Nejc Šarabon[1]*
Polona Palma[2]
Rok Vengust[3]
Vojko Strojnik[4]

EFFECTS OF TRUNK FUNCTIONAL STABILITY TRAINING IN SUBJECTS SUFFERING FROM CHRONIC LOW BACK PAIN: A PILOT STUDY

UČINKOVITOST SENZORIČNO-MOTORIČNE STABILIZACIJSKE VADBE TRUPA PRI PACIENTIH S KRONIČNO BOLEČINO V LEDVENEM DELU HRBTENICE: PILOTSKA ŠTUDIJA

ABSTRACT

The aim of our study was to examine the effectiveness of sensory-motor trunk stability training for patients with chronic low back pain. Ten volunteers (three male, seven female; 47.7 ± 8.1 years), suffering from chronic low back pain, undertook eight weeks of guided trunk stability training. Flexibility, strength and subjective self-evaluation measures were measured before and after the training. The subjects were generally very satisfied with the exercise programme (8 out of 10). After the training, the Oswestry Questionnaire totals as well as pain levels decreased ($p < 0.01$). The strength tests showed a significant improvement in the trunk flexors and lateral trunk flexors ($p < 0.001$ and $p < 0.05$, respectively). The flexibility tests indicated an improved maximal range of motion for hip flexion and extension ($p < 0.05$ and $p < 0.01$, respectively). Our data suggest that the neuro-muscular control of patients with chronic low back pain can be changed by undertaking systematic trunk stability training.

Key words: low back pain, chronic, kinesiotherapy, training effects

IZVLEČEK

Namen študije je bil preveriti učinkovitost senzorično-motorične stabilizacijske vadbe za trup pri pacientih s kronično bolečino v ledvenem delu hrbtenice. Deset prostovoljcev (3 moški, 7 žensk, 47,7±8,1 let), s kronično bolečino v ledvenem delu hrbtenice, je izvajalo osemtedenski program vadbe za funkcionalno stabilnost trupa. Vadba je potekala pod strokovnim nadzorom. Pred in po vadbi so bili izmerjeni testi moči, gibljivosti in subjektivne mere samovrednotenja. Splošno zadovoljstvo pacientov z vadbenim programom je bilo zelo visoko (8 od 10). Po vadbi sta se statistično značilno izboljšali oceni bolečine ter rezultat Oswestry vprašalnika (p<0,01). Testi moči so pokazali značilen napredek v moči upogibalk in bočnih upogibalk trupa (p<0,001 in p<0,05). Značilno se je povečala gibljivost upogibanja in iztegovanja kolčnega sklepa (p<0,05 in p<0,01). Rezultati raziskave dokazujejo, da s sistematično vadbo funkcionalne stabilizacije trupa lahko vplivamo na mehanizme živčno-mišičnega nadzora pri pacientih s kronično bolečino v križu.

Ključne besede: bolečina v križu, kronična, kinezioterapija, učinki vadbe

[1]*Univesity of Primorska, Science and Research Centre, Koper*
[2]*University College of Health Care, University of Ljubljana, Ljubljana*
[3]*Department of Orthopaedic Surgery, University Medical Centre, Ljubljana*
[4]*Faculty of Sport, University of Ljubljana, Ljubljana*

*Corresponding author:
University of Primorska, Science and Research Centre
Institute for Kinesiological Research
Garibaldijeva 1
6000 Koper
Tel.: +386 40 429 505
E-mail: nejc.sarabon@zrs.upr.si

INTRODUCTION

Low back pain (LBP) is a major health problem in industrial countries and is responsible for high costs related to treatment, work absences and disability. LBP affects over 80% of people (Gauthy, n.d.) at some point in their lives and its chronic manifestation represents a complex bio-psycho-social problem. Eighty-five percent of LBP cases have an unidentifiable cause (McGill, 2007). The biomechanical risk factors for LBP include: prolonged static posture (Marras et al., 1993; McGill, 1997; Punnett, Fine, Keyserling, Herrin, & Chaffin, 1991), sedentary work (Liira, Shannon, Chambers, & Haines, 1996), frequent bending with rotations (Andersson, 1981; Marras et al., 1995; Punnett et al., 1991; Snook, 1982), lifting, pulling and pushing (National Institute for Occupational Safety and Health, 1981), vibrations, especially in a sedentary position (Pope, 1989) and muscular weakness. Among the psychosocial characteristics significantly correlating with the frequency of LBP the following are worth noting: dissatisfaction with one's job (Bigos et al., 1986; Marras et al., 1993), an unpleasant climate at the workplace, a lack of understanding of one's colleagues and a low education level (Norman et al., 1998) as well as anxious states and depression (Iles, Davidson, & Taylor, 2008). Beside the two abovementioned groups of factors, some other individual characteristics influence the incidence of LBP such as gender, age (O'Donoghue, Fox, Heneghan, & Hurley, 2009), smoking (Cholewicki & McGill, 1996), obesity (Leboeuf-Yde, 2000) and shortening of the muscles, particularly the hip and knee flexors, as well as ligament laxity (Primožič & Turk, 2008).

These days therapeutic training to ease LBP is very heterogeneous and varies considerably with the type, intensity, frequency and duration of training. The basic purpose is to improve the posture, release muscle cramp, improve the intensity, strength and endurance of the trunk muscles as well as increase general aerobic physical fitness (Quittan, 2002). Many flexion exercises which are routinely applied in LBP treatment have been proven to cause an unfavourable biomechanical loading (Callaghan, Gunning, & McGill, 1998). Yet other exercises give preference to executing a posterior pelvis tilt which also adds to the possibility of irritation. Probably the most comprehensive study about the potential of movement therapy in the treatment of non-specific chronic LBP was carried out by Hyden et al. (2005). In their meta-analytical review they summarise that the most effective exercises for improving pain and function in adults with chronic LBP are stretching and strengthening, respectively. In addition, they show that supervised individually tailored programmes have the best outcomes. However, a limitation of the mentioned study is that the analysis did not include balance and stability exercises as a separate specific entity of the movement therapy.

Alaranta et al. (1995) established that muscle endurance is more important for protecting the lumbar region than strength alone. Likewise, for a long time it was considered that good flexibility of the lumbar region is very important; however, Biering-Sørensen (1984) proved that it can only intensify problems, not diminish them. Subsequent research has proven that LBP can be mitigated with appropriate training, primarily of the local stabilisers which ensure better stability of the spine, and also emphasised that muscle recovery is not spontaneous even when the pain disappears (Hides, Jull, & Richardson, 2001; Hides, Richardson, & Jull, 1996; O'Sullivan, Phyty, Twomey, & Allison, 1997). Therefore, rehabilitation must focus on boosting strength and endurance as well as on the correct time activation of the local and global trunk stabilisers. This study thus aimed to examine the effectiveness of trunk functional stability training for patients suffering from LBP, which also includes therapeutic exercises for maintaining trunk control

in dynamic activities on a stable and unstable support platform. Unlike previous studies in which standard balance exercises were primarily used (i.e. sustaining postures while standing on an unstable surface) the exercise programme used in this study was based on the theoretical principles known from neuromuscular control that are relevant to LBP. Therefore, more than half the exercises included sudden voluntary movements or mechanical perturbations of the distal parts of the body, thereby activating the lower back automatic stabilising neuromuscular actions. This conceptually different exercise approach was the main novelty of this study.

METHODS

Subjects

The study included 10 volunteers (three female and seven male; age: 47.7 ± 8.1 years; body height 166.0 ± 9.1 cm; body weight 68.3 ± 13.9 kg) suffering from chronic non-specific pain in the low-back/lumbar spinal region. Chronic pain was defined as either: (i) persistent pain lasting for over three months, without any marked cyclic changes; or (ii) pain with regular cyclic exacerbations at least twice a year, not shorter than one week each time. The exclusion criteria included acute LBP and diagnosed acute post-traumatic conditions. The selection of subjects eligible for the experiment was made by an orthopaedist specialist who also invited them to take part in the research. The subjects were instructed not to take any painkillers during the course of the study, although no other instructions about the medication were given to the subjects.

The research was approved by the Medical Ethics Committee of the Republic of Slovenia and was conducted in accordance with the Helsinki Declaration and the Oviedo Convention.

Training Programme

A classic research approach was applied to establish the effects of the training, including the initial measurements, the period of kinesiotherapeutic intervention and final measurements. The training was supervised by two physiotherapists and took place eight weeks in a row, with sessions scheduled in even intervals twice a week. Each individual training session consisted of a general warm-up (10 minutes), the main part (35 to 60 minutes) and a cool-down (5 minutes). It was organised as circuit training (eight stations) and was based entirely on functional stability exercises using two fundamental approaches: (i) "bottom-to-top" where trunk stability responses are triggered by means of an unstable standing surface; and (ii) "top-to-bottom" where trunk stability responses are triggered by abrupt movements or unexpected disturbances of the upper limbs. In both exercises conducted according to the first principle, the focus on maintaining balance was used once and the focus on establishing balance once. The methods for increasing the level of difficulty were defined in advance for each station and thus enabled individualisation in terms of a person's pace of progress throughout the entire training period. Besides the increased intensity, the training volumes were also increased gradually (from three to four circuits, from 30 s to 50 s of the active phase and from 60 s to 40 s of rest between the stations). One circuit consisted of the exercises presented in Figure 1.
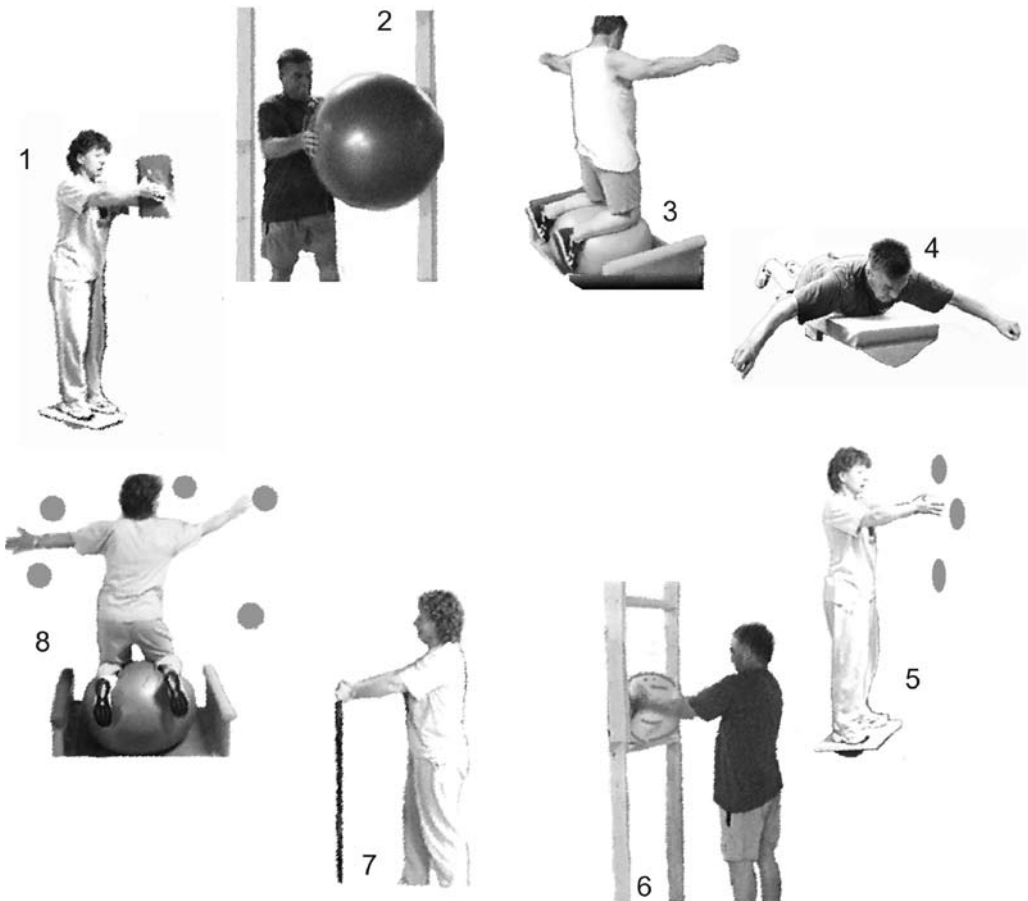
Figure 1. The exercise programme based on the circuit training encompassed: (1) maintaining equilibrium while standing on a balance board with passively extended knees / [intensity progression according to individual needs] decreasing compliance of the floor, changing tilt-board for a wobble-board and progressive elimination of vision; (2) fast swinging/striking movements with a big therapeutic ball in a horizontal direction / increasing the frequency of punches and increasing the power of punches; (3) maintaining balance kneeling on a therapeutic ball / widening the roll-restrictors, increasing ball inflation pressure and vision manipulations; (4) active balancing lying prone on a large tilt board / decreasing compliance of the floor and increasing extreme amplitudes of the tilt; (5) dynamic body weight shift during maintaining equilibrium while standing on a balance board with passively extended knees / decreasing compliance of the floor, changing tilt-board for a wobble-board and increasing the distance for reaching; (6) fast swinging/striking movements with a big therapeutic ball in a vertical direction / the same as exercise no. 2; (7) shoulder flexion against an elastic load with superimposed unexpected perturbations of the pulling force done by a therapist; and (8) dynamic body weight shift during balancing kneeling on a therapeutic ball / widening the roll-restrictors, increasing the ball inflation pressure and increasing the distance for reaching.

Measurements and Data Processing

To monitor the effects of the training, the initial and final testing included 11 measurement procedures in total. The experienced measurers were the same on both occasions and ensured they were as consistent in their testing procedures as much as possible. The tested areas and the specific tests were the following:

- *Maximal force of static voluntary contraction tests.* All the tests were performed in static conditions and a subject was asked to gradually develop the maximal force and sustain it for 2 to 3 s. Static conditions were assured using tightly fixed straps that were regularly checked. A subject was verbally encouraged during the maximal voluntary contractions in order to achieve high motivation and maximal effort. Before the measurement started, each subject performed two preliminary trials to become accustomed to the test. Using a strain gauge based load cell (HBM, Darmstadt, Germany) and the accompanied data acquisition unit (1000 Hz sampling rate; National Instruments, Huston, Texas, USA) the data were captured by a PC and quantified online. The maximal average force on a 1 s time interval was calculated. A subject performed three repetitions of the same task (separated by a 20 to 30 s rest interval) and the repetition during which the highest force was achieved was included in further analysis. The static strength tests used in the initial and final measurements were:
  - ○ strength of the trunk flexors (TR-FL-S) tested in an upright standing position;
  - ○ strength of the trunk lateral flexors (TR-LFL-S) tested in an upright testing position,;
  - ○ strength of the hip flexors (HI-FL-S) tested in a prone lying position; and
  - ○ strength of the hip extensors (HI-EX-S) tested in a supine lying position.

- *Passive flexibility tests.* In the whole range of motion tests the movement of the tested body part was performed passively; either by a subject himself/herself or by the measurer. Standard clinical testing procedures were used (Jakovljević & Hlebš, 2008). The subject was instructed to relax during this maximal amplitude movement. Each test was performed three times and the best result was used in later statistical analysis:
  - ○ lumbar trunk flexion flexibility (TR-FLL-F) tested by the Schober test for the L5-T12 region of the spine, using a tape measure;
  - ○ lumbo-thoracic trunk flexion flexibility (TR-FLLT-F) tested by the Schober test for the L5-C7 region of the spine, using a tape measure;
  - ○ trunk lateral flexion flexibility (TR-LFL-F) tested as the middle finger-to-floor vertical distance measured by a tape measure, during the lateral flexion in an upright standing position;
  - ○ hip flexion with knee extended flexibility (HI-FL-F) tested in a supine lying position with the pelvis fixation, using a standard goniometer (EZ Read Jamar, Sammons Preston, Mississauga, Canada); and
  - ○ hip extension flexibility (HI-EX-F) tested in a prone lying position with the pelvis fixation, using the same standard goniometer as for HI-FL-F.

- *Patients' subjective self-evaluations:*
  - ○ total score of the Oswestry Questionnaire (Oswestry) (Niskanen, 2002);
  - ○ pain grading on a 10-level analogue visual scale (Pain); and
  - ○ the patient's personal satisfaction with the training programme (Satisfaction).

The data were processed using the SPSS 16.0 statistical software (IBM, Chicago, Illinois). The statistical significance of the training effects was established using a one-way t-test for paired samples where the absolute values of individual tests (pre-post training) were applied.
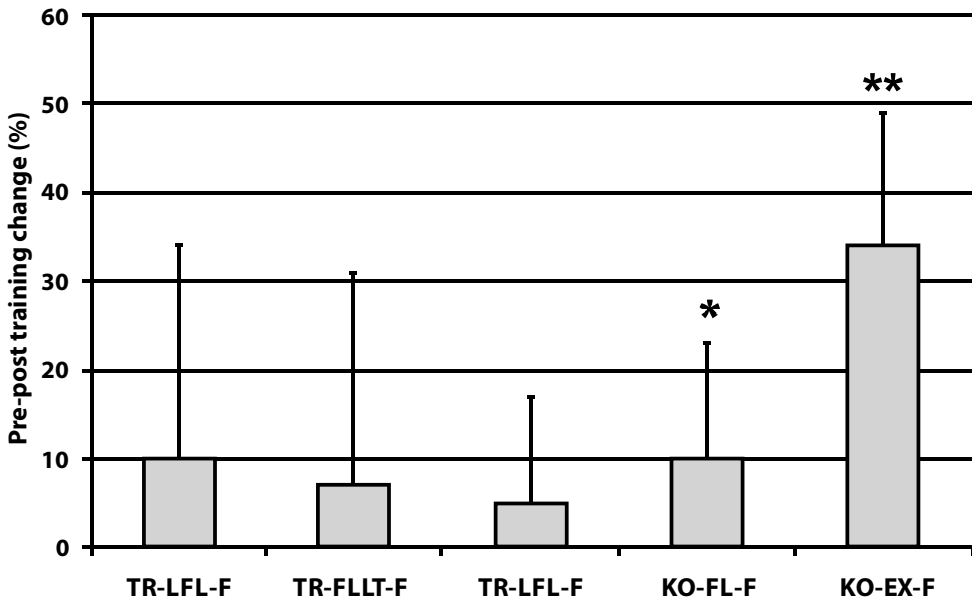
RESULTS

The changes in the strength tests, expressed in relative terms, are shown in Graph 1. The post-training increase in TR-FL-S ($42 \pm 15\%$) and TR-LFL-S ($33 \pm 25\%$) was statistically significant ($p < 0.01$ and $p < 0.001$, respectively), whereas HI-HL-S and HI-EX-S remained practically unchanged.
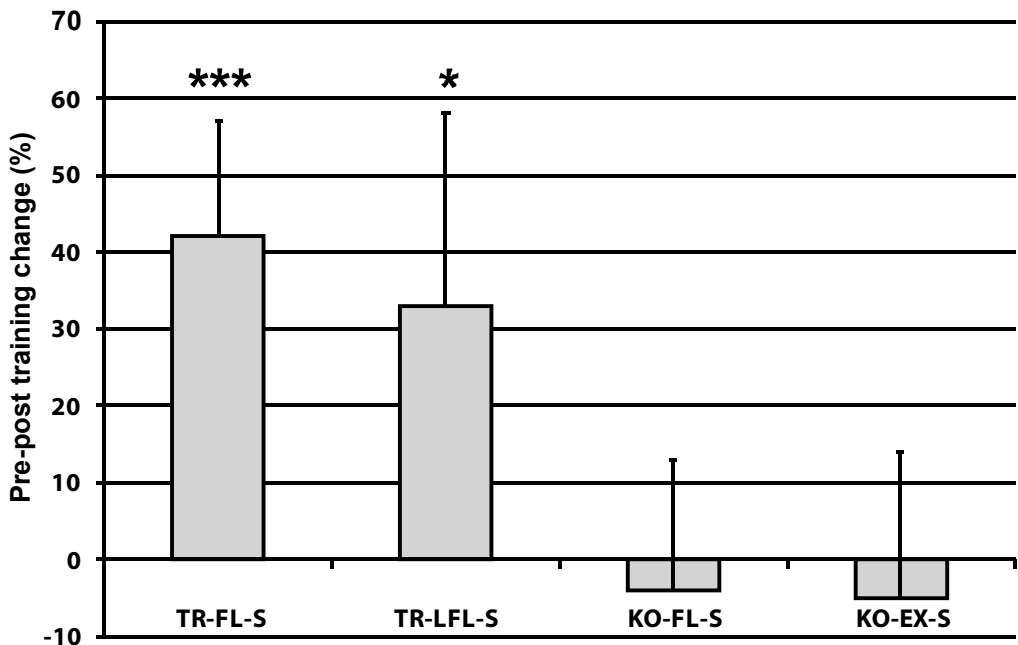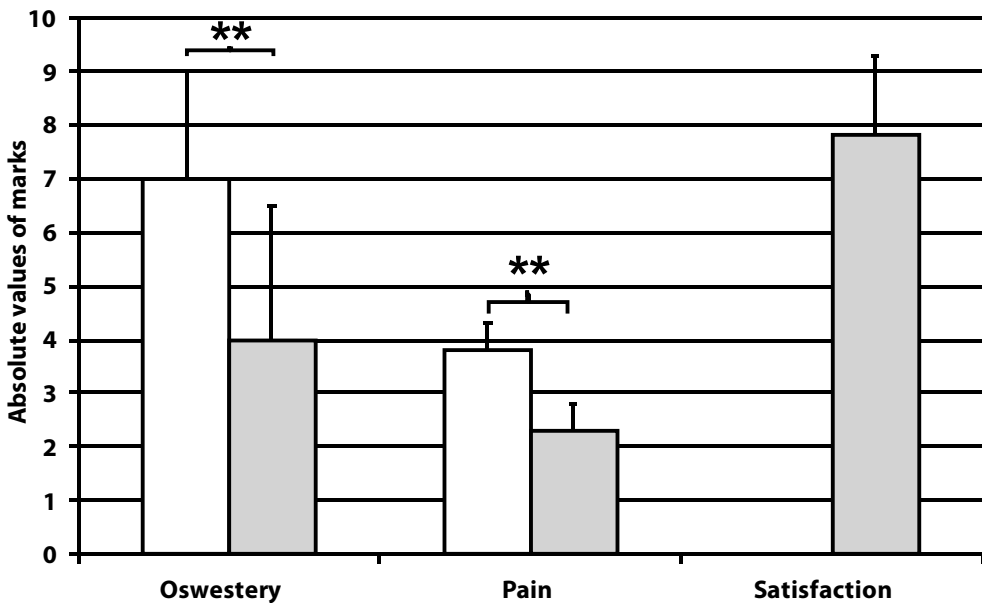

Graph 1. Relative changes in results of the strength tests (average ± standard deviation). Level of the t-test statistical significance is identified as * - $p < 0.05$, ** - $p < 0.01$ and *** - $p < 0.001$. For abbreviations of the tests, see the Methods section.

The changes in the flexibility tests, expressed in relative terms, are shown in Graph 2. The changes in the results of the tests of the lumbo-thoracic area (TR-FLL-F, TR-FLLT-F and TR-LFL-F) were not statistically significant, whereas HI-FL-F and HI-EX-F statistically significantly increased ($p < 0.05$ and $p < 0.01$, respectively).

The results of the subjective evaluation of the training programme's effectiveness and the subjects' satisfaction with it are shown in Graph 3. From the overall perspective (organisation, contents, expert support, motivation etc.), the subjects were highly satisfied (7.8 ± 1.5 points out of 10). The sum total of the points of the Oswestry decreased statistically significantly (7.1 ± 2.2 to 4.0 ± 2.5; $p < 0.01$), along with the LBP grading on a visual pain scale (3.8 ± 0.5 to 2.3 ± 0.5; $p < 0.01$).

Graph 2. Relative changes in results of the flexibility tests (average ± standard deviation). Level of the t-test statistical significance is identified as * - $p < 0.05$, ** - $p < 0.01$ and *** - $p < 0.001$. For abbreviations of the tests, see the Methods section.

Graph 3. Results of the subjective self-evaluation of the training effects (average ± standard deviation) for pre- (white bars) and post-training (hatched bars). Level of the t-test statistical significance is identified as * - $p < 0.05$, ** - $p < 0.01$ and *** - $p < 0.001$. For abbreviations of the tests, see the Methods section.

DISCUSSION

The eight-week training programme used in this study contributed to an improvement of trunk strength and passive hip flexibility in the patients suffering from non-specific chronic LBP, whereas the hip strength and passive trunk flexibility remained unchanged. Concurrently, the results of the clinical questionnaire and the pain evaluation improved.

Instability of the lumbar spine and/or lumbo-pelvic area is characteristic of people suffering from LBP (Friberg, 1987). The spine stabilising system consists of three functionally interdependent sub-systems: passive (vertebrae, facet articulations, intervertebral discs, spinal ligaments and joint capsules), active (muscles) and control (neural structures) (Panjabi, 1992). The muscles contributing to spine and pelvis stabilisation can be divided into local stabilisers attached directly to the lumbar vertebrae and maintaining segmental stability, and global stabilisers linking the pelvis and the thorax and maintaining general trunk stability. The local active stabilisers (m. transversus abdominis and m. multifidus) are responsible to a greater extent for intersegmental stability and control of the position of lumbar segments (Bergmark, 1989). With people suffering from LBP a change occurs in the function of local stabilisers. The major changes in the function of m. transversus abdominis are as follows: a delayed contraction reducing the vigour of the spine at the beginning of movement (Hodges & Richardson, 1996), a higher activation threshold i.e. it only activates before abrupt movements (Richardson, Jull, & Hodges, 1999), a specifically directed contraction (Hodges & Richardson, 1996), a loss of independent control as its activation is delayed compared to other superficial trunk muscles (Hodges & Richardson, 1998), and tonic activation becomes phasic (Hodges & Richardson, 1996). The dysfunction of m. multifidus is reflected in a reduced activation resulting in decreased muscle support and protection (Sihvonen, Partanen, Hänninen, & Soimakallio, 1991), higher fatigability (Biedermann, Shanks, Forrest, & Inglis, 1991), atrophy of type II muscle fibres and a change in the composition of type I muscle fibres (Rantanen et al., 1993) as well as a reduction of the cross-section of muscle at the location of the pain (Hides et al., 1996).

The training programme used in our study primarily aimed to stimulate the automated neuromuscular stabilisation actions of the trunk which, as mentioned above, have changed due to LBP. The exercises were selected so as to stimulate either the reflex or the anticipation activation of the deep trunk stabilisers. Stemming from basic neurophysiological principles according to which a more pre-activated muscle shows greater responsiveness in terms of extension reflex, and based on the findings of other LBP studies (McGill, 2007), we put a strong emphasis on the quality of the performance of the exercise and highlighted the importance of maintaining the active stabilisation of the neutral spine position. This was used as a base which was supplemented by concurrent movements with arms and legs while standing/kneeling/lying on an unstable surface so as to trigger automatic equilibrium reactions of the trunk.

In our case, the relatively prolonged execution of an individual exercise (30 to 50 s) at the training stations was to some extent a stimulus for the development of muscle strength endurance. The bulk of classic strength endurance training methods suggest 20 to 30 repetitions in one series (Ušaj, 2008) which, given that the pace is uninterrupted and constant, equals roughly the duration of the loadings in our study. By choosing a circuit training organisation where the loading intervals dynamically alternate with loading-free intervals, we concurrently affected the general anaerobic-aerobic endurance whose indirect significance is also supported in the literature (Quittan, 2002). Our test battery included tests of the static strength and passive flexibility of both the

trunk and the hip, considering that the legs are linked with the spine through the pelvis, thus forming an integral functional complex. That is why we wanted to monitor the key segments of the complex. Even though our training contents required quite comprehensive activity, the trunk muscles groups were engaged most intensely. With chronic LBP these muscles are the weakest due to a lack of activity (Hides, Stokes, Saide, Jull, & Cooper, 1994). Hence, the results showing progress in the trunk strength were expected, but not those related to the hip. During the most intense muscle contraction in static conditions (maximum static strength) the trunk flexors progressed the most. McGill et al. (2003) concluded that, in terms of muscle strength, the ratio between the trunk flexors and extensors is the most important, not the absolute values of the former or the latter. It has been shown that, as a rule, the trunk flexors are nearly always too weak and that optimisation of the abovementioned ratio should be achieved by increasing the flexor strength. Even though our study did not measure the trunk extensors' strength, it can be assumed that this considerable progress in TR-FL-S contributed to the occurrence of a more favourable muscle ratio as mentioned above. It should also be highlighted that even if our study did not directly measure muscle endurance, other studies have shown a correlation between progress in maximum strength and strength endurance (Popadic Gacesa et al., 2009) which leads us to conclude that the improvement in the clinical picture of the subjects in our study was to some extent a consequence of their improved muscle endurance. The latter plays an important role in the prevention and cure of LBP (Alaranta et al., 1995; Holmström, Moritz, & Andersson, 1992; McGill et al., 2003; Nicolaisen & Jørgensen, 1985).

In kinesiotherapeutic LBP treatment, spine stability must first be achieved and the strength and endurance of trunk muscles improved; only then can the trunk flexibility training be implemented. In view of the fact that our training programme intentionally left out passive stretching elements, we concluded that the increased range of hip movement was an indirect consequence – through a decrease in pain and protective spasms, and the resulting ability of the patient to relax. Namely, both HI-FL-F and HI-EX-F trigger an extension of the muscle groups (the former hamstring and the latter m. iliopsoas) linked with proximal attachments to the lumbo-pelvic area of the skeleton. Thus, the two tests can cause a mechanical loading on the sensitive segment and evoke pain, resulting in a smaller range of movement than in the absence of such a stimulus. Moreover, in the training programme and in everyday activities the patients performed movements mainly in the hip joint and not in the lumbar spine area which had to be in a neutral position to reduce pressure on the spine. Contrary to the increased flexibility of the hip, the subjects in our study preserved the same level of trunk flexibility as before the training. This was one of our goals since previous studies have established some negative effects of an increase in passive spine flexibility in people suffering from chronic LBP (Biering-Sørensen, 1984; Nachemson, 1992). Moreover, Williams et al. (2000) proved that back extension and flexibility training can weaken the extension reflex which may trigger a muscle spasm as a protective mechanism, and this again leads to pain symptoms.

In our case, the functional stability training obviously led to some favourable functional adjustments of the neuromuscular system which was reflected in the results of the strength and flexibility tests. Consequently, the clinical picture improved and that is often the most important thing for the subjects in our study. The Oswestry Questionnaire in which the subjects in our study answer questions related to limitations in their daily activities and the presence of pain in these activities etc. showed a statistically significant improvement. The self-evaluation of pain using an analogous visual scale also decreased statistically significantly. The subjects were highly

satisfied with the training and this was, beside the achieved results, due to the good organisation of the training with expert guidance and because the training itself was varied, interesting and motivating.

Successful training programmes focus on maintaining trunk stability using exercises which keep the spine in a neutral position while movements are performed in the knees and hips (Cholewicki, McGill, & Norman, 1991; Hides et al., 2001; Koumantakis, Watson, & Oldham, 2005a, 2005b; Saal & Saal, 1989). The kinesiotherapeutic approaches used in our study are original and stem from some basic principles of motor control and biomechanics which are also briefly presented in this article. The results of this study suggest that the presented trunk stability training approach could be a promising way that could find a place in the comprehensive physiotherapeutic treatment of patients suffering chronic LBP. However, the outcomes of this pilot study are certainly limited because of the small number of the subjects and the lack of a control or even a placebo group. In particular, a study design that inspects the comparison of the effects of different movement interventions in subjects with chronic LBP would be most welcome. Therefore, in our further research we will address some of these deficiencies and aim to more thoroughly investigate the adaptation mechanisms of the neuromuscular system during such training. For this purpose, the biomechanical and motor tests will be complemented by electrophysiological monitoring of muscle activation patterns in circumstances relevant to LBP.

CONCLUSION

The study investigated the effectiveness of a training programme aimed at improving spine functional stabilisation and yielded some encouraging results. The patients were satisfied with the eight-week training programme that was undertaken since it helped alleviate pain as well as improved trunk strength and passive flexibility of the hip. In our opinion, the contents pertaining to trunk functional stability play an important role in LBP prevention and rehabilitation; therefore, our future endeavours will aim at examining in greater detail neuromuscular mechanisms against the background of such training.

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