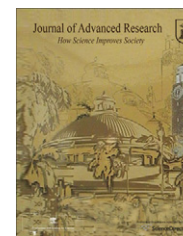




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**ORIGINAL ARTICLE**

Effect of sensorimotor training on balance in elderly patients with knee osteoarthritis

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KEYWORDS

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Abstract Osteoarthritis (OA) is a chronic disabling disease that generates many impairments of functional health status. Impairments of balance are recognized in patients with knee OA. This study investigated the short term effect of sensorimotor training on balance in elderly patients with knee OA, and whether these changes were associated with impairment of functional performance. In addition the possible independent predictors of impaired balance were determined. Forty female patients with knee OA were divided into two equal groups. The control group received a traditional exercise programme and the study group received sensorimotor training in addition to traditional exercises. Blind assessment was conducted at the beginning of the study and after 6 weeks of training to measure balance [in the form of overall stability index (OSI), medial/lateral stability index (MLSI), anterior/posterior stability index (APSI)], perceived pain, proprioception acuity, knee extensor muscle torque, and functional disability. For the sensorimotor group, statistically significant improvements were recorded in all measured parameters, while the traditional exercise group recorded significant improvement only on measures of perceived pain, proprioception acuity, muscle torque, and functional disability, and non-significant changes on all balance measurements. Furthermore, the sensorimotor group produced significantly better improvement than the traditional group. The main predictor of balance was proprioception. The classic traditional exercise programme used in the management of knee OA is not enough for improving balance. Addition of

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sensorimotor training to the rehabilitation programme of these patients could produce more positive effects on balance and functional activity levels. The association between balance, proprioception and functional activity should be considered when treating knee OA.

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Introduction

Osteoarthritis (OA) is a degenerative joint disease affecting mainly weight bearing joints. The pathological changes associated with OA affect not only articular cartilage, but also all joint structures [1,2]. These changes combine to result in reduction of joint proprioception, and muscle weakness [3,4]. Patients with knee OA clinically complain of pain, a decreased range of motion, and joint instability, all of which lead to decrease or loss of function [5,6].

The ageing process is accompanied by a decline in the function of the systems that are responsible for the control of balance [7,8]. The presence of knee OA may cause changes that speed up the deterioration of these systems or compound the effects of ageing [9].

Several protocols are available for management of knee OA with the aim of improving both patient complaints and overall functional activities. These protocols include traditional exercises programmes with a variety of strength training, flexibility exercises and range of motion exercises [10–12]. Nevertheless patient complaints often persist and function activities levels cannot be fully restored.

Balance deficits are documented in patients with knee OA [13–15]. These defects were correlated to many factors that are considered as contributors to balance control, such as pain, loss of proprioception, and decreased muscle strength [3,16]. Balance training is often neglected during rehabilitation of patients with knee OA. It has been suggested that enhancing sensorimotor function can lead to improvement of functional performance in patients with knee injury as well as slowing its progression, especially in the geriatric population [17,18].

Recently, attention has been given to other approaches that focus on improving sensorimotor function by emphasizing sensory inputs, such as proprioception training and balance exercises. Balance training may allow patients to develop adequate motor skills for dealing with potentially destabilizing forces on the knee that may be encountered during activities of daily living [19,20]. Programmes aiming to improve sensorimotor function, therefore, would be of value in the management of patients with knee OA.

Sensorimotor training is a special form of proprioceptive and balance exercise that was designed for management of patients with chronic musculoskeletal pain syndromes. It is based on the concept that instead of emphasizing the isolated strength of a group of muscles around a joint, we should realize the importance of the central nervous system in regulating movement in order to reach proper firing patterns for maintaining joint stability [21–23].

The purposes of the current study were to investigate the short term effect of sensorimotor training in addition to traditional exercises on balance in elderly patients with knee OA and to clarify whether there is an association between functional disability and balance; and also to determine the independent predictors of balance, such as pain, proprioception, and knee extensor muscle torque.

Subjects and methods

Subjects

This study was approved by the ethical committee of the Faculty of Physical Therapy, Cairo University. This is a randomized single blind study in which forty women with unilateral chronic knee OA were recruited from the outpatient clinic of the Faculty of Physical Therapy, Cairo University. Their mean age was 61 ± 3.4 years, height 164 ± 5.4 cm, and weight 79.5 ± 4.1 kg. Patients included in this study were diagnosed by an orthopaedist as having grade II knee OA with the presence of knee pain, osteophytes and definite joint space narrowing based on the American College of Rheumatology criteria [24]. Exclusion criteria included knee surgery, intra-articular steroid injection, rheumatoid arthritis, any neurological condition affecting lower limbs, or use of assistive devices for walking. All patients were required to refrain from seeking other forms of treatment during the study, other than a stable dose of non-steroidal anti-inflammatory drug equivalent to 300 mg Aspirin.

Patients were randomized into two equal groups. A control group received a traditional exercise programme and a study group received sensorimotor training in addition to traditional exercise. Randomization was achieved using the one-to-one randomization method by allocating patients according to their arrival at the outpatient clinic alternatively to the study group and the control group.

Assessments were conducted at baseline and after 6 weeks by an assessor who was blinded to the group allocation. Assessment included balance measurement in the form of overall stability index (OSI), medial/lateral stability index (MLSI), and anterior/posterior stability index (APSI). Perceived pain, proprioception acuity, knee extensor muscle torque, and functional disability were also measured.

Measurement of balance

Biodex Stability System (BSS) was used to measure balance at the Balance Lab, Faculty of Physical Therapy, Cairo University. The system provided measurement of OSI, MLSI and APSI. The reliability of the BSS has been reported [25]. The device was calibrated before each measurement according to the manufacturer's manual.

Subject preparation

Patients were instructed to step onto the platform of the BSS with the knee of the supported leg flexed about 10° . In addition the subject was instructed to keep her hands at her sides throughout the test. The platform was unlocked and the subject was instructed to adjust the foot position to a comfortable stable position. Then the platform was locked and the foot position coordinate was recorded.

Testing procedure

A single limb test was conducted. The test consisted of 30 s test using all eight levels provided by the system. The patient was asked to stand on the tested limb with the same foot coordinate that was determined at the pre-test and to look straight at the X mark and to try to maintain balance.

Measurement of knee extensor muscle torque

Biodex 3 Pro multijoint Isokinetic dynamometer (Biodex Medical Inc., Shirley, NY, United States) was used to measure quadriceps muscle torque. The assessment was conducted at the Isokinetic Lab, Faculty of Physical Therapy, Cairo University. Each patient was informed about the steps of the test procedures and the apparatus was calibrated according to the manufacturer's manual.

The patient was seated with hip at 120° flexion and knee at 60° flexion. Large straps were applied horizontally across the pelvis and diagonally across the trunk to minimize body movement during testing. The thigh was stabilized by a system of pads and belts. The fulcrum of the lever arm was aligned with the lateral epicondyle of the femur and the cuff of the force transducer was placed at 5 cm superior to the medial malleolus. To overcome the effect of gravity, the leg weight was determined for gravity correction by asking the subject to extend the leg. The patient performed three trials of 5 s maximum voluntary isometric contraction with 1 min rest between trials. The subject was asked to maximally extend the knee joint while verbal encouragement was given. The maximum voluntary isometric torque (MVIT) was recorded and the average of the three trials in Newton-metres was taken. Muscle torque has been reported to be a valid method for evaluation of muscle strength capacity [26].

Measurement of proprioception

Proprioception accuracy was determined using the passive-active joint position reproduction method, which has been reported to be a valid method in the evaluation of proprioception [27]. Biodex 3 Pro multijoint Isokinetic dynamometer (Biodex Medical Inc., Shirley, NY, United States) was used to test the ability of the patient to actively repeat the passively positioned knee angle. The target angle was 45° and the test was repeated three times and the difference between the target angle position and the patient perceived end range position was calculated and averaged.

Measurement of pain

Visual numerical scale (VNS) was used to determine the degree of perceived pain. The subject was asked to choose a number between 0 and 10 on a 1 cm chart with 0 indicating no pain and 10 indicating unbearable pain. The subject marked the number corresponding to the pain intensity [28].

Functional level

The functional disabilities of the patients were assessed by the arthritis impact functional assessment scale. This scale has demonstrated reliability in patients with OA [29]. It measures

level of disability on five subscales including pain, walking distance, walking aids, standing, and climbing stairs. Patients were asked to rate their pain and ability to perform various ADL, scoring between 0 and 24 points. Lower scores indicate better subjective functional abilities.

Exercise programme

The study group received a sensorimotor training programme in addition to a traditional programme of strengthening and stretching exercises. The control group received only the traditional exercise programme. The exercises were done for three sessions a week on alternate days for 6 weeks in succession.

Traditional exercise programme

The traditional exercise programme included isometric and isotonic exercises. Isometric exercises were applied for 6 s with eight repetitions and a rest period of 4 s. Isotonic resisted exercises started from the fifth week. The maximum weight that could be lifted up to 10 times was determined; the exercises were then conducted as 10 repetitions with half of this weight, then three quarters of this weight, and finally the whole weight. The 10 repetition maximum was determined again at the sixth week [19]. The exercise programme was carried out according to the following protocol:

1st and 2nd weeks: Range of motion and stretching exercises applied to hamstring and calf muscle, and quadriceps and hamstring isometric strengthening exercise.

3rd and 4th weeks (in addition): Straight leg raising exercises, short-arc terminal extension exercise for the knee joint, and isometric exercises for the abductor and adductor muscles of the hip.

5th and 6th weeks (in addition): Short-arc terminal extension exercise with resistance for the knee joint, and isotonic strengthening exercise with resistance for the hamstring muscles.

Sensorimotor training programme

Patients were trained through three stages: static, dynamic and functional. Each exercise was repeated 3–5 times during a session and with enough periods of rest between each set of exercises. The exercise graduated from easy to more difficult and the patient was not progressed to a more difficult stage until performing the easier one according to the following protocol [22,23,30]:

1st and 2nd weeks: First phase (Static)

1. Standing upright position (30 s) on a firm surface, then on a soft surface (a mat).
2. Single leg stance with closed eyes (first the affected limb, then the non-affected limb) for 10 s on a firm surface, then on a soft surface (a mat).
3. Half-step position for 10 s.
4. One-leg balance for 10 s.

3rd and 4th weeks: Second stage (Dynamic), in addition:

1. Forward stepping lunge.
2. T-band kicks exercise.

5th and 6th weeks: Third phase (Functional), in addition:

1. Walking exercise on a firm surface, then on a foam surface:
 - (a) Toe skipping with toes straight ahead for 20 m, toes pointing outward for 20 m and toes pointing inward for 20 m.
 - (b) Heel skipping with toes straight ahead for 20 m, toes pointing outward for 20 m and toes pointing inward for 20 m.
2. Squatting exercise:
 - (a) Against a wall and away from the wall.
 - (b) One leg squats on the affected and non-affected limb.
3. Balance exercise on wobble board:
 - (a) Multidirectional rolling movement from sitting.
 - (b) Multidirectional rolling movement from standing on both legs between parallel bars with eyes open, then eyes closed.
 - (c) Multidirectional rolling movement from standing on one leg between parallel bars with eyes open, then eyes closed.
 - (d) Balance with two legs, eyes open, multidirectional, then eyes closed.
 - (e) Balance with one leg, eyes open, multidirectional, then eyes closed.

Data analysis

Statistical analysis was performed using “SPSS” for the Windows evaluation version 15.0. Data were presented as mean and standard deviation (SD). Differences between and within groups were assessed using Student’s *t*-test. The degree of association between functional disability and balance measures was estimated using the Pearson correlation. Multiple regression analysis was used to determine the possible predictors of balance in the whole cohort. The significance level was set at (0.05).

Results

There were no significant differences between the groups with respect to age, body weight, or height ($P > 0.05$), as shown in Table 1.

Effect of sensorimotor training

As shown in Table 2, regarding changes in balance measures when comparing pre- and post-exercise scores, statistically significant improvements were obtained in all balance measures in the study group trained with sensorimotor training in addition to traditional exercise. There were no statistically significant improvements in any of the balance measures in the control group trained with traditional exercise alone.

In both groups, statistically significant improvements were obtained in proprioception accuracy, muscle torque of the quadriceps, and pain and functional levels, at post-exercise compared with pre-exercise ($P < 0.05$), see Table 2.

In neither group were there significant differences at pre-exercise for all tested measures but at post-exercise there were significant improvements on all tested measures in the study group compared to control group, see Table 3.

Correlation of balance and functional activity level

Significant direct associations were observed between all balance measures and functional activity level at baseline. Changes in balance measures were also directly associated with changes in functional activity level with exercises, see Table 4.

Independent predictors of balance

Regression analysis showed that proprioception, quadriceps muscle torque and pain were significant independent predictors of balance, but among these independent predictors the proprioception is considered as the most significant predictor of balance. The model accounted for 55–62% of variation in balance, see Table 5.

Discussion

In this study we have investigated the effect of sensorimotor training on balance in elderly patient with knee OA. Sensorimotor training is a special programme aimed at restoring motor control through maximizing sensory input from different parts of the body to improve balance and overall function level of the patient [22,23]. For this purpose, we measured balance stability, proprioceptive sense accuracy, quadriceps isokinetic muscle strength, pain level, and functional level.

The main findings of this study were that sensorimotor training produced significant improvement of all balance measurements, while a traditional exercise programme produced non-significant improvement in all the balance measures. It was suggested that the sensorimotor training increased coordination between muscle groups and improved the response to sensorial information. In sensorimotor training, the patient progresses through exercises in different postures, base of support, and challenges to their centre of gravity. So, each exercise elicits automatic and reflexive muscular stabilization demanding the patient to maintain postural control under a variety of situations [31,32].

The association between OA and loss of proprioception, muscle weakness and pain has been reported [4–6]. These declines in sensory output from the knee joint affects sensorimotor function and may result in balance impairment [14–16]. In the current study, the improvement of balance in the study group could be attributed to the afferent acquisition and transmission to central integration centres, where the propagation of an efferent neural signal to the muscle can be initiated [23].

Regarding all other measured parameters, although both groups produced statistically significant improvements at post-exercise compared with pre-exercise, statistically significant positive changes were detected in the sensorimotor group compared with the traditional exercises group. There are many studies that have investigated the effect of standard traditional exercises in the management of knee OA and reported decreased pain and increased muscle power with consequent improvement in proprioception and functional level [10,11,33]. However, according to the results of the current study, it is thought that this type of exercise programme is not enough and cannot achieve optimal functional capacity levels. Exercises should increase neuromuscular control and meet the needs of daily activities.

Table 1 Characteristics of patients in both groups.

	Age (years)		Weight (kg)		Height (cm)	
	Study	Control	Study	Control	Study	Control
Mean	60	62	78.5	80.5	162	166
SD	3.6	3.2	2.3	1.8	3.1	2.3
<i>t</i>	1.43		1.04		0.81	
<i>P</i>	0.1		0.2		0.4	

Table 2 Comparison of measured parameters at pre- and post-exercise in both the control and study groups.

Measured parameters	Control		Study	
	Pre Mean ± SD	Post Mean ± SD	Pre Mean ± SD	Post Mean ± SD
OSI	15.1 ± 2.2 <i>t</i> = 1.8, <i>P</i> = 0.07	14.8 ± 2.04	14.4 ± 2.6 <i>t</i> = 12.9, <i>P</i> < 0.000*	11.1 ± 2.3
APSI	11.7 ± 2.6 <i>t</i> = 0.5, <i>P</i> = 0.6	11.2 ± 2.05	11.2 ± 2.7 <i>t</i> = 3.5, <i>P</i> = 0.001*	8.5 ± 2.6
MLSI	10.09 ± 2.54 <i>t</i> = 1.5, <i>P</i> = 0.1	9.7 ± 2.2	9.2 ± 1.8 <i>t</i> = 6.8, <i>P</i> < 0.000*	5.5 ± 1.6
Proprioception	6.2 ± 0.45 <i>t</i> = 3.4, <i>P</i> < 0.003*	5.9 ± 0.47	6.1 ± 0.35 <i>t</i> = 9.8, <i>P</i> < 0.000*	4.6 ± 0.69
Muscle torque	127.7 ± 14.1 <i>t</i> = 10.8, <i>P</i> < 0.000*	135.3 ± 13.8	127.7 ± 17.3 <i>t</i> = 18.5, <i>P</i> < 0.000*	149.1 ± 15.6
Pain	7.5 ± 1.1 <i>t</i> = 7.3, <i>P</i> < 0.000*	5.1 ± 1.3	7.35 ± 1.13 <i>t</i> = 14.3, <i>P</i> < 0.000*	4.25 ± 1.2
Function	17.8 ± 1.8 <i>t</i> = 10.7, <i>P</i> < 0.000*	15.9 ± 1.8	17.9 ± 2.3 <i>t</i> = 13.2, <i>P</i> < 0.000*	12 ± 3.1

OST: overall stability index; APSI: anterior/posterior stability index; MLSI: medial/lateral stability index.

* Significant.

Table 3 Comparison between control and study groups at pre- and post-exercise.

Measured parameters	Pre		Post	
	<i>t</i>	<i>P</i>	<i>t</i>	<i>P</i>
OSI	0.92	0.29	5.4	0.000*
APSI	0.06	0.2	7.9	0.000*
MLSI	1.58	0.1	7	0.000*
Proprioception	0.34	0.73	7.02	0.000*
Muscle torque	0.01	0.99	2.9	0.005*
Pain	0.42	0.67	2.1	0.04*
Function disability	0.22	0.82	4.7	0.000*

OST: overall stability index; APSI: anterior/posterior stability index; MLSI: medial/lateral stability index.

* Significant.

Table 4 Correlation coefficient between functional activity level and balance measures at baseline and post-exercise.

Balance measures	Baseline		Post-exercise	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
OSI	0.7	0.001	0.8	0.0001*
APSI	0.7	0.02	0.7	0.005*
MLSI	0.8	0.02	0.8	0.002*

OST: overall stability index; APSI: anterior/posterior stability index; MLSI: medial/lateral stability index.

* Significant.

Theoretically, it could be predicted that sensorimotor training affects proprioception more than classic traditional exercise programme as sensorimotor training improves sensory input to the central nervous system thus improving sensorimotor function of the knee joint [32]. Kinesthesia and balance training were reported to improve proprioception and functional performance of knee OA patients [19,20].

The study group showed more significant reduction of pain than the control group. In chronic OA patients, the patient is usually entrapped in a closed loop cycle called the physical reconditioning cycle where the patient tries to compensate for his pain by adapting unnatural and restricted posture; this may lead to muscle spasm and reduced joint range of motion. This adaptation leads to increased pain [1]. Sensorimotor training was originally designed for the management of chronic musculoskeletal painful conditions [22].

In the current study, the study group also showed better improvement in muscle torque than the control group.

Table 5 Regression analysis of balance measures.

Dependent variable	Independent variable	Adjusted r^2 (as percentage)	t value	P
OSI	Constant	68	-2.1	0.034*
	Proprioception		-6.7	0.000*
	Muscle torque		2.8	0.005*
	Pain		-2.2	0.02*
APSI	Constant	62	-5.2	0.23
	Proprioception		-9.4	0.000*
	Muscle torque		2.9	0.001*
	Pain		-3.2	0.002*
MLSI	Constant	58	-1.09	0.28
	Proprioception		-7.2	0.000*
	Muscle torque		2.8	0.005*
	Pain		-2.1	0.03*

OST: overall stability index; APSI: anterior/posterior stability index; MLSI: medial/lateral stability index.

* Significant.

Increasing muscle force-generating capability can be achieved by two means. The first is by central nervous system adaptation, whereby greater maximum voluntary contraction is produced by CNS "learning and adaptation of the pattern of excitation". The force gains are achieved by greater and more effective recruitment of muscle fibres. The second means is by building the physical bulk of the muscle to produce a greater force output for the same neural input [21]. Also the increase in muscle force can be explained by the decrease in pain. Pain leads to decreased activation level of the muscle. The anticipation of pain causes the patient to guard their physical activities and this in turn aggravates the disability and muscle weakness [34].

The current results show that there was significant positive correlation between balance and functional activity level at baseline and after exercise. These results were in agreement with Hassan et al. who measured postural sway, proprioception, and maximal voluntary quadriceps contraction in patients with knee OA and reported that postural stability was associated with changes in functional level [4]. Also, Hurley et al. studied the sensorimotor changes and functional performance in patients with knee OA and concluded that decreased postural stability was associated with reduced functional performance [35].

Proprioception, quadriceps strength, and pain level, are clearly important for balance control. The present study showed that there was significant correlation between balance and the previously mentioned parameters; but proprioception is considered as the most dependent predictor for balance. The factors responsible for balance defects in knee OA were reported to be pain, deficits in muscle strength, and proprioception [15]. Others found that increased body weight can be added to the previously mentioned factors [4,35].

In conclusion, the addition of sensorimotor training to traditional strengthening and stretching exercises could provide more motor control and help neuromuscular restoration of balance and subsequently improve the functional level of OA patients. Also, the close association between balance and functional level should be kept in mind during rehabilitation of knee OA. Nevertheless, as the current study investigated the short term effect of sensorimotor training, more studies with

long term follow up are needed. Ultimately, it might be feasible to include sensorimotor training in the management protocol of patients with knee OA.

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References

- [1] Felson DT. Developments in the clinical understanding of osteoarthritis. *Arthritis Res Ther* 2009;11(1):203–24.
- [2] Benjamin M, McGonagle D. Histopathologic changes at "synovio-entheseal complexes" suggesting a novel mechanism for synovitis in osteoarthritis and spondylarthritis. *Arthritis Rheum* 2007;56(11):3601–9.
- [3] Shakoor N, Agrawal A, Block JA. Reduced lower extremity vibratory perception in osteoarthritis of the knee. *Arthritis Care Res* 2008;59(1):117–21.
- [4] Hassan BS, Mockett S, Doherty M. Static postural sway, proprioception, and maximal voluntary quadriceps contraction in patients with knee osteoarthritis and normal control subjects. *Ann Rheum Dis* 2001;60(6):612–8.
- [5] Neogi T, Nevitt M, Zhu Y, Xie H, Curtis JR, Clark ECea. Inconsistent knee pain: prevalence, predictors and association with function. *Osteoarthr Cartilage* 2006;14(Suppl. 2):S120–1.
- [6] Felson DT, Niu J, McClennan C, Sack B, Aliabadi P, Hunter DJ, et al. Knee buckling: prevalence, risk factors and associated limitations in function. *Ann Intern Med* 2007;147(8):534–40.
- [7] Slemenda CW. The epidemiology of osteoarthritis of the knee. *Curr Opin Rheumatol* 1992;4(4):546–51.
- [8] Whipple R, Wolfson L, Derby C, Singh D, Tobin J. Altered sensory function and balance in older persons. *J Gerontol* 1993;48, Spec No. 71–76.
- [9] Verzijl N, Bank RA, TeKoppele JM, DeGroot J. AGEing and osteoarthritis: a different perspective. *Curr Opin Rheumatol* 2003;15(5):616–22.
- [10] Huang MH, Lin YS, Yang RC, Lee CL. A comparison of various therapeutic exercises on the functional status of patients with knee osteoarthritis. *Semin Arthritis Rheum* 2003;32(6):398–406.
- [11] Deyle GD, Allison SC, Matekel RL, Ryder MG, Stang JM, Gohdes DD, et al. Physical therapy treatment effectiveness for osteoarthritis of the knee: a randomized comparison of supervised clinical exercise and manual therapy procedures versus a home exercise programme. *Phys Ther* 2005;85(12):1301–17.
- [12] Eyigor S, Hepguler S, Capaci K. A comparison of muscle training methods in patients with knee osteoarthritis. *Clin Rheumatol* 2004;23(2):109–15.
- [13] Allum JH, Carpenter MG, Adkin AL. Balance control analysis as a method for screening and identifying balance deficits. *Ann NY Acad Sci* 2001;942:413–27.
- [14] Wegener L, Kisner C, Nichols D. Static and dynamic balance responses in persons with bilateral knee osteoarthritis. *J Orthop Sports Phys Ther* 1997;25(1):13–8.
- [15] Hinman RS, Bennell KL, Metcalf BR, Crossley KM. Balance impairments in individuals with symptomatic knee osteoarthritis: a comparison with matched controls using clinical tests. *Rheumatology (Oxford)* 2002;41(12):1388–94.

- [16] Foley SJ, Lord SR, Srikanth V, Cooley H, Jones G. Falls risk is associated with pain and dysfunction but not radiographic osteoarthritis in older adults: Tasmanian Older Adult Cohort study. *Osteoarthr Cartilage* 2006;14(6):533–9.
- [17] Dye SF, Wojtys EM, Fu FH, Fithian DC, Gillquist I. Factors contributing to function of the knee joint after injury or reconstruction of the anterior cruciate ligament. *Instr Course Lect* 1999;48:185–98.
- [18] Roos EM. Joint injury causes knee osteoarthritis in young adults. *Curr Opin Rheumatol* 2005;17(2):195–200.
- [19] Diracoglu D, Aydin R, Baskent A, Celik A. Effects of kinesthesia and balance exercises in knee osteoarthritis. *J Clin Rheumatol* 2005;11(6):303–10.
- [20] Tsauo JY, Cheng PF, Yang RS. The effects of sensorimotor training on knee proprioception and function for patients with knee osteoarthritis: a preliminary report. *Clin Rehabil* 2008;22(5):448–57.
- [21] Janda V, Vavrova M. Sensory motor stimulation. In: Liebenson C, editor. *Spinal rehabilitation: a manual of active care procedures*. Baltimore: Williams and Wilkins; 1996. p. 319–28.
- [22] Riemann BL, Lephart SM. The sensorimotor system. Part I: The physiologic basis of functional joint stability. *J Athlet Train* 2002;37(1):71–9.
- [23] Riemann BL, Lephart SM. The sensorimotor system. Part II: The role of proprioception in motor control and functional joint stability. *J Athlet Train* 2002;37(1):80–4.
- [24] Altman R, Asch E, Bloch D, Bole G, Borenstein D, Brandt K, et al. Development of criteria for the classification and reporting of osteoarthritis. Classification of osteoarthritis of the knee. Diagnostic and Therapeutic Criteria Committee of the American Rheumatism Association. *Arthritis Rheum* 1986;29(8):1039–49.
- [25] Schmitz R, Arnold B. Intertester and intratester reliability of the Biodex Stability System. *J Sport Rehabil* 1998;7:95–101.
- [26] Iossifidou AN, Baltzopoulos V. Peak power assessment in isokinetic dynamometry. *Eur J Appl Physiol* 2000;82(1–2):158–60.
- [27] Beynnon BD, Renström PA, Konradsen L, Emlqvist LG, Gottlieb D, Dirks M. Validation of techniques to measure knee proprioception. In: Lephart SM, Fu FH, editors. *Proprioception and neuromuscular control in joint stability*. USA: Human Kinetics; 2000. p. 127–38.
- [28] Price DD, McGrath PA, Rafii A, Buckingham B. The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. *Pain* 1983;17(1):45–56.
- [29] Meenan RF, Gertman PM, Mason JH. Measuring health status in arthritis. The arthritis impact measurement scales. *Arthritis Rheum* 1980;23(2):146–52.
- [30] Pavlu D, Novosadova K. Contribution to the objectivization of the method of sensorimotor training stimulation according to Janda and Vavrova with regard to evidence-based-practice. *Rehabil Phys Med* 2001;8(4):178–81.
- [31] Solomonow M, Krogsgaard M. Sensorimotor control of knee stability. A review. *Scand J Med Sci Sports* 2001;11(2):64–80.
- [32] Kapreli E, Athanasopoulos S, Papatheanasiou M, Van Hecke P, Kelekis D, Peeters R, et al. Lower limb sensorimotor network: issues of somatotopy and overlap. *Cortex* 2007;43(2):219–32.
- [33] Hurley MV, Scott DL. Improvements in quadriceps sensorimotor function and disability of patients with knee osteoarthritis following a clinically practicable exercise regime. *Br J Rheumatol* 1998;37(11):1181–7.
- [34] Arvidsson I, Eriksson E, Knutsson E, Arner S. Reduction of pain inhibition on voluntary muscle activation by epidural analgesia. *Orthopedics* 1986;9(10):1415–9.
- [35] Hurley MV, Scott DL, Rees J, Newham DJ. Sensorimotor changes and functional performance in patients with knee osteoarthritis. *Ann Rheum Dis* 1997;56(11):641–8.