

Received:

12 July 2018

Revised:

30 September 2018

Accepted:

26 November 2018

Cite as: Koichi Wakimoto,
Toshifumi Dakeshita,
Junichi Wakimoto,
Toshiaki Watanabe,
Saiki Terasawa,
Masao Okuhara, Yuki Murata,
Naoya Taki, Ryoji Uchiyama,
Kazuki Ashida,
Suchinda Jarupat Maruo,
Koji Terasawa. Effects of
triple-treatment trunk
stretching on physical fitness
and curvature of the spine.
Heliyon 4 (2018) e00985.
doi: [10.1016/j.heliyon.2018.e00985](https://doi.org/10.1016/j.heliyon.2018.e00985)



Effects of triple-treatment trunk stretching on physical fitness and curvature of the spine

Koichi Wakimoto^a, Toshifumi Dakeshita^a, Junichi Wakimoto^a, Toshiaki Watanabe^b,
Saiki Terasawa^c, Masao Okuhara^d, Yuki Murata^b, Naoya Taki^b, Ryoji Uchiyama^e,
Kazuki Ashida^e, Suchinda Jarupat Maruo^f, Koji Terasawa^{b,*}

^a SEISEN Medical Corporation, Seisen Clinic of Orthopedics, 191-1 Kakita, Shimizuchyo, Suntougun, Shizuoka 411-0904, Japan

^b Shinshu University, Faculty of Education, 6-Ro Nishinagano, Nagano City, Nagano 380-8544, Japan

^c Shinshu University Faculty of Electrical and Electronic Engineering, 4-17-1 Wakasato, Nagano City, Nagano 380-0928, Japan

^d Suwa University of Science Faculty of Engineering, Department of Applied Information Engineering, 5000-1 Toyohara, Chino City, Nagano 391-0292, Japan

^e National Institute of Technology, Nagano College, 716 Tokuma, Nagano City, Nagano 381-8550, Japan

^f Faculty of Public Health, Mahidol University, 420/1 Ratchathewi District, Bangkok, 10400, Thailand

* Corresponding author.

E-mail address: terasawa007@gmail.com (K. Terasawa).

Abstract

Background: Research on the effectiveness of treatment for low back disorders has been made, however yet no established method has been found. Therefore, we devised a triple-treatment trunk stretching program comprising the following three trunk stretching exercises: stretching using an unstable flex chair; stretching using a stretching bench; and stretching using a stretch pad. Our three-treatment trunk stretching program is based on the principles of static muscular stabilization of the spine and uses well-known physiological strength-training principles. In this study, we investigated the effects of triple-treatment trunk

stretching on physical fitness levels and curvature of the spine measured by X-ray photographs.

Methods: Thirteen healthy male subjects (mean age, 26.3 ± 4.0 years; height, 173.5 ± 4.9 cm; weight, 64.9 ± 5.7 kg; BMI 21.6 ± 1.7) were enrolled in this study. In consideration of safety and simplicity, we applied the physical fitness test introduced by the Ministry of Education, Culture, Sports, Science and Technology of Japan for 65- to 79-year-olds.

Results: Triple-treatment trunk stretching led to significant improvements in sit-and-reach flexibility, 10-m obstacle course walking time, standing forward flexion, thoracolumbar extension and horizontal flexion. Significant improvements were also observed in the neutral angle of the curvature of the lower thoracic spine and the neutral angle of the curvature of the lower lumbar spine.

Conclusions: Significant improvements were evident in the neutral angles of both the curvature of the lower thoracic spine and the curvature of the lower lumbar spine after triple-treatment trunk stretching. This suggests that triple-treatment trunk stretching can help improve the curvature of the spine and physical fitness.

Keyword: Rehabilitation

1. Introduction

The goal of physical training is to improve muscle strength, functional mobility, and motor control for better balance, coordination, and endurance. Functional stabilization training begins with identifying range of motion, particularly that of the lumbopelvic region [1]. Spinal stability is thought to be an important factor in exercise programs for individuals with healthy backs [2]. It has been observed that low back pain may be caused by deficits or errors in motor control that lead to inefficient muscular stabilization of the spine [3, 4, 5]. However, low back pain may also occur as a result of leisure time physical activity. Individuals with back pain have been reported to have impairments in muscular and connective tissue, functional limitations in muscle strength, endurance, and speed, deficits in neuromuscular function, and physical, social, and psychological disabilities [4, 6]. The primary goals of physical exercise are to prevent pain, to increase strength, flexibility, and endurance, to restore the ability to perform activities of daily living, including work activities, and sometimes, to enhance social life [7, 8]. The rehabilitative exercises utilizing mid-range oscillatory movements and end-range stretches in prone and sitting rotational movements promote a reduction in pain [1]. Bourdillon et al. found that exercises involving spine extension, side-gliding, backward bending while standing, different rotational movements, and forward bending while standing improved faulty mechanical habits and muscular imbalance in the trunk and pelvis [8]. Aquafitness programs utilize exercises in water to allow safer and more pain-free movement [9]. The effects of physical

training on the musculoskeletal system and the ability of the neuromuscular system to adapt to the speed, resistance, and duration of specific types of training have long been known [10, 11]. In the acute phase, the goals of training are to alleviate pain and promote muscle relaxation, to reduce pressure on neurological structures sensitive to pain, to promote positions and movements that reduce intradiscal pressure, and to restore spinal alignment [12]. Further clinical trial-based studies on the efficacy of treatment for low back disorders are greatly needed. Therefore, in this study, we developed a treatment program, which we call triple-treatment trunk stretching, comprising the following three trunk stretches: stretching using an unstable flex chair; stretching using a stretching bench; and stretching using a stretch pad. These three stretches are based on well-known physiological strength-training principles and utilize static muscular stabilization of the spine. Early adaptation by means of short-term core exercise programs using a physioball or a Swiss ball enhances gains in torso balance and EMG neuronal activity [13]. Sitting on unstable Swiss balls is often advocated to promote proper seated posture to prevent lower back pain by stretching consecutively contracted hip flexors and extensors to posteriorly and anteriorly rotate the hip [14]. Similarly, sitting on a flex chairs and stretching benches used for spine rehabilitation and hamstring stretches can reduce back pain [1]. The foam roller used for spine rehabilitation is an excellent tool for mobilizing the mid-back that can be used in various ways with an emphasis on increasing dorsal extension [1]. It was hypothesized that these three stretches improved the state of spinal stability and included the possibility of enhance physical performance.

The aim of this study was to investigate the effects of a treatment program using these three trunk stretches on physical fitness levels and curvature of the spine as measured by X-ray photographs.

2. Methods

2.1. Subjects

Thirteen healthy men (mean age, 26.3 ± 4.0 years; height, 173.5 ± 4.9 cm; weight, 64.9 ± 5.7 kg; BMI 21.6 ± 1.7) were enrolled in this study, which was approved by the Institutional Ethics Committee at Shinshu University (UMIN000008135) and conducted in accordance with the Helsinki Declaration of 1975, as revised in 1983. Written informed consent was obtained from all subjects prior to their participation. Consent was also obtained for the publication of this study and any accompanying images.

2.2. Design

No subject had a history of neurological, major medical, or physical disorders, and none were taking medication at the time of the study. The subjects underwent

physical fitness tests before and after triple-treatment trunk stretching. The three trunk stretches were designed to alleviate pain in the low back and hip joints and to restore normal mobility of muscles and joints. Stretching was carried out using the following equipment: an unstable flex chair (HU-800, Minato Medical Science Co. Ltd., Tokyo, Japan); a stretching bench (K2590SB, Minato Medical Science Co. Ltd.); and a stretch pad (SS-1, Minato Medical Science Co. Ltd.). All stretches were completed within six minutes. Subjects gave the same explanation to each of the thirteen subjects and performed three trials with the same time in the same order as below, one session at the same interval, and then the next physical strength measurement was performed on immediate. Each subject was capable of moving their pelvis while seated in the flex chair, and the seat could pivot in any direction (Fig. 1). After sitting in the chair, the subjects were instructed to first contract their hip flexors and extensors anteriorly and posteriorly (40 seconds), and then laterally (40 seconds), and then to rotate their hips (40 seconds). The stretching bench could be anteverted to reduce anterior pelvic tilt and relieve hamstring strain (Fig. 2). The subjects first conducted this stretching exercise with both legs (40 seconds), and then with each leg separately (40 seconds). The stretch pad was used to loosen muscles in the back (Fig. 3). The subjects lay down on the pad and breathed deeply (40 seconds). They then placed their hands at the top of their rib cage and continued breathing deeply (40 seconds). Finally, they slowly moved their hands up and down the sides of their body while breathing deeply (40 seconds).

2.3. Physical fitness tests

The average age of subjects was 26.3 ± 4.0 years, and the Ministry of Education, Culture, Sports, Science and Technology of Japan's physical fitness measurement from 20 to 64 years old had repeated lateral jump and 20 m shuttle run which may be accompanied by danger such as injury. For that reason, in consideration of safety and simplicity, we applied the physical fitness test introduced by the Ministry of Education, Culture, Sports, Science and Technology of Japan for 65- to 79-



Fig. 1. Flex chair.

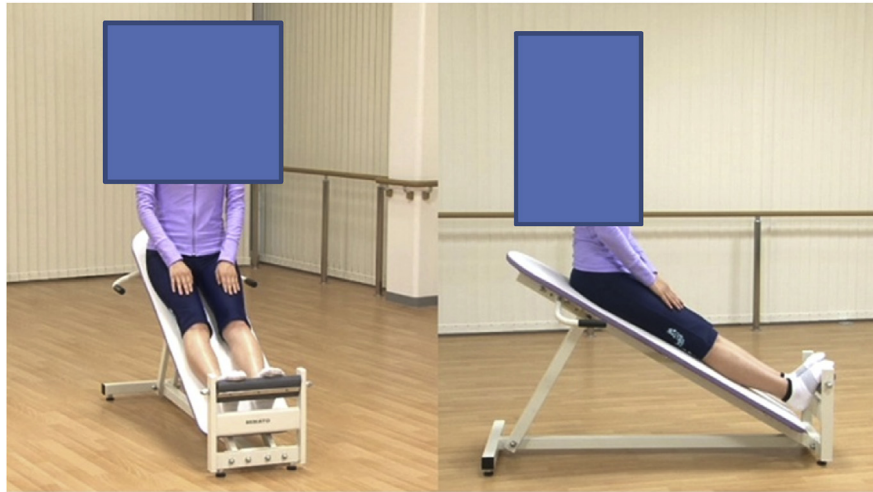


Fig. 2. Stretching bench.

year-olds. This test measures muscular strength (grip strength), muscular endurance (sit-ups), sit-and-reach flexibility, single-leg standing time, and both 10-m walking time and 6-min walking distance in an obstacle course. Most of the subjects achieved the maximum measurement time of 120 seconds in the single-leg standing test with their eyes open, so we also conducted the test while their eyes were closed. Improvements in flexibility and instantaneous power (vertical jump) were also seen in preliminary experiments with these three stretches. From this situation, the subjects also performed standing forward flexion, thoracolumbar extension, horizontal flexion and vertical jumping. Standing forward flexion was measured using an analog flexion meter (5003 FLEXION-A, Takei Scientific Instruments Co. Ltd., Tokyo, Japan). The subjects stood on a platform with the tips of their feet about 5 cm apart, held their arms out in front of their body, and then bent forward to touch a cursor plate with the middle fingers of both hands. In the thoracolumbar extension test, subjects placed their hands at their sides while standing, and tilted backwards without moving their pelvis. The basic axis was set as the rear aspect of the sacrum,



Fig. 3. Stretch pad.

and the crossing angle was measured between the basic and movement axes, which connected the first thoracic and fifth lumbar vertebrae. For the horizontal flexion test, the subjects raised their arms anteriorly until reaching 90° relative to the flexed shoulder joint. The basic axis was taken as the line perpendicular to the sagittal plane, which passed along the acromion, and the movement axis was regarded as the humerus. Vertical jumps were assessed using a jump meter (LC020267, Senoh Corporation, Matsudo, Japan).

2.4. Angle measurement of the spine

To assess the effects of triple-treatment trunk stretching on the curvature of the spine, X-ray photographs of the spinal column were taken from each side. We then measured the flexion, neutral, and extension angles of the spine on the X-ray photographs as follows: overall curvature of the thoracic spine, curvature of the upper and lower thoracic spine, curvature of lower lumbar spine, and inclination of the sacrum (Fig. 4). All measurements were conducted by three licensed physical therapists, each of whom had at least two years of clinical experience measuring angles of the spinal column.

2.5. Statistical analysis

We compared physical fitness test scores and measurements on the X-ray photographs before and after triple-treatment trunk stretching using paired t-tests. The sample was assumed to be a normal distribution, and parametric analysis was performed.

Statistical analyses were performed using SPSS 11.0.1. Statistical Packages (SPSS Inc., Chicago, USA). The significance level was set at 0.05.

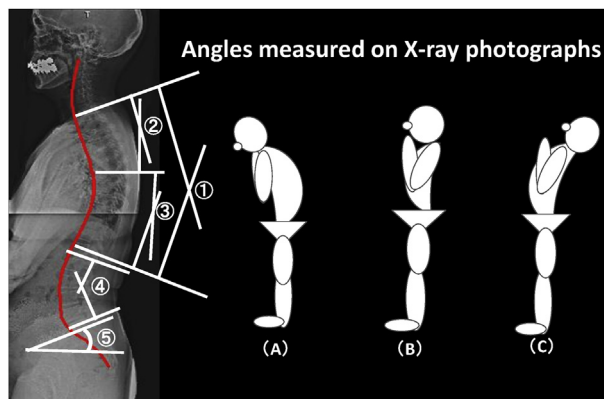


Fig. 4. Flexion (A), neutral (B), and extension (C) angles of the spine were measured on X-ray photographs as follows: ① Overall curvature of the thoracic spine; ② curvature of the upper thoracic spine; ③ curvature of the lower thoracic spine; ④ curvature of lower lumbar spine; and ⑤ angle of inclination of the sacrum.

3. Results

3.1. Physical fitness tests

Significantly improvements were seen in sit-and-reach flexibility (before vs. after: 33.8 ± 2.8 cm vs. 35.9 ± 2.8 cm, $P = 0.003$, *Power analysis*; 0.935, *Relative differences*; 2.077) and in 10-m obstacle course walking times (8.6 ± 0.4 sec vs. 8.3 ± 0.4 sec, $P = 0.035$, *Power analysis*; 0.588, *Relative differences*; 0.266) after stretching. Significant improvements were also seen after stretching in standing forward flexion (-4.7 ± 2.9 cm vs. -10.3 ± 4.1 cm, $P = 0.024$, *Power analysis*; 0.570, *Relative differences*; 5.654), thoracolumbar extension ($53.5^\circ \pm 3.6^\circ$ vs. $58.8^\circ \pm 3.5^\circ$, $P = 0.024$, *Power analysis*; 0.737, *Relative differences*; 5.385), and horizontal flexion ($127.3^\circ \pm 2.6^\circ$ vs. $132.3^\circ \pm 2.2^\circ$, $P = 0.009$, *Power analysis*; 0.817, *Relative differences*; 5.000) (Table 1). Improvements in sit-ups, single-leg standing, 6-min walking distance and vertical jumping were also evident after stretching, as was a decrease in grip strength; however, none of these differences were significant.

3.2. Angle measurement of the spine

To assess the effects of triple-treatment trunk stretching on the curvature of the spine, X-ray photographs of the spinal column were taken from each side before and after stretching. After stretching, significant differences were seen in the flexion angle of the thoracic spine (before vs. after: $70.1^\circ \pm 14.3^\circ$ vs. $74.1^\circ \pm 13.2^\circ$, $P = 0.034$, *Power analysis*; 0.577, *Relative differences*; 4.060), the neutral angle of the lower thoracic spine ($9.8^\circ \pm 6.9^\circ$ vs. $11.4^\circ \pm 7.3^\circ$, $P = 0.008$ *Power analysis*; 0.779, *Relative differences*; 1.667), the neutral angle of the lower lumbar spine ($23.3^\circ \pm 10.4^\circ$ vs. $28.8^\circ \pm 9.8^\circ$, $P = 0.001$ *Power analysis*; 0.997, *Relative differences*; 5.555) and

Table 1. Effects of stretching on physical fitness.

Physical fitness test parameter	General stretching		
	Pre	Post	P
Grip strength (kg)	50.9 ± 2.0	49.4 ± 2.1	NS
Sit-ups (n)	29.5 ± 1.4	29.8 ± 1.5	NS
Sit-and-reach flexibility (cm)	33.8 ± 2.8	35.9 ± 2.8	**
Single-leg standing (sec)	114.4 ± 3.9	115.7 ± 3.5	NS
10-m obstacle course (sec)	8.6 ± 0.4	8.3 ± 0.4	*
6-min walk (m)	503.5 ± 21.6	499.6 ± 20.8	NS
Vertical jumping (cm)	52.2 ± 2.2	54.7 ± 1.8	NS
Standing forward flexion (cm)	-4.7 ± 2.9	-10.3 ± 4.1	*
Thoracolumbar extension ($^\circ$)	53.5 ± 3.6	58.8 ± 3.5	*
Horizontal flexion ($^\circ$)	127.3 ± 2.6	132.3 ± 2.2	**

Values are shown as means \pm SD. NS: not significant, *: $P < 0.05$, **: $P < 0.01$.

the neutral angle of inclination of the sacrum ($27.3^\circ \pm 8.9^\circ$ vs. $30.8^\circ \pm 8.4^\circ$, $P = 0.001$ Power analysis; 0.959, Relative differences; 3.455) (Table 2).

4. Discussion

Mälkiä and Ljunggren reported that individuals with back pain have impairments in muscular and connective tissue, functional limitations in muscle strength, endurance, and speed, deficits in neuromuscular function, and physical, social, and psychological disabilities [4]. Physical exercises in rehabilitation rely on the ability of the neuromuscular system to provide dynamic muscular stabilization during concentric, eccentric, and isometric contractions. The objective of these exercises is to stress both damaged tissue and healthy supporting tissues in order to foster tissue repair while avoiding excessive loading [12]. Exercises for lumbar stability, core stability, and low back stability are believed to be important in physical training for maintenance of a healthy back [13].

We therefore devised a treatment program utilizing the following three types of stretches: stretching using an unstable flex chair; stretching using a stretching bench;

Table 2. Angles measured on X-ray photographs.

Angle measurements	General stretching		
	Pre	Post	<i>p</i>
Overall curvature of the thoracic spine			
Flexion	70.1 ± 14.3	74.1 ± 13.2	*
Neutral	27.2 ± 11.2	27.1 ± 9.7	NS
Extension	9.8 ± 12.3	7.7 ± 13.2	NS
Curvature of the upper thoracic spine			
Flexion	40.2 ± 16.5	42.2 ± 12.3	NS
Neutral	16.5 ± 8.6	15.9 ± 8.6	NS
Extension	8.2 ± 10.4	8.9 ± 8.6	NS
Curvature of the lower thoracic spine			
Flexion	28.0 ± 5.9	27.8 ± 5.6	NS
Neutral	9.8 ± 6.9	11.4 ± 7.3	**
Extension	1.9 ± 6.4	3.4 ± 6.2	NS
Curvature of lower lumbar spine			
Flexion	-8.4 ± 18.0	-8.7 ± 17.2	NS
Neutral	23.3 ± 10.4	28.8 ± 9.8	***
Extension	43.6 ± 12.4	42.0 ± 10.5	NS
Angle of inclination of the sacrum			
Flexion	6.1 ± 23.9	2.8 ± 25.2	NS
Neutral	27.3 ± 8.9	30.8 ± 8.4	***
Extension	44.1 ± 12.7	44.2 ± 12.7	NS

Values are shown as means ± SD. NS: not significant, *: $P < 0.05$, **: $P < 0.01$, ***: $P < 0.001$.

and stretching using a stretch pad. Triple-treatment trunk stretching is based on the principles of static muscular stabilization of the spine and uses well-known physiological strength-training principles. Stretching using an unstable flex chair is based on the same principle as physioballs [13], stability balls [15], Swiss balls [16], and gym balls and wobble boards with labile surfaces [17] in that it promotes a healthy back using extension mobilization stretches as self-treatment [1]. Stretching using a stretching bench is similar to hamstring stretching in that it promotes improved spinal stability [1]. Stretching using a stretch pad is similar to stretching using a foam roll in that it promotes improved posture and increased dorsal extension [1].

This study also compared physical fitness levels before and after triple-treatment trunk stretching. After stretching, significant improvements were seen in sit-and-reach flexibility, 10-m obstacle course time, standing forward flexion, thoracolumbar extension and horizontal flexion. Although improvements were also observed in grip strength, sit-ups, single-leg standing, 6-min walking distance and vertical jumping, none of these improvements were significant. Although triple-treatment trunk stretching was shown to be effective, the underlying reasons remain unclear. Our results from this study are in agreement with those from our former study; greater improvement was seen in physical fitness levels after triple-treatment trunk stretching was performed as a warm-up compared with standard Japanese stretching [18].

To examine the effects of triple-treatment trunk stretching on the curvature of the spine, X-ray photographs of both sides of the spinal column were taken both before and after triple-treatment trunk stretching. After stretching, no significant differences were observed in the neutral and extension angles of the thoracic spine, the flexion, neutral, and extension angles of the upper thoracic spine, the flexion and extension angles of the lower thoracic spine, the flexion and extension angles of the lower lumbar spine, and the flexion and extension angles of inclination of the sacrum; however, significant differences were seen in the flexion angle of the thoracic spine, the neutral angle of the lower thoracic spine, the neutral angle of the lower lumbar spine and the neutral angle of inclination of the sacrum. Furthermore, the flexion angle of the thoracic spine, the neutral angle of the lower thoracic spine, the neutral angle of the lower lumbar spine and the neutral angle of inclination of the sacrum were significantly increased after triple-treatment trunk stretching. This suggests that triple-treatment trunk stretching improved both the curvature of the spine and physical fitness levels, possibly due to the resulting increased angles of the spine as demonstrated by X-ray photographs. It is shown that an increased spinal curvature is associated with greater vertebral stress, intradiscal pressure, low back pain, and disability [19]. However the curvature of the spinal column is made to be dynamically suited to support the body [20]. Therefore, it is considered that there is spinal curvature in an appropriate state. Depending on its appropriate circumstances suggest that triple-treatment trunk stretching led to significant improvements in sit-and-

reach flexibility, 10-m obstacle course walking time, standing forward flexion, thoracolumbar extension and horizontal flexion.

5. Conclusions

In this study, we conducted a program utilizing triple-treatment trunk stretching using an unstable flex chair, a stretching bench, and a stretch pad.

We then compared the effects of triple-treatment trunk stretching on physical fitness levels and curvature of the spine. The effects of triple-treatment trunk stretching on curvature of the spine were assessed by X-ray photographs of both sides of the spinal column taken both before and after stretching.

Regarding physical fitness, significant improvements were seen in sit-and-reach flexibility, 10-m obstacle course walking time, standing forward flexion, thoracolumbar extension and horizontal flexion after stretching.

Regarding curvature of the spine, X-ray photographs showed significant increases in the neutral angles of the lower thoracic spine and the lower lumbar spine after triple-treatment trunk stretching. This suggests that triple-treatment trunk stretching promoted improvement in both physical fitness levels and the curvature of the spine possibly due to the resulting increased angles of the spine.

Declarations

Author contribution statement

Koichi Wakimoto, Koji Terasawa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Toshifumi Dakeshita, Junichi Wakimoto: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Toshiaki Watanabe, Masao Okuhara, Yuki Murata, Naoya Taki: Performed the experiments; Analyzed and interpreted the data.

Saiki Terasawa: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ryoji Uchiyama, Kazuki Ashida, Suchinda Jarupat Maruo: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Funding statement

This work was supported by a research grant from the Preventive Medical Center of Shinshu University Hospital and the Ministry of Education, Culture, Science and

Technology of Japan. Koji Terasawa was supported by a Grant-in-Aid for the Scientist (Houga: 26560380, Kiban A: 16H02713) from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

- [1] L. Craig, *Rehabilitation of the Spine. A Practitioner's Manual*, 1996, pp. 407–459.
- [2] S.M. McGill, A. Childs, C. Liebenson, Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database, *Arch. Phys. Med. Rehabil.* 80 (1999) 941–944.
- [3] P.W. Hodges, C.A. Richardson, Inefficient muscular stabilization of the lumbar spine associated with low muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis, *Spine* 21 (1996) 2640–2650.
- [4] E. Mälkiä, A.E. Ljunggren, Exercise programs for subjects with low back disorders, *Scand. J. Med. Sci. Sports* 6 (1996) 73–81.
- [5] S.M. McGill, Low back stability: from formal description to issues for performance and rehabilitation, *Exerc. Sport Sci. Rev.* 29 (2001) 26–31.
- [6] I. Lindström, C. Ohlund, C. Eek, L. Wallin, L.E. Peterson, W.E. Fordyce, A.L. Nachemson, The effect of graded activity on patients with subacute low back pain: a randomized prospective clinical study with an operant-conditioning behavioral approach, *Phys. Ther.* 72 (1992) 279–293, discussion 291–293.
- [7] C.B. Lewis, T. McNeerney, *Exercise Handouts for Rehabilitation*, Williams & Wilkins, Baltimore, MD, 1993, pp. 153–222.
- [8] J.F. Bourdillon, E.A. Day, M.R. Bookhout, *Spinal Manipulation*, Butterworth-Heinemann, London, 1992, pp. 313–354.
- [9] S.M. LeFort, E.T. Hannah, Return to work following an aquafitness and muscle strengthening program for the low back injured, *Arch. Phys. Med. Rehabil.* 75 (1994) 1247–1255.

- [10] K. Häkkinen, P.V. Komi, Electromyographic changes during strength training and detraining, *Med. Sci. Sports Exerc.* 15 (1983) 455–460.
- [11] C. Kisner, L.A. Colby, *Therapeutic Exercise: Foundations and Techniques*, F. A. Davis, Philadelphia, PA, 1990, pp. 473–497.
- [12] H.A. De Vries, Evaluation of static stretching procedures for improvement of flexibility, *Res. Q. Exerc. Sport* 33 (1962) 222–229.
- [13] L.M. Cosio-Lima, K.L. Reynolds, C. Winter, V. Paolone, M.T. Jones, Effects of physioball and conventional floor exercises on early phase adaptations in back and abdominal core stability and balance in women, *J. Strength Condit Res.* 17 (2003) 721–725.
- [14] D.G. Behm, A.M. Leonard, W.B. Young, W.A. Bonsey, N. Mackinnon, Trunk muscle electromyographic activity with unstable and unilateral exercises, *J. Strength Condit Res.* 19 (1) (2005) 193–201.
- [15] J.M. Carter, W.C. Beam, S.G. McMahan, M.L. Barr, L.E. Brown, The effects of stability ball training on spinal stability in sedentary individuals, *J. Strength Cond. Res.* 20 (2006) 429–435.
- [16] I.R. Scott, A.R. Vaughan, J. Hall, Swiss ball enhances lumbar multifidus activity in chronic low back pain, *Phys. Ther. Sport* 16 (2015) 40–44.
- [17] F.J. Vera-Garcia, S.G. Grenier, S.M. McGill, Abdominal muscle response during curl-ups on both stable and labile surfaces, *Phys. Ther.* 80 (2000) 564–569.
- [18] S. Tokimasa, K. Wakimoto, T. Dakeshita, H. Tabuchi, S. Misaki, S. Osawa, M. Okuhara, K. Terasawa, Exercise based on flexibility of the trunk improves physical fitness and cognition, in: *Paper Presented at: 21st IUHPE World Conference on Health Promotion, Pattaya Thai, 2013; Aug.*
- [19] V. Luca, M. Francesco, Z. Fabio, G. Manuela, N. Stefano, C. Paolo, Effect of obesity and low back pain on spinal mobility: a cross sectional study in women, *J. NeuroEng. Rehabil.* 7 (2010 18) 3.
- [20] J.E. Macintosh, N. Bogduk, The biomechanics of the lumbar multifidus, *Clin. Biomech.* 1 (1986) 205.