J. Phys. Ther. Sci.
26: 209–213, 2014

# Effects on Hamstring Muscle Extensibility, Muscle Activity, and Balance of Different Stretching Techniques

Kyoung-Il Lim, PT, MSc[1)], Hyung-Chun Nam, PT, PhD[1)], Kyoung-Sim Jung, PT, PhD[1)*]

[1)] *Department of Physical Therapy, Kyungbuk-College: 77 Daehak-ro, Yeongju-si, Gyeongsangbuk-do750-712, Republic of Korea*

**Abstract.** [Purpose] The purpose of this study was to investigate the effects of two different stretching techniques on range of motion (ROM), muscle activation, and balance. [Subjects] For the present study, 48 adults with hamstring muscle tightness were recruited and randomly divided into three groups: a static stretching group (n=16), a PNF stretching group (n=16), a control group (n=16). [Methods] Both of the stretching techniques were applied to the hamstring once. Active knee extension angle, muscle activation during maximum voluntary isometric contraction (MVC), and static balance were measured before and after the application of each stretching technique. [Results] Both the static stretching and the PNF stretching groups showed significant increases in knee extension angle compared to the control group. However, there were no significant differences in muscle activation or balance between the groups. [Conclusion] Static stretching and PNF stretching techniques improved ROM without decrease in muscle activation, but neither of them exerted statistically significant effects on balance.
**Key words:** Balance, Muscle activation, Stretching

*(This article was submitted Jul. 18, 2013, and was accepted Aug. 28, 2013)*

## INTRODUCTION

A reduction in muscular flexibility not only reduces functional level but also causes damage to the musculoskeletal system due to overuse[1–4)]. Such damage mainly occurs in multi-joint muscles which have large functional excursion and a high percentage of fast twitch muscle fibers, and the hamstring muscle has been reported to be the multi-joint muscle which is most frequently damaged in the human body[5)].

Stretching techniques are the treatments used to improve muscular extensibility to improve ROM, and can help prevent damage in daily life or sports, reduce muscle pain, and improve muscle capability, and athletic performance[6–12)].

Stretching techniques are divided into static stretching, dynamic stretching, active self-stretching, ballistic stretching, PNF (proprioceptive neuromuscular facilitation) stretching, etc[6, 13–15)]. The most frequently used techniques are the static stretching and PNF stretching techniques.

The static stretching technique is the most widely used method that extends the muscle length by autogenic inhibition exciting the Golgi-tendon organ, and its effects have been proven by several studies[2, 16–18)]. The resistance to musculotendinous stretching involves not only the viscoelastic properties of muscle and connective tissue, but also neurological reflex and voluntary components of muscular contraction. The PNF stretching technique increases joint range of motion by performing voluntary muscle contraction and promoting muscle relaxation before stretching in order to reduce the reflexive components which cause muscle contraction[19)].

Although the effects of both the static stretching and PNF stretching techniques on muscle extensibility have been proven, their effects on muscle relaxation remain very much open to debate. A study by Cramer, et al.[20)] reported that muscle activity was reduced by autogenic inhibition after applying the static stretching technique, but in disagreement with theory, several studies have reported that only muscle length was increased without reduction of muscle activity[21, 22)]. Many studies have compared the static stretching technique with the PNF stretching technique in terms of muscle extensibility, muscle activity and force generation, but few studies have demonstrated their effects on persons with hamstring muscle tightness. Also, research about the effects of stretching techniques the balance is currently insufficient. The intrafusal fiber, Golgi tendon organ and other proprioceptors perform the roles of detecting body position and keeping balance. Changes in length and stiffness of muscle tendon units change the proprioception which detects environmental changes and initiates the corresponding muscle responses, consequently affecting balance. Static balance measures postural sway in the standing position. David, et al.[23)] reported that the performance of short-term stretching of the hamstrings, quadriceps, and plantar flexors of normal adults reduced the

*Corresponding author. Kyoung-Sim Jung (E-mail: jkspt@hanmail.net)

stiffness of the musculotendinous unit excessively, causing a temporary reduction in static balance. However, there is a lack of research on how stretching influences the balance of patients with tight hamstrings. This study aimed to find out the effects of different types of stretching technique on muscle extensibility, muscle activity and balance of adults with reduced hamstring muscle extensibility.

## SUBJECTS AND METHODS

This experiment was conducted as randomized controlled trial with a 3×2 (group×measure) mixed repeated measures experimental design.

The subjects were male adults in their 20s and 30s whose nervous system and musculo skeletal system did not have any abnormalities which might have affected the extensibility of hamstring muscle and whose extensibility of hamstring muscle was reduced by over 20 degrees as measured by the Active Knee Extension Test (AKE Test). Persons with a history of injury which could have affected hamstring muscle extensibility, such as herniated intervertebral disk, cruciate ligament damage, femoral muscle or hamstring muscle damage, sciatic neuralgia, etc, as well as dose who were or a history of surgery nervous or musculo skeletal systems, within the last 5 years, currently engaged in exercises such as stretching, yoga, Pilates, etc. for improving flexibility were excluded (Table 1).

In order to observe the effects of each stretching technique, the 48 subjects were equally and randomly divided into 3 groups: the control group (n=16), the static stretching group (n=16), and the PNF hold-relax stretching group (n=16). The subjects were randomly assigned to the test groups. Sixteen pieces of paper for each group with the group name written on them were placed in an opaque box, and subjects drew one which determined their group. The lot drawing was performed as sampling without replacement.

This study was conducted after receiving approval for all research works including the research procedure, safety, ethics, etc, from the research ethics committee of Kyungbuk University. Before the study, sufficient explanation of the procedure was provided to all the subjects and their written agreement to participation in the research was obtained.

All stretching techniques were applied to the hamstring just once. In order to ensure the time between the pre- and post-test periods was kept equal among the groups, the control group was given 30 seconds break after the pre-test. After the stretching techniques has been applied, active knee extension angle, muscle activation during maximum voluntary isometric contraction, and static balance were measured.

The stretching techniques were applied as follows.

For the static stretching technique, subjects lay supine in a straight posture on the treatment table and relaxed. Then, the pelvis and thighs opposite to the lower limb to which the stretching technique was to be applied were tied with Velcro straps. With the knees extended and the hip joint bent as much as possible within its range, the hip joints were bent more until the hamstring muscle was stretched with light, tolerable pain, and kept there for 30 seconds. After the stretching technique had been applied, active knee extension angle and maximum voluntary isometric contraction were measured again.

For the PNF Hold-Relax stretching technique, after active knee extension angle and maximum voluntary isometric contraction had been measured, the subjects were lay supine in a straight posture on the treatment table and relaxed. Then, the pelvis and thighs opposite to the lower limb to which the stretching technique was to be applied were tied with Velcro straps. With the knees extended, the therapist bent the hip joints as much as possible until the medial hamstring muscle was stretched with light, tolerable pain. In this state, with the hip joint extended for stretching of the hamstring muscle, the subjects were instructed to extend the hip joint and bend the knee to contract the hamstring muscle. The subjects were instructed to contract the hamstring muscle for 6 seconds while the lower limb was fixed by resistance exerted to the subject's ankle. After the contraction was complete, the lower limb was laid down on the table and relaxed for 5 seconds. The subjects were then instructed to contract the muscles again for 6 seconds while the hamstring muscle was extended, and relax the muscles for 5 seconds, and then to contract the muscles for 6 seconds again with the hamstring muscle stretched to the maximum. Immediately after the stretching technique was applied, active knee extension angle and maximum voluntary isometric contraction were measured again.

The active knee extension test measures the extensibility of hamstring muscle. While the subjects are lying supine on a table, a line connecting the apex of the lateral malleolus with fibular head is drawn. The subjects are then instructed to bend the hip joint to 90° and extend their knees to the maximum while the pelvis and the lower limb opposite to the lower limb to be measured are fixed with Velcro straps. Next, the subjects are instructed to extend their hip joints as much as possible 6 times to prevent the muscle from trembling. During the final 6th extension, the angle between the line connecting the apex of the lateral malleolus with the fibular head and the axis rising vertically from the ground is measured using a manual protractor (360° stainless steel 7518 goniometer, Jamer, USA). Larger decreases in angle indicate greater hamstring extensibility.

**Table 1.** Subject characteristics

| | Control group | Static stretching group | PNF stretching group |
|---|---|---|---|
| Age (years) | 22.38 ± 2.31 | 22.25 ± 2.29 | 23.50 ± 2.16 |
| Height (cm) | 173.63 ± 3.59 | 172.88 ±6.09 | 173.44 ± 5.15 |
| Weight (kg) | 68.50 ± 9.15 | 68.06 ± 10.83 | 69.00 ± 8.33 |

Values are expressed as mean ± standard deviation (SD).

To measure the muscle activity during maximum voluntary isometric contraction (MVIC test), the contractions of hamstring muscles were measured with surface EMG (Noromed MES 9000, FA MyotronicsNoromedInc., Seattle, Washington, USA). With the subject lying face down, the pelvis and the thigh opposite to the lower limb to be measured were fixed with Velcro straps. Then, with the ankle fixed so that the knee of the lower limb to be measured was bent at 30°, resistance was exerted against hip joint flexion. Subjects were instructed to bend the hip joint with weak force, and the muscle bellies of the hamstring muscles were disinfected with alcohol cotton. If the EMG signal contained too much noise because of body hair, the body hair was removed. Ag-Cl bipolar EMG electrodes (Norotrode 20 TM, Myotronics-Noromed, Inc., WA, USA) were attached to the muscle belly in a direction parallel to the muscle fibers. After attaching the base electrode to the fibular head, the surface EMG equipment was connected. With the subjects relaxed, after confirming that the noise level was below 1μV in an EMG noise test, EMG recording was started.

In order to measure the muscle activity during the maximum voluntary isometric contraction that can be generated by the hamstring muscles, the subjects were instructed to repeat bending the hip joint with maximum force for 5 seconds and relaxing for 20 seconds, and the surface EMG were recorded. The EMG signals were amplified with a gain of 500 and recorded on a laptop computer (Sens X22, Samsung, Korea) after A/D conversion at a sampling rate of 1,000 Hz. The recorded EMG signals were then band-pass filtered between 20–500 Hz. After performing data processing such as smoothing, RMS values were calculated of the the EMG signals from the 3 seconds in the middle of each 5-second contraction. The muscle activity of maximum voluntary isometric contraction was expressed as the average RMS value of 3 muscle contractions. The muscle activity after applying the stretching technique was normalized to the value of maximum voluntary isometric contraction (100%) for statistical analysis[24)].

The static balance pability was evaluated using a force measuring plate (PDM, Multifunction Force Measuring Plate, Zebris, Germany, 2004). The force measuring plate has a total of 1504 pressure sensors placed at 1-cm intervals on a 32×47 cm grid, and measures the pressure of walking or standing. The range of measurable pressure is 1–120 N/cm$^2$, with an accuracy of ±5%. Subjects were instructed to stand on the force measuring plate in their bare feet and place their feet in the most comfortable position. The feet were placed at the same location for the post test. The arms were held comfortably at the subject's side. Postural sway was measured for 30 seconds while the subjects started at a circle with a diameter of 15 cm located 3 m to the front. The effect of muscle fatigue was minimized by providing a 3-minute rest between measurements, and after 3 repeated measurements, the average value was recorded.

In order to examine the homogeneity of characteristics of each group, differences in age, height, and weight of subjects in all groups were analyzed using one-way ANOVA.

In order to compare the joint mobility and the maximal voluntary isometric contraction force of each group before and after applying the stretching techniques, data were analyzed using two-way repeated measures ANOVA. The Bonferroni post hoc test was used to examine the differences within each group. In order to examine the significance of differences in the joint mobility and the maximal voluntary isometric contraction force of each group between before and after applying the stretching techniques, the paired t-test was performed. Data were analyzed using the SPSS v12.0 statistical program. All the significance levels used were $\alpha=0.05$.

## RESULTS

The characteristics of the subjects of each group, age, height, and weight, had the same distributions and showed no significant differences in their averages.

Significant difference was found in active knee extension ROM after the application of the stretching techniques ($p<0.05$). Both the stretching technique groups showed significant increases in knee extension ROM compared to the control group ($p<0.05$). There was no significant difference between the static stretching group and the PNF hold-relax stretching group (Table 2). The control group showed no significant difference in knee extension ROM between before and after the application of the stretching techniques, but the static stretching group and the PNF hold-relax stretching group showed significant increases in knee extension ROM after the application of the stretching techniques ($p<0.05$) (Table 2).

The muscle activity during voluntary isometric contraction showed no significant differences after the application of the stretching techniques among the groups. The muscle activity during voluntary isometric contraction signifi-

**Table 2.** Outcome measures before and after the application of the stretching techniques

| | Control group | | Static stretching group | | PNF stretching group | |
|---|---|---|---|---|---|---|
| | pre | post | pre | post | pre | post |
| Knee joint ROM | 37.50±4.44 | 36.75±5.98 | 36.00±6.21 | 26.38±6.63$^{*\#}$ | 35.25±9.53 | 23.38±9.91$^{*\#}$ |
| Muscle activation | 100.00±0.00 | 98.55±16.28 | 100.00±0.00 | 119.11±35.44$^{*}$ | 100.00±0.00 | 108.48±36.61 |
| Balance | | | | | | |
| Medio-lateral | 151.71±40.29 | 157.14±47.92 | 137.72±41.63 | 122.03±38.09 | 142.52±42.59 | 130.11±36.67 |
| Anterio-posterior | 111.21±26.86 | 116.82±24.72 | 121.87±35. | 120.00±27.10 | 115.28±20.57 | 114.21±12.61 |

Values are expressed as mean±SD.* indicates a significant difference from the pre-test condition.# indicates a significant difference compared to the control group.

cantly increased only in the static stretching group after the stretching ($p<0.05$). A decrease in the muscle activation during maximal voluntary contraction indicates muscle relaxation. In this study, only the length of the hamstring increased, there being no change in the muscle activation after the application of the stretching techniques.

There was no significant difference among the groups in balance in either the mediolateral direction and antero-postrior direction after the application of the stretching techniques. Static balance showed no significant difference between before and after the application of the stretching technique in any of the groups.

## DISCUSSION

The proper duration and frequency are very important when applying stretching techniques. Bandy and Irion stated that applying a stretching technique one time for 30 seconds was the most effective[16)] duration, because the extensibility was not increased further in applications lasting more than 30 seconds[17)]. In this study, we examined the effects on the muscle extensibility of applying the static stretching technique and the PNF hold-relax stretching technique one time for 30 seconds between adults who had hamstring muscle tightness. Both methods elicited significant increases in knee extension ROM compared with the control group. A study comparing the long term effects of the static stretching, active self-stretching, and PNF stretching techniques among adults who had hamstring muscle tightness reported that only the group receiving the static stretching technique showed a significant difference from the control group, and that application of the active self-stretching and PNF stretching techniques 3 times a week, the same schedule as the static stretching technique, was not sufficient for stretching a contracted hamstring muscle[14)]. In contrast, several researchers have stated that the PNF stretching technique is more effective at increasing mobility than the static stretching technique[25)]. However, Decoster et al.[15)] stated that it was difficult to determine the most effective hamstring muscle stretching technique, because all the studies that had measured ROM after the application of a stretching technique. Our present study did not find significant differences among the different stretching techniques.

Neurological changes after applying stretching techniques can be confirmed through isometric muscle activity[24, 26–27)], the muscle activity during muscle stretching[28)], and the H reflex[29)]. The effects on muscle activity of each type of stretching technique were compared in the present study, but the stretching techniques showed no significant differences in effect. In a study applying the static stretching technique and the PNF stretching technique to normal adults who had no limit in joint ROM, both group showed significant decreases in muscle activity, a result which was explained as being caused by the muscle relaxation effect activating the self-inhibition mechanism[20)]. Marek et al.[30)] suggested that results may differ with muscle type, and the frequency and duration of application of the stretching technique. In the present study, stretching techniques were applied to patients who had hamstring muscle tightness, but only the group receiving the static stretching technique showed a significant increase in muscle activity. The muscle generates maximum muscular strength at the proper length. As the sarcomere becomes shorter or longer than the stable length, the cross-bridge number is reduced, and force generated is reduced[31)]. Our present result, showing that hamstring muscle activity is increased only after applying static stretching technique, significantly different from the PNF hold –relax technique result was not, but we believe this is due to the increase in muscle length being larger than in the PNF hold-relax stretching technique.

Balance is achieved by the interaction between automatic posture reflex and voluntary motion[32, 33)]. On an unstable surface, voluntary motions of the body and the limbs adjusting to postural changes become more important, as the central nervous system suppresses proactive postural control[34)]. In a study examining postural sway on an unstable surface after the application of the static stretching technique to adults who had no limit on hamstring muscle extensibility, postural sway increased more as the detection speed of Golgi-tendon organ and the muscle spindles became slower because the musculo-tendinous unit was loose after the application of the stretching technique. Also, it was reported that stretching interfered with the warm-up effect by reducing the response speed[23)]. However, in the present study, unlike previous study findings, stretching did not increase the postural sway of patients with hamstring shortening; rather, postural sway showed a decreasing tendency, although it was not statistically significant. This means that application of stretching can produce the opposite effect depending on the condition of the subjects, and appropriate workouts need to be conducted according to the subjects' condition, to produce the warm up effect. We consider that the balance effect of stretching techniques was not observed in this study, because the frequency and duration of stretching were insufficient. We conjecture the postural sway after stretching was small, because the state of balance was not measured with the eyes closed, or in an unstable state, conditions under which subjects rely more on proprioceptive sense. In the future, studies examining the effects of stretching on proprioception and the balance of patients with hamstring shortening, by measuring postural sway with eyes closed after stretching will be necessary. Also, since only the short term effects on muscle extensibility, muscle activity and balance of patients with hamstring muscle tightness were examined in this study, it will be necessary to study the long term effects of applying stretching techniques for patients with hamstring muscle shortening.

Based on the results of this study, the application of the static stretching technique or the PNF stretching technique for shortened hamstring muscles is effective at increasing muscle extensibility without reducing muscle activity, since no significant difference was found between these two techniques. Also, unlike the findings of previous studies which applied stretching techniques to normal adults, postural sway was not increased after the application of stretching to patients with hamstring shortening. The result of this study should provide useful data for improving the functional state of several diseases which cause hamstring muscle tightness.

## REFERENCES


1) Bandy WD, Sanders B: Therapeutic Exercise: Techniques for Intervention. Philadelphia: Lippincott Williams & Wilkins, 2001.
2) Halbertsma JP, Mulder I, Goeken LN, et al.: Repeated passive stretching: acute effect on the passive muscle moment and extensibility of short hamstrings. Arch Phys Med Rehabil, 1999, 80: 407–414. [Medline] [CrossRef]
3) Hartig DE, Henderson JM: Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. Am J Sports Med, 1999, 27: 173–176. [Medline]
4) Hreljac A, Marshall RN, Hume PA: Evaluation of lower extremity overuse injury potential in runners. Med Sci Sports Exerc, 2000, 32: 1635–1641. [Medline] [CrossRef]
5) Safran MR, Seaber AV, Garrett WE Jr: Warm-up and muscular injury prevention. An update. Sports Med, 1989, 8: 239–249. [Medline] [CrossRef]
6) Jaggers JR, Swank AM, Frost KL, et al.: The acute effects of dynamic and ballistic stretching on vertical jump height, force, and power. J Strength Cond Res, 2008, 22: 1844–1849. [Medline] [CrossRef]
7) McHugh MP, Nesse M: Effect of stretching on strength loss and pain after eccentric exercise. Med Sci Sports Exerc, 2008, 40: 566–573. [Medline] [CrossRef]
8) Yuktasir B, Kaya F: Investigation into the long-term effects of static and PNF stretching exercises on range of motion and jump performance. J Bodyw Mov Ther, 2009, 13: 11–21. [Medline] [CrossRef]
9) Sheard PW, Smith PM, Paine TJ: Athlete compliance to therapist requested contraction intensity during proprioceptive neuromuscular facilitation. Man Ther, 2009, 14: 539–543. [Medline] [CrossRef]
10) Bazett-Jones DM, Gibson MH, McBride JM: Sprint and vertical jump performances are not affected by six weeks of static hamstring stretching. J Strength Cond Res, 2008, 22: 25–31. [Medline] [CrossRef]
11) Ross MD: Effect of a 15-day pragmatic hamstring stretching program on hamstring flexibility and single hop for distance test performance. Res Sports Med, 2007, 15: 271–281. [Medline] [CrossRef]
12) Nordez A, Gennisson JL, Casari P, et al.: Characterization of muscle belly elastic properties during passive stretching using transient elastography. J Biomech, 2008, 41: 2305–2311. [Medline] [CrossRef]
13) Manoel ME, Harris-Love MO, Danoff JV, et al.: Acute effects of static, dynamic, and proprioceptive neuromuscular facilitation stretching on muscle power in women. J Strength Cond Res, 2008, 22: 1528–1534. [Medline] [CrossRef]
14) Davis DS, Ashby PE, McCale KL, et al.: The effectiveness of 3 stretching techniques on hamstring flexibility using consistent stretching parameters. J Strength Cond Res, 2005, 19: 27–32. [Medline]
15) Decoster LC, Cleland J, Altieri C, et al.: The effects of hamstring stretching on range of motion: a systematic literature review. J Orthop Sports Phys Ther, 2005, 35: 377–387. [Medline] [CrossRef]
16) Bandy WD, Irion JM: The effect of time on static stretch on the flexibility of the hamstring muscles. Phys Ther, 1994, 74: 845–850. [Medline]
17) Bandy WD, Irion JM, Briggler M: The effect of time and frequency of static stretching on flexibility of the hamstring muscles. Phys Ther, 1997, 77: 1090–1096. [Medline]
18) Chan SP, Hong Y, Robinson PD: Flexibility and passive resistance of the hamstrings of young adults using two different static stretching protocols. Scand J Med Sci Sports, 2001, 11: 81–86. [Medline] [CrossRef]
19) Knott M, Voss DE: Proprioceptive neuromuscular facilitation: patterns and techniques. New York: Harper & Row, 1968.
20) Cramer JT, Housh TJ, Weir JP, et al.: The acute effects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. Eur J Appl Physiol, 2005, 93: 530–539. [Medline] [CrossRef]
21) Condon SM, Hutton RS: Soleus muscle electromyographic activity and ankle dorsiflexion range of motion during four stretching procedures. Phys Ther, 1987, 67: 24–30. [Medline]
22) Osternig LR, Robertson R, Troxel R, et al.: Muscle activation during proprioceptive neuromuscular facilitation (PNF) stretching techniques. Am J Phys Med, 1987, 66: 298–307. [Medline] [CrossRef]
23) Behm DG, Bambury A, Cahill F, et al.: Effect of acute static stretching on force, balance, reaction time, and movement time. Med Sci Sports Exerc, 2004, 36: 1397–1402. [Medline] [CrossRef]
24) Olivo SA, Magee DJ: Electromyographic assessment of the activity of the masticatory using the agonist contract-antagonist relax technique (AC) and contract-relax technique (CR). Man Ther, 2006, 11: 136–145. [Medline] [CrossRef]
25) Tanigawa MC: Comparison of the hold-relax procedure and passive mobilization on increasing muscle length. Phys Ther, 1972, 52: 725–735. [Medline]
26) Ferber R, Osternig L, Gravelle D: Effect of PNF stretch techniques on knee flexor muscle EMG activity in older adults. J Electromyogr Kinesiol, 2002, 12: 391–397. [Medline] [CrossRef]
27) Mahieu NN, Cools A, De Wilde B, et al.: Effect of proprioceptive neuromuscular facilitation stretching on the plantar flexor muscle-tendon tissue properties. Scand J Med Sci Sports, 2009, 19: 553–560. [Medline] [CrossRef]
28) Lee GP, Ng GY: Effects of stretching and heat treatment on hamstring extensibility in children with severe mental retardation and hypertonia. Clin Rehabil, 2008, 22: 771–779. [Medline] [CrossRef]
29) Etnyre BR, Abraham LD: H-reflex changes during static stretching and two variations of proprioceptive neuromuscular facilitation techniques. Electroencephalogr Clin Neurophysiol, 1986, 63: 174–179. [Medline] [CrossRef]
30) Marek SM, Cramer JT, Fincher AL, et al.: Acute Effects of Static and Proprioceptive Neuromuscular Facilitation Stretching on Muscle Strength and Power Output. J Athl Train, 2005, 40: 94–103. [Medline]
31) Neumann DA: Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabilitation, 1st ed. Louis: Mosby, 2002.
32) Bloem BR, Allum JH, Carpenter MG, et al.: Is lower leg proprioception essential for triggering human automatic postural responses? Exp Brain Res, 2000, 130: 375–391. [Medline] [CrossRef]
33) Shiratori T, Latash M: The roles of proximal and distal muscles in anticipatory postural adjustments under asymmetrical perturbations and during standing on rollerskates. Clin Neurophysiol, 2000, 111: 613–623. [Medline] [CrossRef]
34) Aruin AS, Forrest WR, Latash ML: Anticipatory postural adjustments in conditions of postural instability. Electroencephalogr Clin Neurophysiol, 1998, 109: 350–359. [Medline] [CrossRef]