated by the knee and spine extensor muscles. To ensure a high signal quality, the EMG signals were amplified (with a preamplifier integrated into the electrode cables) and then filtered with an 8 to 500 Hz bandwidth. Sampling was performed at 1000 Hz. Two muscle functions were evaluated as follows:

- for knee extension: the subject was seated, with a trunk/thigh angle of 105° (± 5) and a thigh/leg angle of 60°. The knee extension was tested for the leg on the side of the take-off foot;
- for spine extension: the subject stood on the dynamometer platform with his/her trunk inclined at an angle of 20°.

The surface electrodes were placed on the *vastus lateralis* and on the *lumbar erector spinae* at the L4 level according to the recommendations from the SENIAM project [24]. After shaving the area (if necessary), the skin was cleaned with 70% alcohol.

For each function, each individual had to perform three trials after being instructed to develop his/her maximum force and to move as fast as possible. The acquisition time for the force and EMG signals was 5 s. One-minute rest periods were allowed between trials. The biomechanical parameter taken into consideration was the maximum torque associated to maximum voluntary isometric contraction (MVIC, in N.m) during knee and spine extension. The EMG parameter taken into consideration for the maximum strength test was the maximum root mean square (RMS_{max}, in mV) corresponding to the mean electrical muscle activity calculated during acquisition of a maximum torque. Moreover, we determined the neuromuscular efficiency, defined as the ratio of the maximum torque to RMS_{max} (N.m/mV).

Fig. 2. A sample statokinesigram surface area plot.

Two evaluations were performed:

- an initial evaluation to establish the baseline for each participant;
- a final evaluation in the week following the eight-week training programme in order to evaluate the latter's effect.

2.3. The training programme

The Huber®/SpineForce™ rehabilitation device (designed by LPG Systems Valence, France) was used for the training sessions. The device is an oval motorised platform, which performs rotating, oscillatory movements of variable amplitude and speed. It includes a handle system equipped with force sensors. The platform interferes with the balance of the subject who must continually adjust his posture by exerting pushing and pulling efforts with the arms. More specifically, the device provides postural and muscle adaptation with visual feedback. A set of four programmes for four different levels of use allows the system to adapt to various user profiles.

Each training session started with a warm-up phase on a bicycle ergometer (for five minutes between 50 and 60% of the theoretical maximum heart rate). This warm-up phase was followed by a stretching phase performed on the mobile platform, where the subject adopted various positions without using the arms. Next, exercises from the rehabilitation device's "intermediate" programme were performed at 60% of the maximum force determined at the beginning of the study and then readjusted at the beginning of the first session of each new week of training. This programme included push and pull exercises on the handles in different postures (feet parallel, apart at waist wide, right or left forward lunge). Three roughly 30-minutes training sessions were performed per week for eight weeks, giving a total of 24 sessions.

2.4. Statistics

The first goal of our statistical analysis was to find out whether the individuals in the study population differed in terms of their physical activity profile. We therefore used a Mann and Whitney (MW) test with a confidence level set at 0.05.

Next, the analysis consisted of a Wilcoxon (W) test to evaluate any post-training modifications that had occurred in all the subjects and then within each subgroup (i.e., sedentary, active). The confidence level was set tat 0.05.

We also sought to determine whether or not there was a correlation between the various parameters studied using the Spearman (S) nonparametric correlation coefficient. Lastly, to determine whether or not the initial values of the monitored parameters were predictive of post-training modifications, the same Spearman coefficient was calculated with a confidence level set at 0.05.

Table 1
Daily energy expenditure calculated with the Bouchard questionnaire

Energy expenditure (kcal/day)	Sedentary	Active
Mean	2510	3813**
Standard deviation	±278	±304

** $p < 0.01$.

Table 2
Changes in CoP displacement (Y_{IP} mean) in the maximum backward lean condition, eyes open, at an acquisition time of 12.8 s and 51.2 s

Y_{IP} mean (mm ± S.D.)	Acquisition time (s)	Before training	After training
Mean	12.8	−94.0 ± 9.8	−87.6 ± 12.7**
Mean	51.2	−92.5 ± 12.5	−84.6 ± 15.3**

** $p < 0.01$.

3. Results

3.1. Population characteristics according to the Bouchard questionnaire

Each subject's completed Bouchard questionnaire enabled the identification of two statistically different subgroups (MW, $p < 0.01$): an active subgroup and a sedentary subgroup, each containing six individuals (Table 1).

3.2. Effects of training

3.2.1. Effects of training for all subjects

3.2.1.1. Static balance. In the maximum backward lean condition "eyes open" and at any acquisition time, the CoP became more anterior after training (Table 2) (W, $p < 0.01$).

In a maximum forward lean condition "eyes open" at an acquisition time of 12.8 s, the CoP sway area was 33.2% lower (W, $p < 0.01$) (Fig. 3). The maximum CoP displacement was 13.7% lower after training, but only with an acquisition time of 12.8 s (W, $p < 0.01$).

In the standing on foam condition "eyes closed", the maximum CoP displacement and CoP sway area were lower after training (W, $p < 0.05$) (Fig. 4).

3.2.1.2. Muscle function. No significant differences were found in the assessment of muscle function (i.e., for either strength or EMG values). The maximum isometric torque developed by the knee extensors increased by 7% following training. However, this trend did not achieve statistical significance ($p = 0.07$) (Fig. 5). The RMS value of the *vastus lateralis* increased by 4% following training. Again, however, this increase was not significant.

For the spine, the MVC increased (+ 5.5%) following training, but this result is not statistically significant ($p = 0.09$). The RMS increased by more than 20% on each side. However, only the increase on the left body side was significant ($p < 0.05$) (Fig. 6).

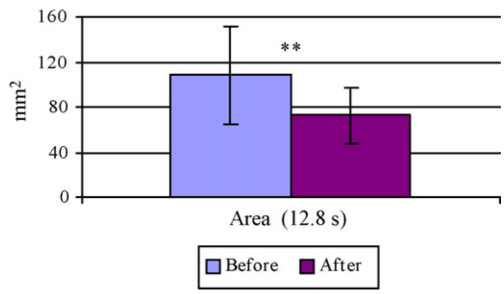

Fig. 3. CoP sway area in a standing position with maximum forward inclination, eyes open, for 12.8 s. Mean and standard deviation (± S.D.) for the entire population before and after training. **$p < 0.01$.

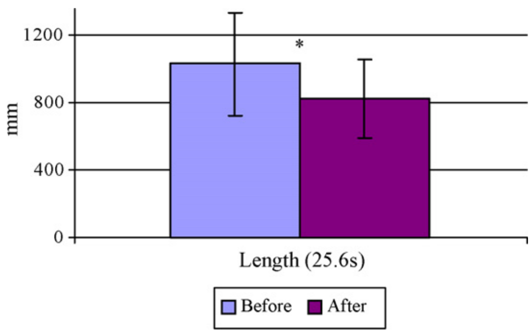

Fig. 4. Maximum centre of pressure displacement in the standing position on foam "eyes closed" for 25.6 s. Mean (± S.D.) for the entire population before and after training. *$p < 0.05$.

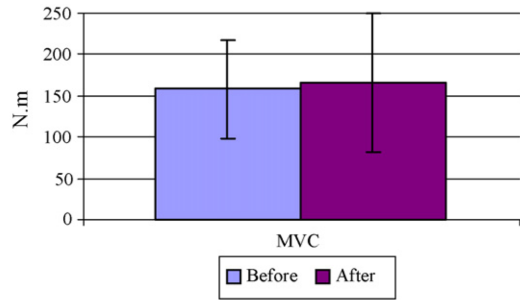

Fig. 5. Knee extensor maximum torques (MVCs). Mean (± S.D.) for the entire population before and after training.

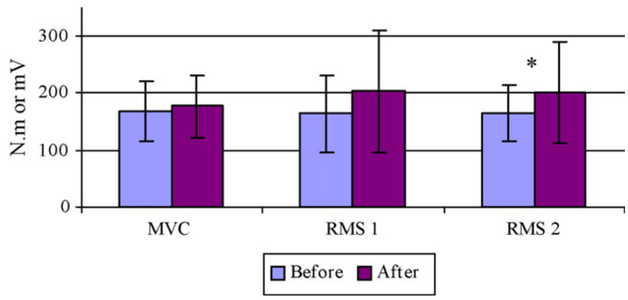

Fig. 6. Spine extensor maximum torques (MVC) and root mean square (RMS) of the lumbar (L4) *erector spinae* muscle. Mean (± S.D.) values for the entire population before and after training. RMS 1 and RMS 2 correspond to the right and left body sides, respectively. *$p < 0.05$.

Table 3
Maximal torque (MVC) developed by the knee extensors of the sedentary subjects, before and after training

MVC for knee extensors (N m)	Before training	After training
Mean	125.2	147.8*
Standard deviation	±32.1	±42.5

* $p < 0.05$.

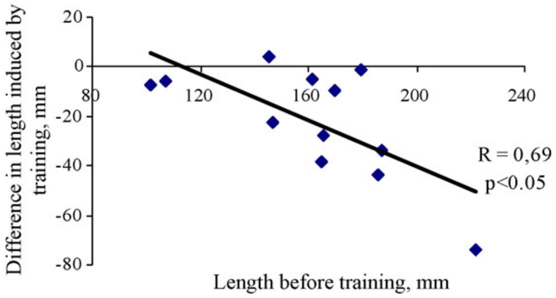

Fig. 7. Linear relationship between the maximum centre of pressure displacement before training and its change after training, in a standing position, maximum forward inclination.

Neuromuscular efficiency was not significantly modified, since its two component parameters (maximum torque and RMS) changed in the same direction.

3.2.2. Within each subgroup

Of the two muscle functions studied, only the MVC of the knee extensors increased by 18.1% following training in sedentary individuals (W, $p < 0.05$) (Table 3).

3.3. Correlations between studied parameters

No correlation was found between training-induced changes in static balance and muscle strength parameters.

While assessing static balance, it was found that for maximum forward lean condition and while standing on foam, eyes closed, the greater the pretraining maximum CoP displacement, the easier it was to lower this value through training (S, $p < 0.05$) (Figs. 7 and 8).

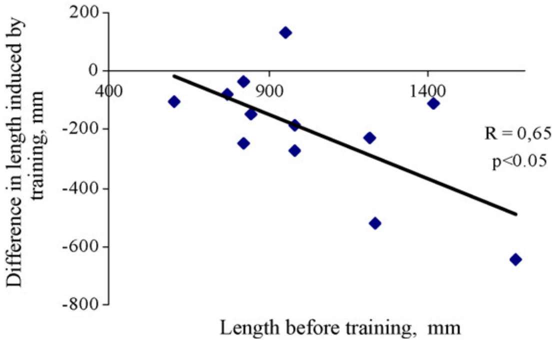

Fig. 8. Linear relationship between the maximum centre of pressure displacement before training and its change after training, in standing position on foam, eyes closed.

4. Discussion

One of the purposes of this study was to analyse changes in static balance and muscle function following training on a Huber®/SpineForce™ rehabilitation device (with a mobile platform and handle system equipped with force sensors). In fact, these various elements stimulate a high proportion of the body's muscles: in postural control, muscle contractions allow posture maintenance and stabilise joints. The other aim of this work was to find out whether or not there was a correlation between the modifications resulting from training and, in particular, whether if the baseline (pretraining) values for each of the parameters responsible for static balance and muscle function were predictive of changes brought about by training.

4.1. Static balance

In the maximum backward lean condition, our results show that the post-training mean CoP coordinate in the sagittal plane is more anterior than before training. The rehabilitation device might be responsible for this modification because all the exercises involved pushing on the handles located in front of the subject. Thus, training involving anterior support might, for instance, allow elderly subjects to transfer weight to the front of the foot. In fact, the elderly can suffer from retropulsion syndrome, as described by Pfitzenmeyer et al. [17], and can display an overly posterior CoP in comparison with a healthy population – causing a loss of balance and backward falls.

Our results indicate that there is an improvement in stability indexes following training in maximum forward lean position and at an acquisition time of 12.8 s. This result agrees with the literature on post-training improvements in postural control [12]. In these leaning conditions, a decrease in stability is predictive of falls in elderly subjects [16]. Therefore, Huber®/SpineForce™ training could be a factor in the prevention of falls.

In the standing on foam "eyes closed" condition, the maximum CoP displacement and CoP sway area decreased after training. We hypothesize that in order to see improvement in postural control after training, healthy subjects must be placed in a complex experimental environment. In fact, in this condition, the visual system is not greatly involved in regulating balance. Furthermore, in parallel with the absence of visual references, the subject cannot fully exploit his/her proprioceptive references because the latter are significantly distorted by the presence of the foam. The vestibular system remains therefore more responsive for obtaining postural control [4]. Following training, the subjects might have developed their vestibular sensitivity and/or improved their adaptation capacity in relation to proprioceptive interference. This hypothesis fits with the way that the rehabilitation device was used in our study, with frequent changes in the direction, speed and amplitude of the motion of the platform on which the subject stands during the training session.

4.2. Muscle function

Training on the Huber®/SpineForce™ system induced an increase in the strength of the muscle groups evaluated here (quadriceps and spine extensors) and this increase was greatest in subjects in poor initial physical condition. However, this increase did not achieve statistical significance. There was a significant increase in knee-muscle strength in the sedentary group. In our study, exercises performed on the Huber® system (despite the semi-bent-over stance maintained for all the exercises) did not electively recruit the quadriceps, but induced muscle work in series at 60% of the maximum force obtained during the overall movement corresponding to the requested exercise. In fact, on untrained subjects, 45 to 50% of the MVC would be sufficient to generate a significant increase in the force, whereas for expert subjects, the training intensity must be about 80% of the MVC. Our results agree with literature data [19] showing that significant developments in muscle strength and mass require training between 60 and 100% of the MVC [23]. The increase in muscle strength can be explained by structural factors (volume, typology, etc.) and neural factors (inter- and intramuscular coordination and the recruitment of motor units). Since our study only lasted for eight weeks, it is clear that we cannot observe modifications in muscle morphology (increase in mass). Even though the training performed here was not specific for quadriceps strength, the recruitment generated by these exercises was sufficient to induce a significant increase in quadriceps strength in sedentary subjects. This strength increase is probably linked to neural factors. Indeed, it is known that neural factors are more often responsible for this initial adaptation phase (particularly in beginners), with an increase in the EMG signal [7]. Even though our study does not show a significant increase in muscle activation (represented by RMS), there is nevertheless a change over time in strength, which is concomitant with a change over time in muscle activation. Likewise, the neuromuscular efficiency was not significantly modified over the course of the study. This can be explained by the fact that maximum torque is developed by a muscle group, whereas the EMG is only recorded on a single muscle from the group. Considering the complexity of muscle activation synergies, we can consider that the EMG collected on a subelement of the muscle system is not necessarily representative of the level of activation of the muscle itself and, *a fortiori*, of the muscle group.

4.3. Parameter correlation

Our study did not reveal any correlation between static balance and isometric muscle strength parameters, whereas the study by Ryushi et al. [22] reported that an increase in quadriceps strength allows a backward displacement of the CoP in a maximum backward lean stance. Conversely, in the same stance in our study, sedentary subjects were the only ones to show an increased quadriceps strength but did not modify their CoP position or their stability.

The pretraining value of the maximum CoP displacement parameter in the maximum forward lean condition and while standing on foam, eyes closed was found to be predictive of the post-training value. The greater the maximum CoP displacement prior to training, the more it improved after training. In other words, subjects who improve the most after exercising on this system are those whose stability was worst beforehand. This result agrees with those observed for posture and muscle strength in the sedentary group. The Huber®/SpineForce™ rehabilitation device appears to enable the improvement of motor function in disabled subjects. This system could therefore be very useful for managing rehabilitation in subjects suffering from certain pathologies.

5. Conclusions and perspectives

This study on the effects of training on the Huber®/SpineForce™ system shows that the results are coherent with the literature data in the areas of physical exercise, balance problems and falls. Overall, the effects of training are positive in the two main functional areas monitored here: force and balance. The improvements obtained over eight weeks were greatest in subjects in poor initial physical condition.

Training on the Huber®/SpineForce™ system (with its whole-body approach to locomotor system function) modified parameters linked to static balance and muscle function in healthy subjects who did not do any sport. The CoP moves forward in a maximum backward lean stance, suggesting a postural reorganisation and weight transfer onto the front of the foot. Subjects also become more stable in maximum forward lean stance and when standing on foam with their eyes closed. For all subjects, the pretraining value of the maximum CoP displacement can predict its post-training value.

Given the reasonable results for static balance parameters in healthy subjects, even better outcomes can be anticipated for subjects with pathologies (such as for with sensory disabilities) or elderly subjects following the same training programme. The progress could be even more marked if the initial sway was significant. Patients presenting sensory disabilities, and elderly subjects would be less hindered by their problems with this type of training. However, additional studies with this type of population would be necessary.

This type of training moderately improved the strength of the quadriceps and *erector spinae* muscles. However, other muscles (such as the scapular muscles) are probably significantly recruited during this training. The combination of different postures during Huber®/SpineForce™ exercises probably contributes to development of the locomotor system's various functional potentials. Additional measurements would allow the confirmation of these hypotheses.

One of the major perspectives is the possibility of adapting the experimental protocol to study certain pathologies. In fact, a few protocol modifications (choice of the material, condition of uses, parameters monitored and the study population) might give workable results in the therapeutic field and would be likely to improve the quality of life for the elderly and patients with neurological, lumbar- and scoliosis-related problems. Furthermore, it would be interesting to analyse the persistence of the training effects. Application of this device in the management of subjects at risk of falls appears to be particularly interesting.

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