Journal of Bodywork and Movement Therapies (2008) **12**, 22–30

Journal of
Bodywork and
Movement Therapies

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PILOT STUDY

Effects of a program for trunk strength and stability on pain, low back and pelvis kinematics, and body balance: A pilot study

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Received 22 March 2007; received in revised form 30 April 2007; accepted 1 May 2007

KEYWORDS
Trunk strength;
Trunk stability;
"Core";
Lumbar;
3-D kinematics;
Balance;
Gait

Summary The purpose of this pilot study was to investigate the effects of trunk strength and stability training on body balance and low back and pelvis kinematics during gait in females. Six subjects volunteered to do 20 sessions of training. Data collection involved a qualitative pain grade test, low back stabilization tests, low back and pelvis kinematics, and body balance assessment. Results indicate the absence or decrease in the low back pain, and also an increase in the stabilization and strength of low back and pelvis complex. The 3-D kinematics showed statistically significant differences ($p<0.05$) when compared pre- to post-training. The body balance was improved as well as the range of motion (ROM) was improved for trunk rotation, pelvis inclination and low back flexion. The results suggest the influence of trunk strength and stability on low back and pelvis pain and kinematics as well as on body balance. Further studies with a larger sample and/or a control group must be conducted in an attempt to confirm this hypothesis.

Introduction

The skeletal elements of the spine form a column that transfers the load to the lower limbs for static and dynamic situations with a behavior similar to an

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doi:10.1016/j.jbmt.2007.05.001

inverted pendulum system. Wagner et al. (2005) suggests that the spine structure is able to give support and stability when active and passive tissues are working together, but the stability may not be guaranteed when only passive structures are considered.

Low back pain is a common medical problem (Panjabi, 2003) and it has been frequently related to lumbar instability when lumbar bone architecture defects are not found (O'Sullivan, 2000). This represents a growing problem in modern society with prevalence ranging from 15% to 20% in the United States, and from 25% to 40% in European countries, with a lifetime prevalence as high as 60–90% (Van Tulder, 1996). There is also evidence that low back pain is more frequently observed in young adult women (Clarke and Buckley, 1980; Lanese et al., 1990; Nadler et al., 1998; Andersen et al., 2006).

Even though the prevalence of low back pain has been reported worldwide, there is no consensus as to the specific causes (Pool-Gouzwaard et al., 1998). Factors such as negative social interaction and the problem of a mechanical origin (such as inappropriate loading due to posture) have been suggested (Panjabi, 2003). Clinical spinal instability is related to a reduced capacity of response to physiological loading when a neurological deficit, deformity or pain does not exist (Panjabi, 2003). Strength training regimens that increase spinal stabilization have been effectively employed to reduce low back pain through the specific recruitment of muscles of the lumbo–pelvic complex. Training of the abdominal and lumbo–pelvic region is frequently described as "*core training*". Marshall and Murphy (2005) have suggested that the stability of this region is dependent on a combination of global—superficial muscles around the abdominal and lumbar region and local stability—intrinsic muscles of the abdominal wall (Behm et al., 2002; McGill, 2001). According to Nadler et al. (2002), the focus of such a training regimen should also include muscular stabilization of the abdominal, paraspinal, and gluteal muscles, to provide better stability and control.

In the present study, "core" strengthening was described as a program for trunk strength and stability. This sort of therapy has been promoted as a preventive regimen, as a rehabilitation therapy, and as a strategy to avoid various lumbar spine and musculoskeletal injuries (Akuthota and Nadler, 2004; Ericksen et al., 2006). Dynamic neuromuscular training regimens have also been demonstrated to reduce gender-related differences in force absorption, active joint stabilization, muscle imbalances, and functional biomechanics, while increasing strength of structural tissues (Myer et al., 2005).

However, while several studies have evaluated the muscular activity of the low back complex during gait in response to strength training regimens (Richardson and Jull, 1995; Hodges and Richardson, 1996; Hodges, 1999; Lee et al., 1999; O'Sullivan, 2000; Radebold, 2001; Panjabi, 2003), the implications of these regimens have not addressed static postural stability and kinematics during gait in females, who may be more likely to suffer from low back pain (Clarke and Buckley, 1980; Lanese et al., 1990; Nadler et al., 1998), due to a decrease in strength of the back, legs, and abdomen (Jeng, 1999). The main purpose of this study was to verify the effects of a program for trunk strength and stability on low back and pelvic kinematics during walking, as well as the effects on static postural stability in women.

Methods

Institutional approval for all phases of this study was obtained from the Committee of Ethics in Research with Humans in agreement with resolution number 196/96 in the Federal University of Santa Maria (protocol number CEP/CCS/UFSM 044/2005). Six adult women with more than 1 year of nonspecific low back pain were evaluated (mean ± SD age of 23 ± 1 years old). Subjects were excluded if they presented any of the follow criteria: history of lumbar surgery, spine abnormalities detected previously on X-ray exam, neuromuscular, joint and reflex deficits, equine tail, carcinoma, pregnancy, or radicular symptoms observed during functional evaluation.

All subjects signed a consent form for participation in the study. The subjects were evaluated in the Department of Physiotherapy and Rehabilitation of the Santa Maria's University Hospital, including low back and pelvic strength tests. A 3-D gait kinematics assessment and static postural stability evaluation before and after the period of the training were also conducted. During the period of training, the subjects refrained from participating in any other regular physical activity.

Pain and strength evaluation

Low back pain was rated on a 5–0 scale, where 5 represented 'without pain' and 0 represented 'unbearable pain' (Nusbaum et al., 2001). Specific tests for the low back region of each subject were conducted by the same physiotherapist to evaluate the voluntary mobility and evoked pain-employing tests previously described in the literature (Gross et al., 2000).

Trunk strength and stability tests were also applied to verify the strength and muscular capacity based on a protocol described in the literature (Lee, 2001; Richardson and Jull, 1992). In these tests, each position was continuously sustained for each level of movement, for 6 s or until the beginning of muscle fibrillation, which was used as indicator of local fatigue. ''Maximal capacity'' was defined when muscle fibrillation occurred and continued for three consecutive seconds. These tests were previously described by Liebenson (1998), and therefore are not fully detailed in this paper.

Kinematics evaluation

The 3-D kinematics measurement was taken to verify the angles of trunk rotation, pelvis rotation and lumbar lordosis. The 2-D kinematics measurement was employed to verify the pelvic tilt angle in the sagittal plane. The measurements were taken during three trials with two complete unshod gait cycles at a self-selected velocity. The gait was measured pre- and post-training.

Three-dimensional angular data were acquired by a video-based analysis system (Peak Motus, Peak Performance Technologies Inc., Englewood, CO) with two high-speed cameras (Peak HSC) synchronized and operating at a sampling rate of 60 Hz. The individual trials were recorded on a standard SVHS tape using VCR devices (Panasonic AG-5700, Panasonic Matsushita Electric Corporation of America, Secaucus, NJ). The Peak Motus system has an angular displacement reliability of 0.99 and measurement error of 0.5% (Scholz and Millford, 1993). The defined laboratory (global) orthogonal coordinate system (frame) followed the right-hand rule with the positive *x*-direction oriented in the direction of forward progression, the positive *y*-direction oriented to the left and the positive *z*-direction oriented vertically upwards (Gruen, 1997).

Two cameras were placed perpendicularly in relation to each other and positioned approximately 4 m from the center of the movement. The direct linear transformation method (Abdel-Aziz and Karara, 1971) was employed to obtain 3-D coordinates from 2-D data from two synchronized cameras. The raw 3-D coordinates were smoothed using a quintic spline[1] function with a smoothing factor of 0.003 (Xu et al., 2006). The markers path data were filtered using a fourth-order low-pass Butterworth digital filter with a cutoff frequency of 5 Hz (Winter, 1990).

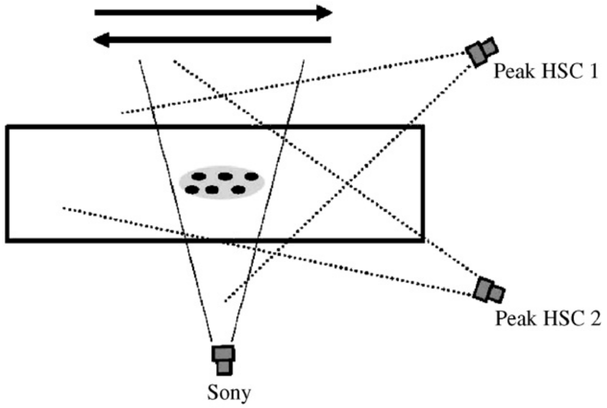

Figure 1 Camera positioning. The arrows indicate the movement orientations.

The reflexive markers for 3-D evaluation were positioned over the right and left shoulder acromions, both anterior–superior and posterior iliac spines, first and second lumbar spinous processes (L1, L2) and second sacral spinous process (S2). The L1, L2 and S2 spinous process markers were used to calculate the lumbar lordosis angle projected in the sagittal plane (Whittle and Levine, 1997). The pelvis rotation projected angle was calculated from the transverse plane based on the markers placed on the right and left posterior superior iliac spines (Vogt et al., 2003). The marker in the right and left acromions was used to calculate the trunk rotation projected angle in the transverse plane.

Due to instrumentation limitations, a third camera (DCR-VX2100E, Sony, USA) was also used, which operated at sampling rate approximately of 30 Hz to measure only the 2-D sagittal pelvis tilt angle (Vogt et al., 2003) from markers placed in the anterior and posterior right iliac spines. This third camera was synchronized with the Peak Motus System cameras by using a manual light signal that permits the analysis of the same two gait cycles for all cameras for each trial. The positioning of the cameras for data acquisition is depicted in Fig. 1.

Body balance evaluation

A biomechanical 3-D force plate (Advanced Mechanical Technology, Inc., Watertown, MA) was used to measure the center of pressure displacement (COP). The COP expresses the location of the resultant ground reaction force, which indicates the neuromuscular responses to postural stability due to changes in the position of center of gravity (Winter, 1990).

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[1] Spline describes devices used to draw smooth shapes.

The COP anteroposterior and mediolateral ranges of displacement were analyzed before and after training for the combined situations of unipedal and bipedal stance that were repeated randomly in eyes closed and eyes open situations. The testing protocol was conducted in a quiet room with data collected at sampling rate of 100 Hz via personal computer using specific software (data acquisition and offline analysis) for the biomechanical force plate (NetForce, Advanced Mechanical Technology, Inc., Watertown, MA). The subjects were instructed to stand with their feet separated at a comfortable width (about shoulder-width apart) and their arms at their sides (Duarte and Zatsiorsky, 1999). Also, they were asked to sustain their static posture continuously during the 30 s of data acquisition. Each trial was repeated three times to reduce the variability commonly observed in this type of evaluation (Corriveau et al., 2001; Lafond et al., 2004).

Program for trunk strength and stability

The trunk strength and stability training was performed over 20 individual sessions during 7 weeks (Clark and Cummings, 2002; Liebenson, 1998) on Mondays, Wednesdays and Fridays. The training sessions lasted 50 min and were always conducted by the same physiotherapist. In the beginning, the difficulty level was adjusted, based on the initial conditioning level (determined from the pre-test strength training) of each subject. Subjects progressed until their capacity to perform the exercises, with the correct technique, declined.

The exercises were based on isometric contraction of muscles of the low back, pelvis and lower limbs, with two sets of 12 repetitions, which lasted 5 s for each repetition. Before the contraction level was increased, the contraction times were increased to 10, 15 and a maximum of 20 s without muscle fibrillation. After reaching 2 sets of 12 repetitions for 20 s without fibrillation, the contraction level was increased, and the subsequent exercises in the program were applied.

The training was conducted as described by Liebenson (1998). Subjects were first taught to produce and explore lumbo–pelvic movement, and then, the subjects learned abdominal hollowing/bracing (co-contraction) in a variety of postures: sitting, quadruped, standing, supine, kneeling, and prone, as well as different degrees of inclination to control loading/gravity. Among the exercises employed:

- *Dead bug* exercises are classified as excellent endurance exercises for training postural control of the abdominal muscles.

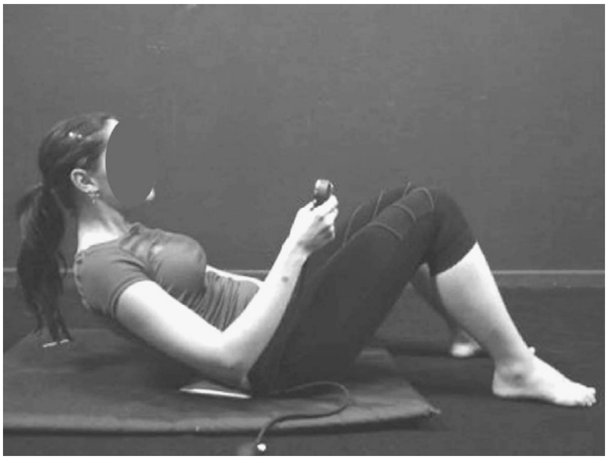

Figure 2 The curl-up exercise done on the floor with pelvic position being monitored using a sphygmomanometer.

- *Quadruped* exercises encourage postural endurance and control of the multifidi. This is facilitated by having the patient perform leg extensions.
- *Curl-ups* can be used to train either strength or torque production during trunk flexion maneuvers. Slower curls isolate transversus abdominis action, while rotations facilitate the oblique muscles action (Liebenson, 1998).
- *Resisted trunk rotation* help isolate transversus abdominis. Trunk rotation exercises were performed using Thera-Band® elastic bands, elastic tubing, and exercise balls (Hygenic Corporation, Akron ,OH, USA). Trunk rotation was also resisted through the pelvis during a bridge exercise, or in a more advanced form, by rotating the lower limbs.
- The *horizontal side support* exercises train both the deep abdominal and low back muscles.
- *Superman* exercises train the trunk extensors (Liebenson, 1998).

While these exercises can be difficult to master initially, the postural-motor control that is trained is vital for spinal stabilization during activities of daily living and occupational demands (Liebenson, 1998). While Liebenson has described these exercises, they have also been used and described by numerous Pilates Instructors, Physiotherapists and Exercise Scientists over the last 30 years. Some exercises employed in the training are illustrated in Figs. 2–7.

Statistical procedures

Pre- and post-test scores were obtained from the qualitative pain grade test and from the low back

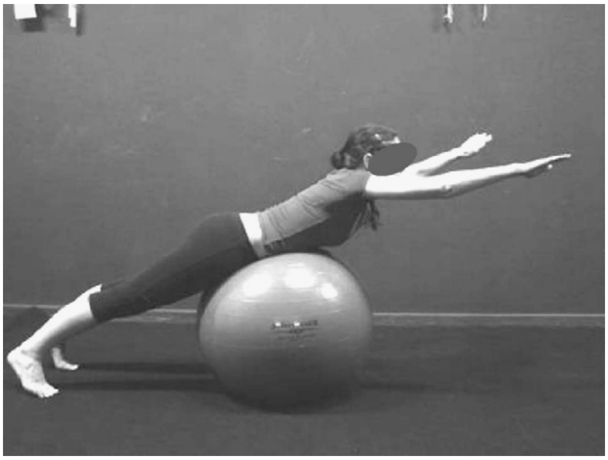

Figure 3 The exercise "superman" executed on the exercise ball.

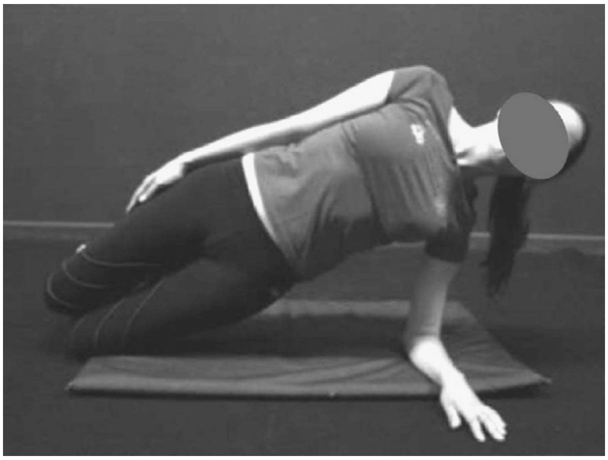

Figure 4 Example of an exercise for body elevation with horizontal side support.

Figure 5 Exercise for pelvic bridging with limb extension, without the use of an exercise ball.

Figure 6 The curl-up exercise performed on the exercise ball.

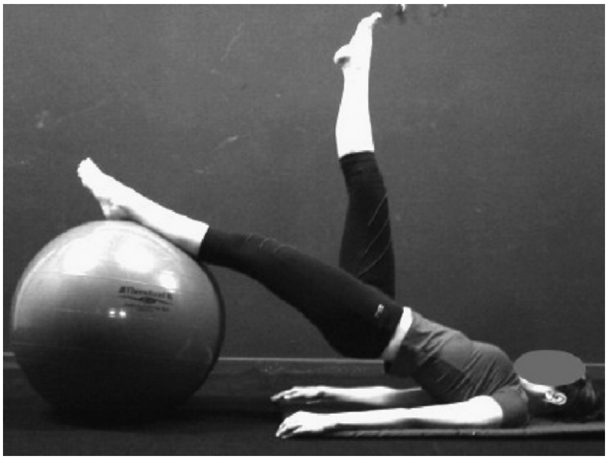

Figure 7 The pelvic bridge exercise performed on the exercise ball with hip in flexion.

and pelvic complex strength and stability tests. The kinematics and postural stability data did not follow a Gaussian curve of normal distribution (Kolmogorov–Smirnov's test), and therefore, non-parametric tests were used to analyze the data. First, all data were grouped for mean ± SD for comparison pre- and post- training using the non-parametric Wilcoxon's test. All the statistical procedures were accomplished using a computational statistical package (Statistica 5.1, StatSoft Inc., USA) with a significance level set at 0.05.

Results

Pain and strength evaluation

The results from the qualitative pain grade test indicate that the low back pain decreased after the training, whereas pelvic strength increased. Low back pain was rated on a 5–0 scale where 5 represented 'without pain' and 0 represented 'unbearable pain' (Nusbaum et al., 2001). The qualitative pain grade test was not statistically evaluated. Considering the scores observed for the classification of low back pain in the beginning of the training period and the results after the period of training, the scores were described in percentiles. Changes noted after the period of training suggest improvements of approximately 60% (±17%).

Low back and pelvis kinematics

The results of the kinematics assessment are summarized in Fig. 8 (mean and SEM). Range of motion (ROM) in the selected movements was found to be statistically different between pre- and post-training for trunk rotation ($p<0.05$) and pelvis tilt ($p<0.05$). Also, lumbar lordosis decreased significantly ($p<0.05$).

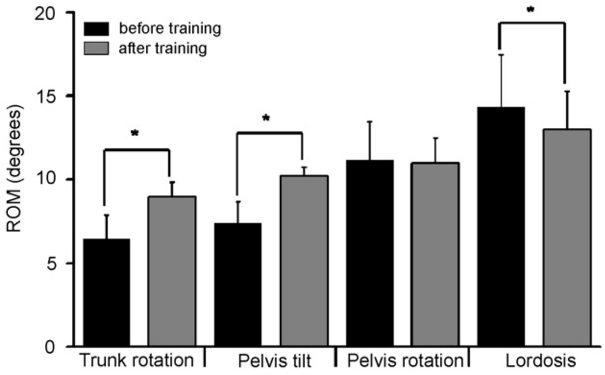

Figure 8 Range of motion (degrees) for each movement analyzed. The asterisk (*) indicates differences statistically significant between pre- and post-training ($p<0.05$).

Body balance

Table 1 provides the results from the COP anteroposterior and mediolateral range of displacement evaluated before and after the training period.

The anteroposterior COP range of displacement demonstrated a statistically significant decrease after training for both eyes opened and closed situations. When the closed eyes situation was evaluated on one leg, there were no statistically significant differences between the pre- and post-training measures. The mediolateral displacement demonstrated statistically significant decreases between pre- and post-training measures for all situations analyzed.

Discussion

This study was designed to verify the effects of a program for trunk strength and stability on low back pain, low back and pelvic kinematics during gait, and postural stability of females after 20 training sessions. The results of this pilot-study suggest that this program may decrease low back pain, improve ROM of the low back and pelvis during gait, and improve postural stability. These inferences should be further evaluated using a larger sample together with the inclusion of a control group in the experimental design.

These results are in agreement with other findings about low back pain exercise programs reported in the literature (Gladwell et al., 2006). Isolated back extensor strength training has been proven effective in the treatment of chronic musculoskeletal disorders, and therefore, it is often prescribed for patients suffering from chronic low back pain (Deutsch, 1996; Manniche et al., 1988; Frost et al., 1998). However, the effects of hip and back extensor strength training on postural

Table 1 The COP anteroposterior and mediolateral range of displacement for the situations evaluated.

Situation	Anteroposterior COP (cm)		Mediolateral COP (cm)	
	Before	After	Before	After
OE	3.39 ± 0.82	$2.52^{*}\pm0.45$	2.90 ± 1.27	$2.20^{*}\pm1.10$
CE	3.17 ± 0.61	$2.52^{*}\pm0.29$	3.11 ± 1.76	$2.15^{*}\pm0.69$
OE unipedal	7.18 ± 3.67	$5.48^{*}\pm1.43$	4.80 ± 3.02	$4.28^{*}\pm1.96$
CE unipedal	16.28 ± 3.88	16.02 ± 3.51	16.16 ± 4.86	$12.18^{*}\pm3.51$

Results expressed as mean±SEM of the three trials for each situation and subject.

OE, opened eyes; CE, closed eyes. Unipedal stay was always in the same limb throughout the trials.

*Indicates difference statistically significant between before and after training period ($p<0.05$).

stability have not been sufficiently investigated (Kollmitzer et al., 2000).

When low muscular endurance is considered to be a reason for low back pain, stabilization training may be an effective treatment strategy (Verna et al., 2002; Andersen et al., 2006), while aerobic conditioning does not necessarily seem to be related to a reduction in low back pain (Oldervoll et al., 2001).

Although not represented in the results, the low back and pelvis kinematics demonstrated an angular displacement along the gait cycle similar to normal gait (Schache et al., 2003; Vogt et al., 2003; Vogt and Banzer, 1999). For subjects with low back pain, some investigators have reported increased motion (Friberg, 1987; Lehmann and Brand, 1983), whereas others report decreased motion (Pearcy et al., 1985; Dvorak et al., 1991).

According to Panjabi (2003), changes in pelvic tilt can be related to the observed increase in trunk rotation as a result of the strengthening of the abdominal muscles. The increase in pelvic tilt ROM indicates improved mobility for the low back region with no changes in pelvic rotation. Some reasons for the aforementioned uncertainties can be attributed to the variability in the subjects' voluntary efforts to produce spinal motion, the presence of muscle spasm and pain during radiographic examination, lack of appropriate control subjects matched in age and gender, and the limited accuracy of in vivo methods for measuring motion.

The fact that suboptimal neuromuscular capacity of control occurs for low back patients can explain alterations of body balance, mainly during dynamic conditions (Panjabi, 2003). Kollmitzer et al. (2000) found decreases in postural stability in response to strength training of back extensors. In accordance with their findings, back extensor strength training may have caused a neuromuscular imbalance between the predominantly trained back and hip extensors, and the abdominal trunk and hip flexors (not trained), thus increasing open loop central control efforts to maintain body balance (Mahboobin et al., 2002). Our results indicate that training of all muscle groups of the lumbar–pelvis–hip complex, and not only the extensors, is an effective strategy to improve static postural stability and assists a return to equilibrium after perturbation (Willson et al., 2005).

The use of a hip strategy could result in a smaller mediolateral COP displacement, and also center of mass displacement, in comparison to an ankle strategy. The hip strategy involves motion at the level of the trunk and hip, and the use of horizontal shear forces resulting from torques at the hip joint, rather than the ankle joint, in order to maintain equilibrium. In contrast, an ankle strategy involves motion primarily about the ankle joint, with ankle joint torques shifting the center of vertical foot pressure, in order to maintain the body center of mass over the base of support (Henry et al., 2006). However, an improvement was also observed in anteroposterior COP displacement in this study. While trunk strength and stability training might elicit changes more related to the hip in low back pain subjects, who may be reluctant to use only a hip strategy, the employment of an ankle strategy is anticipated in an attempt to maintain, or recover, body stability (Mok et al., 2004).

The results indicate that improved body balance control may be related to a better neuromuscular control, which occurs due to an improvement in postural stability (Clark and Cummings, 2002). Neuromuscular strategies related to the hip are also important to maintain erect posture (Nashner and McColum, 1985). Therefore, trunk strength and stability programs of the lumbo–pelvis–hip complex should be considered important in improvement of body balance.

Conclusion

The results of this pilot study indicate that a program for trunk strength and stability conducted over 20 sessions was effective in reducing low back pain and improving strength of the lumbo–pelvic complex in women. In addition, trunk and pelvis ROM significantly improved and lumbar lordosis reduced, which may be related to an improved stabilization of the lumbar spine. Postural stability also improved, indicating increased effectiveness of the hip muscles in maintaining stable posture.

Acknowledgments

This study was supported by the program Thera-Band® Academy of the Hygenic Corporation, United States The authors thank Benjamin Jason Mathis for reviewing the article. Special acknowledges to Mercur® Company of Brazil, Rosana Marin, B.Sc., and Jadir Camargo Lemos, Ph.D. for their aid and support in the development of this study, and Phillip Page and Orlando Laitano for their technical reviewing of this paper.

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