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The Effect of Whole Body Vibration, Pnf Training or a Combination of Both on Hamstrings Range of Motion

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Abstract: Stretching is often used to improve joint range of motion (ROM), but also whole body vibration training seems to help in increasing the range of motion. The purpose of this study was to determine the effect of whole body vibration, PNF training or a combination of both on range of motion of the hamstrings and the maintenance of range of motion after stopping the flexibility training program in male students. The result showed that all groups had a significant increase in hamstring range of motion and combination group showed greater increase. After three weeks of cessation training all groups showed significant decrease in hamstring range of motion but in WBV group decrease was less than other groups. This study showed that WBV in combination with PNF stretching is a more effective regiment to increase range of motion of the hamstrings than PNF or WBV training alone. Also only WBV training can be used for increasing range of motion in the hamstrings.

Key Words: Flexibility · Maintenance · Whole body vibration · Proprioceptive neuromuscular facilitation

INTRODUCTION

Stretching is often used in sports and daily life. It increases range of motion, which is considered to improve athletic performance and functional gains [1,2].

Several researchers have studied various stretching techniques to determine which stretching technique is most effective for increasing joint range of motion (ROM) [3-7]. One of the used techniques is the contract-release method, which has shown very good results in increased joint range of motion and is shown to be more effective than static stretching [8, 9].

Alternatively, like stretching, it is found that vibration training can increase range of motion [10-18]. It is suggested that vibration can increase range of motion through changes in the viscoelastic properties of the muscle as a result of increased blood flow and intra-muscular temperature [19,20]. Other proposed mechanisms for reported increases in ROM include vibration induced muscle relaxation and alteration of the pain threshold [14].

However, the vibration-training studies were conducted in different ways. Some studies used locally applied vibration [10, 12,16,17] by ways of a vibration pad or a specially designed vibration module to show improved hip flexor mobility and range of motion. So researchers used a specialized vibration module placed under the leg being stretched when training for forward split range of motion in young gymnasts [16,17] and Issurin induced vibration through a cable pulley system [14]. Other studies used Whole body vibration training (WBV) in which the participants stood on a vibrating platform in a squat position without any stretching protocol and looked if the range of motion in the hamstring increases [11,13,15] . To our knowledge only in one study subjects performed bouts of stretching (contract-release) between bouts of WBV platform training However, van den Tillaar (2006) only compared a group who did stretching with a group who did stretching combined with vibration training in between[18].

All studies that mentioned above showed that vibration training had a positive effect in enhancement hamstring range of motion. However, to date no study has compared the effect of only vibration on a WBV platform with WBV training combined with a stretching protocol or only using a stretching protocol with each other upon hamstring range of motion.

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Therefore the aim of this study was to investigate the effect three different training protocols of six weeks (contract- release method, whole body vibration training and a combination of these two training protocols) upon the range of motion of the hamstrings. Furthermore to examine what happens with the range of motion of the hamstrings after stopping all intervention programs. It was hypothesized that the combination group would increase most in range of motion since its assumption that underlying mechanisms that existence in PNF training are active in vibration training. After ending intervention this increased range of motion will decreases equally in all groups are the second hypothesis that will be tested.

Methods

Experimental Approach to the Problem: A repeated-measure design with a WBV group and PNF group and a combination WBV/PNF group (COMBO) was used to determine the effectiveness of WBV and PNF and combination of both for hamstring flexibility during 6-week training and observe changes after 3-week stopping training.All subjects were asked to complete four testing sessions. The first test session was performed as a pre-training assessment with the second and third sessions performed at midpoint (3 weeks) and at completion of a six-week training period. The fourth test session was performed three weeks following the third session, after three weeks cessation of training.

Participants were randomly assigned to one of three study groups: WBV, PNF and a combination WBV/PNF group (COMBO). All subjects were asked to complete 18 training sessions over a six week training period. Investigational testers were blinded to the subjects' group assignments. Thus, the study design allowed a controlled examination of the effects of WBV training versus PNF training versus training utilizing both WBV and PNF.

Subjects: Thirty-one male students (height 176±10.2 cm, weight 73.6±9.7 kg and age 24.5±3.6yr; x±SD) (SD is true) from the University of Tehran participated in this study. Study inclusion criteria included visible evidence of hamstring tightness, defined as a limitation in full extension as determined by the active knee extension (AKE) test and participants' self report that they were injury free in the trunk and lower extremities for at least one year before the study. Before participating in this study, the subjects were fully informed about the protocol and written informed consent was obtained prior to all testing, in accordance with the regulations of local ethical committee and with current Iranian law and regulation.

Following completion of the informed consent process, subjects were screened for hamstring tightness using an active knee extension (AKE) test. After a general warm up, the subject was positioned supine on a padded plinth. Hip and knee flexion angles of 90° were maintained by an adjustable bench placed underneath both lower extremities. The subject actively extended one knee as far as possible and a goniometric measurement was taken in degrees of motion with a standard 18-in (45.72-cm) goniometer [21] this was then repeated with the other leg. Potential study participants that had visible evidence of bilateral hamstring (Both legs) tightness, defined as a limitation of 20° or more, were included in the investigation [21].

Based on normative data for the SLR test [22] lower extremities were classified as tight (<60º), normal (60-90º), or loose (>90º) in our study the subjects selected that has minimum 60º ROM in hamstring muscles, they have lowest degree in normal class (60-90º). They selected intentionally to show effects of training obviously.

And I used AKE for screening because I think we can use all methods for screening even visual screening. Now if you think we can't rationalize AKE, can we say subjects included in the study had visible evidence of hamstring tightness, defined as the range of motion of 70° degrees or less of hip flexion when screened using a leg straight-leg-raise test? If it is true, all the details about AKE can be removed)

Testing Procedures: On the test days, the subjects warmed up by walking two minutes on a treadmill at a velocity of 4 km/h. afterward, the hamstring range of motion was evaluated using the straight leg raise test (SLR) [23,24] In the SLR test the subject was positioned supine on a padded plinth. The examiner used one hand to elevate the limb at the heel while the other hand was placed on the contra lateral anterior superior iliac spine to monitor for posterior rotation. The subject's leg, in full knee extension, was moved passively into hip flexion until firm resistance was felt and the pelvis tilted from the plinth. This was defined as the end of range of motion and a goniometric measurement of hip flexion was taken [21] The examiner closely monitored the knee to ensure that full knee extension was maintained during the test. The SLR test was performed bilaterally, with the ROM of each leg measured three times and the average values recorded

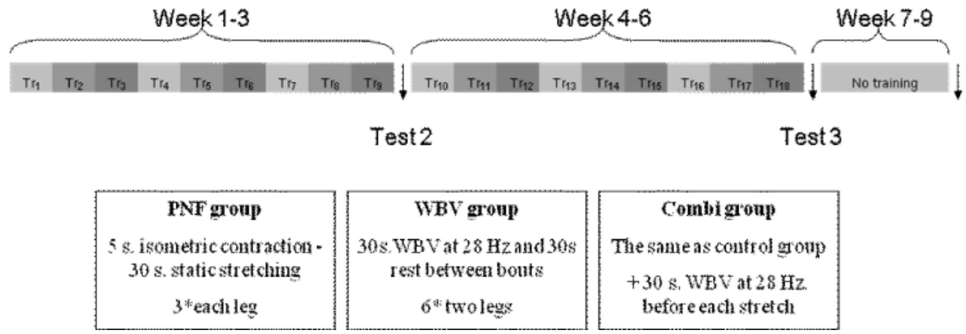

Fig. 1: Experimental time line of the study, which includes the set up of the training- and test sessions

for each limb. And then average both limb calculated for hamstring flexibily. All assessments were performed by an experienced physiotherapist. The test was always performed on the same day of the week (Friday) and at the same time of the day (1500-1800 hours) for each subject. (Training in each week consist Saturday, Monday and Wednesday and testing day held in Friday) The same tester performed the passive stretches on the hamstrings and the measurements on all test days and did not know which group the subjects belonged to when the subjects were tested. The test was performed before the training period started (pretest) and after 3 and 6 weeks of training and after 3-weeks cessation of training (Figure 1). Thus, the range of motion of the hamstrings was measured a total of four times.

Training Procedures: After the pretest, the subjects were randomly assigned to either a WBV group (10 men) or to a PNF group (11 men) or to a combination WBV and PNF group (COMB) (10 men). Each subject was individually supervised during the initial training s regarding proper performance of the respective training protocols. Regardless of group, the participants started all training sessions with a 5-min warm-up, consisting of a light jog at an intensity at which the subjects estimated to be 40% of their maximal speed, or such that they could hold a light conversation while jogging.

After the standardized warm-up, subjects in PNF group stretched their hamstring muscles systematically three times per leg according to the contract-release method protocol described by Bandy and Irion (Bandy Iron 1994). Each subject stood upright facing a table and placed the heel of one leg on the table (the height of the table was the same for all subjects and remained constant throughout the study)(In paper that attached (Rolland Van Den Tillar) height of table not mentioned) so that the knee was fully extended and the ankle was positioned in relaxed plantar flexion. Both legs were straightened without(In attached paper mentioned relaxed plantar flexion. knee extended and hip flexed) any rotation in the hip joint. An isometric contraction of the front leg hip extensors was performed for five seconds by pushing the heel down on the table. Next, the hamstrings muscles were stretched by bending forward at the hip while keeping the lumbar spine extended and maintaining the knee in full extension until the subject perceived tightness in the hamstrings. The subject held this position for 30 seconds. Each leg was stretched alternately three times per training session. Alternating between limbs per repetition

The subjects in the WBV group were exposed to a vibration treatment on the Nemes Bosco system (OMP, Rieti, Italy) vibration platform for 30 seconds with a frequency of 28 Hz and amplitude of 10 mm (peak to peak). Subjects in the WBV group stood on the WBV platform for 6 repetitions of 30-seconds with 30-seconds of rest between the bouts in each session.

Each subject was asked to stand in a squat position on the vibration platform with the knees bent of 90°. This position was chosen because the vertical sinusoidal accelerations of the vibration platform had to be damped by the different muscles around the joints of the under extremity (Nigg, Wakeling 2001). It was thought that standing in this position induces involuntary muscular contractions (tonic vibration reflex) in the different muscles of the under extremity, including the hamstrings [19, 39]. The subjects in the combination group conducted the same vibration training protocol as the WBV group and between each vibration bout they stretched their hamstring muscles according to the same protocol as the PNF training group. In the first sessions, each subject's position was checked and, if necessary, corrected by means of observational techniques. Every participant performed these sessions three times per week for a period of six weeks.

Statistical Analyses: An associated pilot study investigated the error of measurement associated with AKE and SLR ROM assessment. Both techniques were found to be equally reliable and there were no significant differences between the static and dynamic ROM measures. If this is not necessary we can delete this For this reason dynamic ROM assessment (ICC = 0.89) was used in this study.

To localize and compare the effects of the training protocols on the range of motion of the hamstrings a 2-way (3x4) ANOVA (group: PNF, WBV, COMBI x test occasion: pretest, after 3 weeks of training, after 6 weeks of training, after 3 weeks of cessation of training), with repeated measures on the factor test occasion was used. Interaction effects were of particular interest as these outcomes indicate differences between the training protocols. A post hoc test (using Bonferroni probability adjustments) was used to locate significant differences. In addition, in order to identify differences between the different training groups at particular test occasions the changes from occasion to occasion was calculated and a Oneway ANOVA was conducted between the outcomes of the three groups. In cases where sphericity could not be assumed, the Greenhouse-Geisser correction was applied. The level of significance was set for all statistical analysis at $p \leq 0.05$.

RESULTS

No significant difference ($P = 0.41, r = 0.95$) was found in ROM of the hamstrings between the two legs. Therefore, the average ROM of both legs was used for further analysis.

No significant differences in the initial range of motion of the hamstrings between the three groups were found ($p=0.37$). A significant increase in range of motion of the hamstrings after the training period was observed ($p<0.0001$, figure 2). Post hoc comparison (Bonferroni) showed significant increase every three weeks ($p<0.0001$) and significant decrease after 3 weeks of cessation ($p<0.0001$; figure 2).

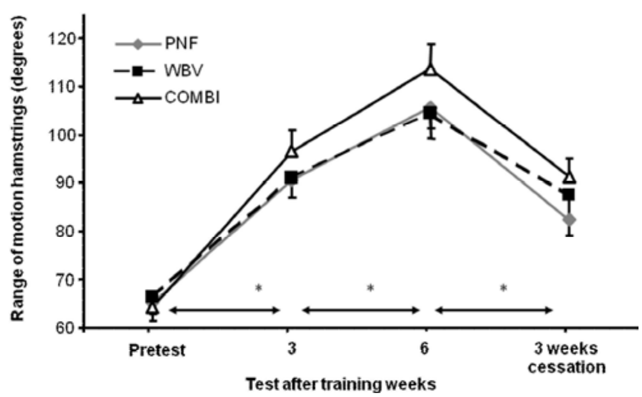

Fig. 2: Average range of motion of the hamstrings for the three training groups at the different tests.
* Indicates significant differences in range of motion between the correspondent test days ($p<0.05$).

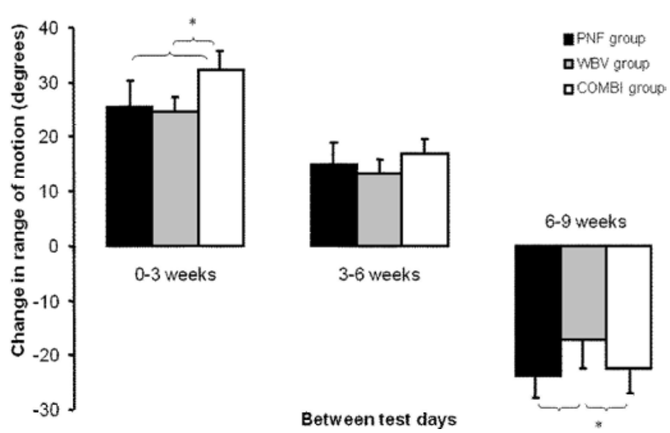

Fig. 3: The average change in the joint range of motion per group in degrees from test to test.
* Significant difference between these two groups on a level of $p<0.05$.

Also a significant interaction between the groups was found ($p < 0.0001$). Post hoc comparison (Bonferroni) showed that the combination-training group had a significantly different change in range of motion during the study when compared with the other two groups ($p=0.048$). When only the differences from test to test were calculated a significant higher increase of range of motion was found for the combination group when compared to the other two groups after three weeks (figure 3; $p<0.0001$). From test 2 (after week 3) to test 3 (after week 6) no significant difference between the groups was found (figure 3; $p=0.054$). After three weeks of cessation of training all groups showed s significant decrease in range of motion of the hamstrings. However, the decrease was significantly less for the WBV group when compared with the other two groups (figure 3; $p=0.01$)

DISCUSSION

In this study the effects of three different training protocols of six weeks (contract-release method, whole body vibration training and a combination of these two training protocols) upon the range of motion of the hamstrings were examined. All training protocols showed a positive effect upon hamstrings range of motion with the combination group enhancing it most.

That all training protocols enhanced range of motion in the hamstrings was in line with the previous studies on PNF training [8,9] and WBV training [11-13,15] and combined WBV and PNF training [18].

As hypothesized, the combination-training group increases the range of motion more than the other two groups, especially in the first three weeks (figure 3).

Prior research has suggested 3 primary possibilities: Increase in temperature and muscle elasticity resulting from increased blood flow [14,17,26,27] Increase in pain threshold [14,17] and golgi tendon organ (GTO) excitation and antagonist inhibition [14,19] Based on prior research we also theorize that there is a possible interplay between pain perception and proprioception when stretching with vibration and that a lack of spindle response may also contribute to the success of stretching with vibration.

While prior research has shown that increasing muscle temperature increases muscle extensibility, further range of motion research has also shown that the use of different forms of heat as adjunctive treatment improve stretching results [27,28].

Recent studies have also reported increases in blood flow and volume due to vibration application [20, 29,30], with blood flow rates even doubling after 9 minutes of WBV in the popliteal artery [20]. This increase in blood flow would result in a concomitant increase in muscle temperature and hence, muscle extensibility [14, 17,30] reported that increases in blood flow increased muscle temperature (as measured in the vastus lateralis) twice as fast as cycling when vibration is coupled with repeated squats. Further research is needed to determine if similar results occur in a PNF training (stretching) of the hamstring muscle group combines with WBV training. This possibility can help explain the increases in range of motion reported by Van den Tillaar [18] when alternating stretching and WBV bouts and also explain the increases seen in our study.

PNF Stretching with vibration may inhibit pain perception, thus resulting in greater range of motion during the stretch. It has been reported that nociceptive (nociceptor: a sensory receptor that reacts to painful stimuli) sensitivity gradually declines as vibration amplitude increased and that vibrations ranging from 20 to 230 Hz interfere with nociception [32] Vibratory rates as low as 30 Hz have been reported to significantly increase pain threshold even after stimulation in the hand [33] and activation of deep and superficial receptors is proposed to interact with nociceptive processing at many levels of the nervous system, including those of the spinal cord [34]. Thus, it is possible that vibration alters the sense of stretch perception and pain through a variety of mediating factors. The mechanically induced muscle contractions by vibration most likely stimulated Ia afferents and resulted in increased intensity of the stretch. Prior research on vibration has also reported that the muscle group on stretch would exhibit an increased firing rate [35]

While it is known that Ia afferents inhibit motor neurons to the antagonistic muscle [26], vibration also induces a tonic vibration reflex (TVR) and increases muscle stiffness [26,36] A study done without use of any type of vibration showed increased muscle stiffness is related to decreased stretch tolerance and repeated stretches only temporarily reduce muscle stiffness [37] Localized vibration at higher frequencies has demonstrated an increase in muscle stiffness during vibration [35,38] Increased stiffness and intensity may affect GTO activity since the

GTO responds to vibration and their capacity to follow vibration frequencies increases with muscle stretch [35] It has been suggested that WBV application may induce changes to muscle stiffness [39], which has been used to try to explain other performance changes seen with WBV training.

Many studies have suggested that the spindle response is responsible for improved performance following WBV training. However, the success in WBV application improving other performance factors such as power and strength is also disputed in the literature. It has even been reported that the effects of neural potentiation from WBV disappear within an hour [40] but the idea that enhanced muscle spindle response, primary Ia recruitment and the tonic vibration response (TVR) are the primary cause of such increases is arguable since the Ia system appears to be involved in complex (mono and polysynaptic) spinal pathways and the role of central or supraspinal input and integration has not been adequately studied. Recent studies have reported that WBV treatment does not affect the timing or amplitude of the quadriceps stretch reflex [41] and does not enhance muscle spindle sensitivity as determined by the inability to alter peroneus longus electromechanical delay, reaction time or peak and average EMG.

We suggest that the vibration variables of duration, total time, frequency and amplitude may be more person specific than previously thought. For example, de Ruiter *et al.* [42] reported an inability to increase maximal voluntary knee extensor contraction or maximal rate of force rise when using a similar vibration protocol as Bosco *et al.* [25,19.39] suggest that shorter durations of WBV (4-5 sets x 60 seconds with 60-second rest intervals) may be an important factor for producing positive training effects, however, both studies by Hopkins [41,43] and the study by Cronin *et al.* (2004)[36] Used this protocol. The apparent discrepancy in results between Bosco [25,19] and these other studies [36,41-43] may lie in the type of population studied. It is possible that the fitness level and physiological make-up of the population undergoing WBV has a significant impact on potential neuromuscular response. Prior studies by Bosco [19, 25] used very fit individuals currently involved in team training while the other studies [36, 41-43] used sedentary to recreationally active subjects. Since prolonged vibration stimulation does result in force reduction capacity of the muscle [39, 44] it is possible that the training and fitness level of subjects may also affect vibration related stretching protocols, but this has yet to be explored.

CONCLUSION

The results of this study indicate that WBV in combination with PNF stretching is a more effective regiment to increase range of motion of the hamstrings than PNF or WBV training alone. However, after three weeks of cessation of training the groups that involved PNF training (PNF and COMBI group) decreased more in range of motion than the WBV training group. Since also only WBV training showed similar changes in range of motion of the hamstrings when compared to PNF training, WBV training alone can be used as a new method for increasing range of motion training of the hamstrings. Figure Legend

REFERENCES

1. DePino, G., W. Webright and B. Arnold, 2000. Duration of maintained hamstring flexibility after cessation of an acute static Stretching Protocol., J. Athletic Training, 35(1): 56.
2. Malliaropoulos, N., S. Papalexandris, A. Papalada and E. Papacostas, 2004. The role of stretching in rehabilitation of hamstring injuries: 80 athletes follow-up. Medicine and Science in Sports and Exercise, 36(5): 756.
3. Hortobagyi, T., J. Faludi, J. Tihanyi and B. Merkely, 1985. Effects of intense" stretching"-flexibility training on the mechanical profile of the knee extensors and on the range of motion of the hip joint. Int. J. Sports. Med., 6(6): 317-321.
4. Sady, S., M. Wortman and D. Blanke, 1982. Flexibility training: ballistic, static or proprioceptive neuromuscular facilitation? Archives of Physical Medicine and Rehabilitation, 63(6): 261.
5. Smith, C., 1994. The warm-up procedure: to stretch or not to stretch. A brief review. The J. Orthopaedic and Sports Physical Therapy, 19(1): 12.
6. Wallin, D., B. Ekblom, R. Grahn and T. Nordenborg, 1985. Improvement of muscle flexibility. The American J. Sports Med., 13(4): 263.
7. Williford, H. and J. Smith, 1985. A comparison of proprioceptive neuromuscular facilitation and static stretching techniques. Am. Corr. Ther. J., 39: 30-33.
8. Etnyre, B. and E. Lee, 1988. Chronic and Acute Flexibility of Men and Women Using Three Different Stretching Techniques. Research Quarterly for Exercise and Sport, 59(3): 222-228.

9. Funk, D., A. Swank, B. Mikla, T. Fagan and B. Farr, 2003. Impact of prior exercise on hamstring flexibility: a comparison of proprioceptive neuromuscular facilitation and static stretching. J. Strength and Conditioning Res., 17(3): 489-492.
10. Atha, J. and D. Wheatley, 1976. Joint mobility changes due to low frequency vibration and stretching exercise. British J. Sports Med., 10(1): 26.
11. Cochrane, D. and S. Stannard, 2005. Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. British J. Sports Med., 39(11): 860.
12. Cronin, J., M. Nash and C. Whatman, 2007. The effect of four different vibratory stimuli on dynamic range of motion of the hamstrings. Physical Therapy in Sport, 8(1): 30-36.
13. Fagnani, F., A. Giombini, Di A. Cesare, F. Pigozzi and V. Di Salvo, 2006. The effects of a whole-body vibration program on muscle performance and flexibility in female athletes. American J. Physical Medicine and Rehabilitation, 85(12): 956.
14. Issurin, V., D. Liebermann and G. Tenenbaum, 1994. Effect of vibratory stimulation training on maximal force and flexibility. J. Sports Sci., 12(6): 561-566.
15. Jacobs, P. and P. Burns, 2009. Acute enhancement of lower-extremity dynamic strength and flexibility with whole-body vibration. The J. Strength and Conditioning Res., 23(1): 51.
16. Kinser, A., M. Ramsey, H. O'bryant, C. Ayres, W. Sands and M. Stone, 2008. Vibration and stretching effects on flexibility and explosive strength in young gymnasts. Medicine and Science in Sports and Exercise, 40(1): 133.
17. Sands, W., J. McNeal, M. Stone, E. Russell and M. Jemni, 2006. Flexibility enhancement with vibration: acute and long-term. Medicine and Science in Sports and Exercise, 38(4): 720.
18. Van den Tillaar, R., 2006. Will Whole-Body Vibration Training Help Increase the Range of Motion of the Hamstrings? J. Strength and Conditioning Res., 20(1): 192.
19. Bosco, C., M. Cardinale and O. Tsarpela, 1999. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. European J. Applied Physiol., 79(4): 306-311.
20. Kerschan-Schindl, K., S. Grampp, C. Henk, H. Resch, E. Preisinger, V. Fialka-Moser, *et al.* 2001. Whole-body vibration exercise leads to alterations in muscle blood volume. Clinical Physiol., 21(3): 377-382.
21. Norkin, C., D. White and J. White, 2003. Measurement of Joint Motion: a Guide to Goniometry: FA Davis Philadelphia.
22. Gleim, G.W., N.S. Stachenfeld and J.A. Nicholas, 1990. The Influence of Flexibility on the economy of walking and jogging. J. Orthop. Res., 8: 814-823.
23. Gajdosik, R. and G. Lusin, 1983. Hamstring muscle tightness: Reliability of an active-knee-extension test. Physical Therapy, 63(7): 1085.
24. Baltaci, G., N. Un, V. Tunay, A. Besler and S. Gerceker, 2003. Comparison of three different sit and reach tests for measurement of hamstring flexibility in female university students. British J. Sports Med., 37(1): 59.
25. Bosco, C., R. Colli, E. Introini, M. Cardinale, O. Tsarpela, A. Madella, *et al.* 1999. Adaptive respsonses of human skeletal muscle to vibration exposure. Clinical Physiology-oxford, 19: 183-187.
26. Mester, J., P. Spitzenfeil, J. Schwarzer and F. Seifriz, 1999. Biological reaction to vibration-implications for sport. J. Science and Medicine in Sport, 2(3): 211-226.
27. Draper, D., J. Castro, B. Feland, S. Schulthies and D. Eggett, 2004. Shortwave diathermy and prolonged stretching increase hamstring flexibility more than prolonged stretching alone. The J. Orthopaedic and Sports Physical Therapy, 34(1): 13.
28. Henricson, A., K. Fredriksson, I. Persson, R. Pereira, Y. Rostedt and N. Westlin, 1984. The effect of heat and stretching on the range of hip motion*. The J. Orthopaedic and Sports Physical Therapy, 6(2): 110.
29. Lythgo, N., P. Eser, P. De Groot and M. Galea, 2009. Whole-body vibration dosage alters leg blood flow. Clinical Physiology and Functional Imaging, 29: 53-59.
30. Zhang, Q., K. Ericson and J. Styf, 2003. Blood flow in the tibialis anterior muscle by photoplethysmography during foot-transmitted vibration. European J. Applied Physiol., 90(5): 464-469.
31. Cochrane, D.J., S.J. Legg and M.J. Hooker, 2004. The short-term effect of whole-body vibration training on vertical jump, sprint and agility performance. J. Strength and Conditioning Res., 18: 828-8.
32. Hollins, M., E.A. Roy and S.A. Crane, 2003. Vibratory antinociception: effects of vibration amplitude and frequency. The J. Pain: Official J. The American Pain Society, 4: 381-391.

33. Zoppi, M., M. Voegelin, M. Signorini and A. Zamponi, 2008. Pain threshold changes by skin vibratory stimulation in healthy subjects. Acta Physiologica Scandinavica, 143(4): 439-444.
34. Dahlin, L., I. Lund, T. Lundeberg and C. Molander, 2006. Vibratory stimulation increase the electro-cutaneous sensory detection and pain thresholds in women but not in men. BMC Complementary and Alternative Med., 6(1): 20.
35. Burke, D., K. Hagbarth, L. Löfstedt and B. Wallin, 1976. The responses of human muscle spindle endings to vibration of non-contracting muscles. The J. Physiol., 261(3): 673.
36. Cronin, J., M. Oliver and P. McNair, 2004. Muscle stiffness and injury effects of whole body vibration. Physical Therapy in Sport, 5(2): 68-74.
37. Magnusson, S., E. Simonsen, P. Aagaard, J. Boesen, F. Johannsen and M. Kjaer, 1997. Determinants of musculoskeletal flexibility: viscoelastic properties, cross-sectional area, EMG and stretch tolerance. Scandinavian J. Medicine and Science in Sports, 7: 195-202.
38. Ribot-Ciscar, E., C. Rossi-Durand and J. Roll, 1998. Muscle spindle activity following muscle tendon vibration in man. Neuroscience Letters, 258(3): 147-150.
39. Cardinale, M. and C. Bosco, 2003. The use of vibration as an exercise intervention. Exercise and Sport Sciences Reviews, 31(1): 3.
40. Torvinen, S., P. Kannus and H. Sievänen, 2002. Effect of four-month vertical whole body vibration on performance and balance. Medicine and Science in Sports and Exercise, 34(9): 1523.
41. Hopkins, J., D. Fredericks, P. Guyon, S. Parker, M. Gage, J. Feland, *et al.* 2008. Whole body vibration does not potentiate the stretch reflex. Int. J. Sports. Med., 30(2): 124-129.
42. De Ruiter, C., Van Der R. Linden, M. Van der Zijden, A. Hollander and A. De Haan, 2003. Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise. European J. Applied Physiol., 88(4): 472-475.
43. Hopkins, T., J. Pak, A. Robertshaw, J. Feland, I. Hunter and M. Gage, 2008. Whole body vibration and dynamic restraint. International J. Sports Med., 29(5): 424.
44. Rittweger, J., G. Beller. and D. Felsenberg, 2000. Acute physiological effects of exhaustive whole-body vibration exercise in man. Clinical Physiol., 20(2): 134-142.