The Relationship between Hip Extension Force Measured by Using a Hand-held Dynamometer and the Effect of Proprioceptive Neuromuscular Facilitation Stretching on Hamstring Flexibility

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Abstract
The purpose of this study was to investigate the relationship between hip extension force measured by using a hand-held dynamometer (HHD) and the effect of proprioceptive neuromuscular facilitation (PNF) stretching on hamstring flexibility. Many athletes try to avoid strains by excessive stress while maintaining or improving performance. It has been widely demonstrated that PNF stretching increases hamstring flexibility by decreasing active resistance. Thirty-four young men and women participated in the study. Active knee extension (AKE) was measured with a goniometer before and after hold-relax PNF stretching. Additionally, AKE data were collected at 2, 6, 10, 20, and 30 min. The maximal isometric contraction force of the hamstring was measured by using a HHD during a single set of PNF stretches (6 trials×5 s/trial). The mean forces measured by using the hand-held dynamometer were not significantly different between the trials: however, the averages of the maximum and minimum values obtained for each trial were significantly different. Hamstring flexibility at pre-stretch differed between men and women, but the immediate and sustained effects of stretching did not differ between the sexes. The isometric contraction force of the hip extensor during hold-relax PNF stretching was successfully measured and quantified with the use of a HHD. The inconsistencies in the isometric contraction force between trials might diminish the effect of stretching. The use of a HHD to monitor the effort applied by a subject and provide real-time feedback might enhance the effectiveness of stretching in the clinical field or in sports physiotherapy.

Key Words: Dynamometer, Hamstring, Proprioceptive neuromuscular facilitation stretching
Introduction

A variety of injuries that occur during exercise can result in serious muscle damage. Among them, strain injury is the most common injury, and the hamstring muscle is the most commonly injured multi-joint muscle (Safran et al., 1989). Individuals who have limited flexibility are more prone to hamstring injuries by excessive stress, and such injuries can negatively affect physical fitness and running economy (Kim MH 2008; Kim OH 2009). Therefore, hamstring flexibility is considered to be important for improving athletic performance and preventing injuries during exercise. This is applicable for both senior and young athletes. (Feland et al., 2001). Many studies have been conducted to determine effective stretching techniques to increase hamstring flexibility under a variety of conditions. Among the various stretching techniques, static stretching, ballistic stretching, and proprioceptive neuromuscular facilitation (PNF) stretching are widely used these days (Covert et al., 2010; Lim CH 2011; Kirmizigil et al., 2014; Cini et al., 2016; Hill et al., 2016; Rodriguez Fernandez et al., 2016).

In comparison with other stretching techniques, PNF stretching is known to be highly effective in increasing range of motion (ROM) (Etnyre et al., 1986a; Etnyre et al., 1986b; Osternig et al., 1990; Magnusson 1998), but the effectiveness is different by specific conditions, such as stretching time, frequency, and duration (Borms et al., 1987; Sullivan et al., 1992; Bandy et al., 1994; Bandy et al., 1997). During PNF stretching, the ROM is increased by the autogenic inhibition of the stretched muscle as a result of the stimulation of the Golgi tendon organ due to the increased tension (Moore et al., 1980; Bae SS 1993; Yuktasir et al., 2009). Many studies have demonstrated that motor pool excitability was significantly decreased by the PNF technique when compared with static stretching; this inhibitory effect enables effective muscle stretching without stimulating the stretch reflex (Etnyre 1986a; Manoel et al., 2008).

The PNF stretching technique involves the following: hold-relax, contract-relax, and contract-relax-antagonist-contract. However, unlike in the case of passive static stretching, the PNF technique requires voluntary muscle contraction by the subject. For example, in hold-relax, the intensity of stretching is driven by the voluntary contraction effort applied by the subject as the practitioner passively withstands the resistance created as a result of the contraction. However, although the voluntary contraction effort by the subject is an important factor that determines the effectiveness of stretching, it is difficult to quantify the contraction effort in the clinical field or in sports physiotherapy. It is not possible for the practitioner to quantitatively measure the contraction effort through touch. In addition, it is difficult for a subject to determine the amount of his/her own muscle contraction.

In this study, hip extension force was measured with a hand-held dynamometer (HHD) while the subjects performed the hold-relax PNF stretching and its effect on hamstring flexibility was determined. Differences between sexes were also investigated to consider strength variations between men and women.

Materials and Methods

1. Subjects

Thirty-four individuals (17 men: 17 women; mean age=21.2±1.1 years), who were college students, were recruited for this experiment. Informed consent was obtained from all subjects prior to participating in the study.

2. Procedure

Knee extension ROM was measured with a double-arm goniometer with the individual in a supine position. Before beginning the experiment, the lateral epicondyle of the femur, greater trochanter of the femur, and the lateral malleolus of the

![Fig. 1. Subject performing active knee extension to measure hamstring flexibility.](image)
Table 1. The mean force measured with hand-held dynamometer

|       | 1st trial | 2nd trial | 3rd trial | 4th trial | 5th trial | 6th trial | Min     | Max     |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|---------|---------|
| Average (N) | 155.3±35.8 | 155.1±41.8* | 160.4±40.5 | 158.9±30.0 | 160.9±37.3 | 161.6±41.0 | 135.5±30.5 | 183.7±36.5* |

Min: average minimum values, Max: average maximum values.
*p<0.05, significant difference compared to Min.

Fibular were palpated to determine the landmarks for ROM measurement. Active knee extension (AKE) was measured after the subjects performed knee extension until the discomfort point was reached while maintaining 90-degree hip flexion. To maintain 90-degree hip flexion, a custom-made metal brace was used (Fig. 1). To warm-up, all subjects performed a total of six AKEs before the experiment and the sixth AKE was recorded as pre-stretch. After the hold-relax technique, AKE was measured again and recorded as post-stretch. The subjects were given a rest break on the table after post-stretch, and additional AKE data were collected at 2, 6, 10, 20, and 30 min.

3. Stretching protocol

During each stretch, subjects performed isometric contraction of the hamstring toward the table while opposing the resistance applied by the practitioner for 5 s. At this time, a HHD (MicroFET3, Hoggan Health Industries Co., UT, USA) was placed under the heel to measure the hip extension muscle force. After performing isometric contraction, the subject’s leg was lifted by the practitioner until the discomfort point was reached. The set involved performing hold-relax PNF stretching for 5 s and repeating this 6 times: hip extension muscle force was measured with a HHD during each session.

4. Statistical analysis

Data analysis was performed using IBM SPSS version 23 for Windows (IBM Corp., Armonk, NY, USA). The repeated measures analysis of variance was used to determine the differences in the mean number of AKEs over the test periods. The Bonferroni test was used to test for pairwise differences. All values are presented as mean±standard deviation. The significance level was set at p<0.05.

Results

There was no significant difference in mean force measured by the HHD (Table 1). When all six trials were considered, the mean force did not decrease, and the range remained constant (155.1 to 161.6). However, the average minimum (min) and maximum (max) values for each subject differed considerably (p<0.001).

The post-stretch AKE value measured immediately after stretching significantly decreased (p<0.001) and did not differ from the AKE value at 6 min (p=0.451) (Fig. 2). The rapid rise of AKE values was observed until 10 min. The AKE values at 10, 20, and 30 min remained constant and did not differ from the pre-stretch values.

The pre-stretch values differed between men and women, but there was no difference in the sustained effect of stretching on hamstring flexibility over time. A significant difference was only observed in both men (p=0.021) and women (p=0.015) at post-stretch when compared with pre-stretch (Table 2). The AKE values at pre-stretch were not different compared with the AKE values even at 2 min.

Discussion

Hamstring strain injury is one of the most common exercise-induced injuries, and increased hamstring flexibility can prevent such injuries. Various stretching techniques are used to improve
flexibility (Chang et al., 2002), among which the PNF technique is known to be highly effective in increasing ROM; however, there is still some controversy regard this technique. During stretching, resistance is affected by both the viscoelastic properties of the tissues and the contractile components (Condon et al., 1987). The PNF technique is considered to increase flexibility by decreasing active resistance (Osternig et al., 1990). Unlike other stretching techniques, the PNF stretching technique requires voluntary muscle contraction by the subject, and it is hard to quantitatively measure the extent of contraction. In this study, the isometric contraction of the hip extensor was successfully measured and quantified with a hand-held dynamometer during hold–relax PNF stretching.

The mean forces were constant from the 1st to the 6th trial, and no significant difference in values was observed between trials. A decrease in strength due to fatigue over time was not observed in this study. However, a significant difference was noted when the total average of each min and max value was calculated for the 6 trials. That is, no difference between trials was observed during the 6 trials if the total average value for the group was considered, but the values of each subject were not constant during the 6 trials. The strength applied by the subjects was not constant between trials, and there was a considerable difference between the max and min values. During isometric contraction, the strength can be changed for each trial. To ensure that PNF stretching has the desired effect, the practitioner should continuously provide verbal encouragement and stimulation to encourage the subject to maintain constant isometric contraction.

The AKE value at pre–stretch did not differ from the value obtained at 2 min. Although there was no significant difference between the values taken at the different time points, the values gradually increased from 6 min. The 5 AKEs performed during warm–up might have temporarily improved hamstring flexibility, decreasing the AKE value at pre–stretch. However, the warm–up effects were diminished because permanent deformity caused by sustained stimulation was not observed in this study. After 10 min, the AKE value returned to the pre–warm–up value and was considerably higher than the pre–stretch AKE value. From pre–stretch to 30 min, two distinct trend lines—one with a rapid increase and the other in a steady state—were observed. The AKE value that decreased due to stretching increased quickly and reached the pre–stretch level within 10 min. The sudden rise in the AKE value remained steady after 10 min. These results were consistent with the results of other previous study (Spernoga et al., 2001).

With regard to differences in hamstring flexibility between men and women, women were observed to have slightly higher flexibility before stretching; however, there was no statistically significant difference in effects of stretching on hamstring flexibility between the sexes. The higher value observed in the women during pre–stretch could be explained by the fact that the women have relatively higher ROM than men (James et al., 1989; Chaparro et al., 2000; Doriot et al., 2006). However, there was no difference in the increase in knee extension ROM after PNF stretching and in the sustained effect between the 2 groups. In conclusion, there was a fundamental difference in flexibility between the men and women; however, the hold–relax PNF stretching performed for a total of 30 s (6 trials×5 s/trial) did not significantly affect this fundamental difference in flexibility between men and women.

This study had limitations. The first one was that the effect of the intensity could not be fully studied owing to the short time and total duration of stretching. A single stretch is not enough to cause a deformity that would lead to permanent tissue change. The increased flexibility due to the viscoelastic properties of the tissues quickly returns to the original condition, and the decrease in stiffness induced by stretching get reversed due to the thixotropic properties of the tissue if there is no

| Table 2. The difference in active knee extension values between men and women |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | PRE             | POST            | 2 min           | 6 min           | 10 min          | 20 min          | 30 min          |
| Men             | 27.6±11.4       | 20.8±10.0       | 22.3±8.9        | 27.2±7.7        | 29.2±7.2        | 29.7±8.4        | 30.7±9.7        |
| Women           | 16.8±11.6       | 12.6±9.9*       | 15.9±10.0       | 17.8±11.6       | 20.2±12.6       | 21.2±13.3       | 22.0±13.2       |

PRE: Pre-stretch, POST: Post-stretch.
*p<0.05, significant difference compared to pre-stretch.
additional movement after stretching (Lakie et al., 1984; Hagbarth et al., 1985; Lakie et al., 1988; Walsh 1992). It is known that routine stretching is required to maintain the effect that is transiently acquired after stretching (Tanigawa 1972; Osternig et al., 1990). The other limitation of this study was that the value measured with the HHD was not the mean force for the entire 5–s duration of a trial because the max value is only displayed on the screen of the device after completion of a trial. Therefore, future studies will be required to investigate the relationship between hip extension strength represented by the mean force, and not a max value, and hamstring flexibility during long-duration stretching.

In conclusion, hip extension muscle force was successfully measured with a HHD during hold-relax PNF stretching to increase hamstring flexibility, and it was found that the voluntary effort applied by the subjects was not consistently maintained between trials. Apart from the duration and frequency of stretching, the voluntary effort applied by a subject during PNF stretching is important, and ensuring that a constant intensity is maintained by measuring the subject’s quantitative strength between attempts will be beneficial to achieving a durable stretching effect. Additionally, providing feedback to subjects in real time based on the value displayed on the screen will be very useful in motivating subjects and achieving effective stretching in the clinical field or sports physiotherapy.

References

Alexander M, Petronis J , Davis D (2010) Comparison of ballistic and static stretching on hamstring muscle length using an equal stretching dose. J Strength Cond Res, 24(11), 3008-3014.
Bae SS (1993) A study of proprioceptive neuromuscular facilitation principles. J Kor Soc Phys Ther, 5(5), 109–114.
Bandy W, Iiron J (1994) The effect of time on static stretch on the flexibility of the hamstring muscles. Phys Ther, 74(9) 880-890; discussion 890-894.
Bandy W, Iiron J, Briggler M (1997) The effect of time and frequency of static stretching on flexibility of the hamstring muscles. Phys Ther, 77(10), 1090–1096.
Bompa, T., Van Roy P, Santos J, et al. (1984) Duration of static stretching exercises for improvement of coxo-femoral flexibility. J Sports Sci, 2(11), 39–47.
Chang C, Jeong D, Park R (2002) A Review of Conception and Developmental Process of Stretching in Sports Physical Therapy. J Kor Soc Phys Ther, 14(4), 423-440.
Chapparo A, Rogers M, Fernandez J et al. (2000) Range of motion of the wrist: implications for designing computer input devices for the elderly. Disabil Rehabil, 22(13-14), 633–637.
Ciri A de Vasconcelos G, Lima C (2016) Acute effect of different time periods of passive static stretching on the hamstring flexibility. J Back Musculoskeletal Rehabil. doi: 10.3233/BMR-160740.
Condon S, Hutton R (1987) Soleus muscle electromyographic activity and ankle dorsiflexion range of motion during four stretching procedures. Phys Ther, 67(11), 24–30.
Doriot M, Wang X (2006) Effects of age and gender on maximum voluntary range of motion of the upper body joints. Ergonomics, 49(3), 269–281. doi: 10.1080/00140130600596873.
Enby E, Abraham L (1990) Gains in range of ankle dorsiflexion using three popular stretching techniques. Am J Phys Med, 69(4), 189–196.
Etnyre B, Abraham L (1986a) H-reflex changes during static stretching and two variations of proprioceptive neuromuscular facilitation techniques. Electroencephalogr Clin Neurophysiol, 63(2), 174–179.
Foland J, Myer J, Schulzies S et al. (2001) The effect of duration of stretching of the hamstring muscle group for increasing range of motion in people aged 65 years or older. Phys Ther, 81(5), 1110–1117.
Hagbarth K, Hagglund J, Nordin M et al. (1985) Thixotropic behaviour of human finger flexor muscles with accompanying changes in spindle and reflex responses to stretch. J Physiol, 358, 326-342.
Hill K, Robinson K, Cuchna J et al. (2016) Immediate Effects of PNF Stretching Programs Compared to Passive Stretching Programs for Hamstring Flexibility: A Critically Appraised Topic. J Sport Rehabil. doi: 10.1123/jsr.2016-0003.
James B, Archer K, Aeschleman J, et al. (1985) Active and passive mobility of lower limb joints in elderly men and women. Am J Phys Med, 64(4), 162–167.
Kim MH (2008) Stretching for Relax of Body and Mind, Korean J. Stress Res. 16:175-179.
Kim J (2009) The Effects of Dance Movement Therapy Program on Somatization, Depression, Kirmizi B, Ozcaldiran B, Colakoglu M (2014) Effects of three different stretching techniques on vertical jumping performance. J Strength Cond Res, 28(5), 1263-1271.
Lakie M, Roberson, L (1988) Thixotropic changes in human muscle stiffness and the effects of fatigue. J Exp Physiol, 73(4), 487–500.
Lim C (2011) Effects of Static, Dynamic, PNF Stretching on the Isokinetic Peak Torque. J Kor Soc Phys Ther, 23(3), 37–42.
Magnusson S (1998) Passive properties of human skeletal muscle during stretch manoeuvres. A review. Scand J Med Sci Sports, 8(2), 65-77.
Manuel M, Harris-Love M, Danoff J et al. (2008) Acute effects of static, dynamic, and proprioceptive neuromuscular facilitation stretching on muscle power in women. J Strength Cond Res, 22(5), 1528–1534.
Moore M, Hutton R (1980) Electromyographic investigation of muscle stretching techniques. Med Sci Sports Exerc, 12(5), 322-329.
Osternig L, Robertson R, Travell R et al. (1990) Differential responses to proprioceptive neuromuscular facilitation (PNF) stretch techniques. Med Sci Sports Exerc, 22(1), 106–111.
Rodriguez Fernandez A, Sanchez J, Rodriguez Marroyo J et al. (2016) Effects of seven weeks of static hamstring stretching on flexibility and sprint performance in young soccer players according to their playing position. J Sports Med Phys Fitness, 56(4), 345–351.
Safar M, Seaber A, Garnett W, Jr, (1989) Warm-up and muscular injury prevention. An update. Sports Med, 8(4), 239–249.
Spernoga S, Uhl T, Arnold B et al. (2001) Duration of Maintained Hamstring Flexibility After a One-Time, Modified Hold-Relax Stretching Protocol. J Athl Ther, 36(1), 44-48.
Sullivan M, Dekuila J, Worrell T (1992) Effect of pelvic position and stretching method on hamstring muscle flexibility. Med Sci Sports Exerc, 24(12), 1383–1389.
Tanigawa M (1972) Comparison of the hold-relax procedure and passive mobilization on increasing muscle length. Phys Ther, 52(7), 725–735.
Walsh E (1992) Postural thixotropy: a significant factor in the stiffness of paralysed muscle. J Physiol, 353, 771-781.
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