Effects of 8-week Static Stretch and PNF Training on the Angle-torque Relationship

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Abstract

This study tested the hypothesis that the extent of enhancement in muscle strength following an 8-week program of static stretch (SS) and proprioceptive neuromuscular facilitation (PNF) training would be related to a shift in optimum angle (OA) toward a longer muscle length. Thirty healthy males were randomly assigned into SS, PNF, and control (CON) groups (n = 10 per group). The SS and the PNF groups engaged in flexibility training three times per week for eight weeks, while the CON group underwent no training during this time. Passive range of motion (P-ROM) of the hip and maximal isokinetic concentric strength (ISO) at the angular velocity of 60°/s (i.e, the angle-torque relationship) were measured before and after training for all groups. The results of this study showed that compared to before training, the P-ROM values of both the SS (25°) and PNF (31°) groups were significantly increased ($P < 0.05$) after training, while those of the CON group remained unchanged ($P > 0.05$). In addition, after the training, both the SS and PNF groups saw a significant increase in ISO (SS: 13%; PNF: 17%; $P < 0.05$), and a marked shift of the OA toward a longer muscle length (SS: 9°; PNF: 10°; $P < 0.05$). The CON group, however, saw no significant change in either of these two variables. There was a positive correlation ($P < 0.05$) between the increase in ISO and the shift of OA toward a longer muscle length for the SS ($r = .69$) and PNF ($r = .78$) groups after training. It was concluded that eight weeks of SS and PNF training can not only effectively improve flexibility, but also increase ISO and cause a shift of OA toward a longer muscle length.

Keywords: Flexibility training, Maximal isokinetic concentric strength (ISO), Passive range of motion (P-ROM), Optimum angle (OA)

1. Introduction

Stretching is classified into five different types, based upon technique [1]: dynamic stretching; static stretching (SS); stretching immediately after a short and almost maximal isometric contraction of the muscle (contract-relax, CR); stretching by antagonist contraction; and stretching by antagonist contraction after agonist contraction (CRAC), as a combination of CR and stretching by antagonist contraction. Among these, SS and proprioceptive neuromuscular facilitation (PNF), such as CR and CRAC, are techniques that have been used to achieve and maintain flexibility [2].

Flexibility is generally defined as the range of motion (ROM) around a joint or group of joints, and reflects the ability of the muscle-tendon unit to elongate [3]. Flexibility has long been recognized as an important component of physical fitness and rehabilitation. It is widely conjectured that benefits of good flexibility include the reduction and prevention of injury risk, and enhanced sports performance [4-6]. Although these are the reasons that many persons participate in stretching, current study provides inconsistent evidence of the effectiveness of stretching in injury prevention or in enhancing muscle performance [5,7-9]. The effects of short- and long-term stretching on the improvement of muscle strength were reviewed by Shrier [10]. The review concluded that long-term stretching training may actually improve muscle strength through stretch-induced hypertrophy; acute bouts of stretching, however, may be detrimental to exercise performance. Many previous studies have also reported that acute bouts of stretching before exercise reduce muscle strength and nervous activation of muscle [11-15]. These results suggested that

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pre-exercise stretching has minimal benefit for preventing injury.

In contrast, nine previous studies have investigated the effects of long-term stretching training on strength, six of which found beneficial effects [4,6,16-19] but three of which showed no effect [20-22]. For example, Handel et al. [4] reported improved strength in male athletes' quadriceps (23%) and hamstrings (11-18%) after 8 weeks of CR training (3 days/week, 10 min/day), with significant increases in the range of active and passive motion in knee flexion (3–6°) and extension (6°). More recently, Kokkonen et al. [6] recruited 8 male and 11 female athletes to participate in 10 weeks of SS training (3 days/week, 40 min/day) designed to stretch all of their major lower-extremity muscle groups (i.e., hamstrings, quadriceps, adductors, abductors, external and internal rotators, plantar flexors, and dorsiflexors). Results showed that SS training led to significant improvements for knee flexion (15%) and knee extension (32%) one-repetition maximal (1-RM). Moreover, Hortobágyi et al. [18] found enhancements in fast isometric force development and in the speed of concentric contractions. However, Dintiman [20], Hunter and Marshall [21], and LaRoche et al. [22] found no significant changes in strength and flexibility after less than 4-week stretching training. Possible reasons for these inconsistent results among the aforementioned studies could be related to the lack of uniformity in the experimental methods and the age differences among the aforementioned studies, as the studies differed in terms of stretch type, stretch intensity, target muscle groups, frequency of training and duration.

It has been reported that a shift of the optimum angle (OA) toward a longer muscle length is probably caused by increases in the number of sarcomeres in series, suggesting that increases in sarcomere number in series are associated with the protective effect [23-25]. It has also been reported that the smaller OA (40.9 ± 2.7°) of previously injured hamstrings in athletes makes them prone to damage from eccentric exercise than uninjured hamstrings (29.8 ± 1.5°), and this may account for the high re-injury rate [26]. Cox et al. [27] found that in rabbits, incrementally applied static stretching over 3 weeks resulted in a 72% increase in the weight of the in situ latissimus dorsi muscle; a 130% increase in the protein content; a 30% increase in the cross-sectional area of the type I fibers; and a 25% increase in muscle length. However, among all of the abovementioned studies, only the study by LaRoche et al. [22] explored the effects of long-term flexibility training on muscle strength, flexibility and OA in humans. That study found that 4 weeks of flexibility training were unable to effectively improve muscle strength and flexibility, or to cause any significant change in OA. One possible explanation for this is that 4 weeks of flexibility training was not long enough to produce any observable changes in muscle strength, flexibility or OA, since it has been reported that the duration of SS training lasting 6 weeks can significantly improve flexibility [28,29].

It is important to clarify whether the significant improvement in muscle strength caused by longer flexibility training (> 6 weeks) is related to the shift in OA toward a longer muscle length. Since the angle-torque relationship produced during isokinetic concentric muscle actions has been often used as the best means to investigate the angle-torque relationship for sarcomeres in human [23,24,26], the values that represent the angle-torque relationship could provide indirect information about the mechanical factors underlying the flexibility training-induced enhancement of strength. Thus, the purpose of the present study was to test the hypothesis that the extent of enhancement in muscle strength following an 8-week program of SS and PNF training would be related to a shift in OA toward a longer muscle length.

2. Methods

2.1 Subjects and groups

Thirty young males, who had not performed regular resistance, endurance or flexibility training in the past one year, provided informed consent to participate after the study was approved by the Institutional Ethics Committee, in conformity with the Declaration of Helsinki. Subjects' mean (± SD) age, height, and body weight were 22.0 ± 2.1 yrs, 173.6 ± 5.0 cm, and 67.7 ± 7.1 kg, respectively. Subjects were placed into one of three groups–control (CON), SS, and PNF–by matching the baseline straight-leg-raise (SLR) passive range of motion (P-ROM; flexibility) of the hip among the groups (n = 10 per group). The CON, SS, and PNF groups had similar mean flexibility, with no significant differences ($P > 0.05$) in age, height, body weight, P-ROM or maximal isokinetic concentric strength (ISO; $60°\cdot s^{-1}$) evident across groups. All subjects were asked to refrain from unaccustomed exercise or vigorous physical activity, and from taking any anti-inflammatory drugs or nutritional supplements during the experimental period.

2.2 Procedures

Following familiarization procedures, which took place 2–6 days prior to flexibility training, baseline measures of hip P-ROM, and ISO (where the full knee extension angle equated to 0°) were assessed for all subjects. Before these measures, all subjects performed a standardized 10-minute warm-up, followed by 5 minutes of static stretching [30]. For the next 8 weeks, the SS and PNF groups met 3 times per week and followed a protocol that included a 10-minute warm-up session as described previously, followed by investigator-led SS or PNF. SS and PNF sessions were taken a minimum of 24 hours apart, and both legs were stretched to minimize muscle imbalances that could result in future injuries [30]. Subjects assigned to the CON group were instructed to maintain their normal activities. Three days after the 8 weeks of flexibility training, flexibility, OA, and ISO were reassessed. The test-retest reliability of the criterion measures was established prior to this study using the data taken 2–6 days apart by an intraclass correlation coefficient (ICC_1) using a statistical software package (SPSS 12.0). The R-values for flexibility, ISO, and OA were more than 0.88.

It should be noted that the SS and PNF protocols were the same as that used by LaRoche et al. [22] and Rowlands et al. [30], respectively, but the duration of training was set to

8 weeks instead of 4–6 weeks used in the aforementioned studies [8,22,30]. Our SS and PNF procedures can be found in previous related studies for further details [8,22,30]. Moreover, the method of assessing SLR P-ROM at the hip was adopted from a previous study [30], and further details regarding the SLR P-ROM procedures can be found in previous related studies [30].

SS sessions were held 3 times per week over a period of 8 weeks, and the total of static stretch duration was 360 minutes. The PNF group performed 5 sets of static stretching separated by 30 seconds before PNF, and performed 2 sets of 10-second static stretching 6 times during PNF. Stretching sessions were held 3 times per week over an 8-week period, for a total static stretching and MVC duration of 108 minutes and 48 minutes, respectively.

The reasons for choosing the same 8-week duration of training but inconsistent total duration for SS and PNF groups were as follows: (a) a previous study showed that 3–6 weeks of similar PNF training protocol was sufficient to increase flexibility associated with the hamstrings [30]; (b) the duration of SS training can significantly improve flexibility requiring 6 weeks [28,29]; and (c) in order to make sure that both SS and PNF training could significantly improve flexibility in this study, we decided to adopt the same SS [8,22] and PNF [30] protocols from the aforementioned studies but extended their duration of training to the same 8-week length.

The ISO protocol was similar to that used by Brockett et al. [24,26], but the testing posture was set to a prone position instead of a seated position. The ISO procedures and gravity corrections for limb mass have been described in previous related studies [24,26]. Briefly, subjects in this study performed a bout of 6 ISO using an isokinetic dynamometer (Biodex System 3 Pro; Biodex Medical Systems, Inc., Shirley, NY, USA) at the angular velocity of $60°\cdot s^{-1}$, while in a fully prone position. All testing took place on the non-dominant leg. All subjects were instructed to resist the lever arm from a knee-extended position (0°) to a knee-flexed position (130°) in 2.3 seconds, keeping the velocity ($60°\cdot s^{-1}$) constant for the movement. After each concentric action, the lever arm of the isokinetic dynamometer ($10°\cdot s^{-1}$) was passively returned to the start position. The movement was repeated every 13 seconds between contractions. Strong verbal encouragement was provided during isokinetic measurement. The peak torque during ISO tests and OA of peak torque for each contraction were assessed by using software provided by the same Biodex Systems, and the average of the three trials for each time-point was used for subsequent analysis.

2.3 Statistical analyses

Baseline measures were compared among the groups using a one-way independent-measures analysis of variance (ANOVA). Normalized changes in flexibility, OA, and ISO after flexibility training among the groups were also compared by using a one-way ANOVA. When a significant main effect was evident, a Bonferroni post hoc test was conducted. Changes in the flexibility, ISO and OA following the 8 weeks of flexibility training were assessed among the groups by a mixed-design of two-way ANOVA. If the ANOVA found a significant effect (groups, time, or groups x time), a Bonferroni post-hoc test was performed. The Pearson product-moment correlation coefficient was also used to determine relationships between the increasing percentage of ISO and the rightward shift of OA after training. Statistical significance was accepted at $P < 0.05$. Data were presented as mean ± SD, unless otherwise stated.

3. Results

3.1 SS and PNF training on flexibility

All subjects in the CON, SS, and PNF groups had similar hip flexibility before flexibility training ($P > 0.05$) and the hip flexibility of all subjects ranged from 97.7 to 101.6º (Table 1). Following the 8 weeks of SS and PNF training, the SS and PNF groups showed significant flexibility improvement (SS: 25º; PNF: 31º; $P < 0.05$), while the CON group showed no significant change ($P > 0.05$). No significant difference ($P > 0.05$) was seen between the SS and PNF groups in terms of flexibility improvement.

Table 1. Changes in passive range of motion (º) at the hip (mean ± SD) before (Pre) and after (Post) 8-week flexibility training for the control (CON), static stretch (SS), and proprioceptive neuromuscular facilitation (PNF) groups.

	Pre	Post	Percentage Δ
CON (n = 10)	101.6 ± 11.8º	103.3 ± 11.6º	1.6 ± 0.9%
SS (n = 10)	99.5 ± 14.8º	124.4 ± 13.8º*	25.9 ± 11.6%*
PNF (n = 10)	97.7 ± 12.0º	128.3 ± 13.2º*	33.0 ± 15.2%*

*Significantly higher than CON ($P < 0.05$); no significant difference was found between SS and PNF ($P > 0.05$).

3.2 SS and PNF training on ISO and OA

Prior to flexibility training, the CON, SS, and PNF groups showed no significant difference ($P > 0.05$; Table 2) in the OA of peak ISO. Following the 8 weeks of SS and PNF training, the SS and PNF groups showed a shift in OA toward a longer muscle length of 9º and 10º, respectively ($P < 0.05$), while the CON group showed no significant change ($P > 0.05$; Table 2).

Table 2. Changes in optimum angle (º) of generating maximal isokinetic concentric strength (ISO) at the hamstrings (mean ± SD) before (Pre) and after (Post) 8-week flexibility training for the control (CON), static stretch (SS), and proprioceptive neuromuscular facilitation (PNF) groups.

	Pre	Post	Percentage Δ
CON (n = 10)	36.8 ± 9.6º	35.8 ± 10.5º	-3.6 ± 4.3%
SS (n = 10)	37.7 ± 8.9º	29.1 ± 9.9º*	-23.2 ± 11.6%*
PNF (n = 10)	35.3 ± 9.1º	25.1 ± 10.8º*	-30.1 ± 12.5%*

*Significantly lower than CON ($P < 0.05$); no significant difference was found between SS and PNF ($P > 0.05$).

Similar results were seen for ISO (Table 3). Prior to flexibility training, the CON, SS, and PNF groups had similar ISO ($P > 0.05$; Table 3). Following the 8 weeks of SS and PNF training, the ISO of the SS and PNF groups had increased by 13% and 17%, respectively, while that of the CON group showed no significant improvement ($P > 0.05$; Table 3). The extent of ISO increase showed no significant difference ($P>0.05$) between the SS and PNF groups.

Table 3. Changes in peak ISO (Nm) at the optimum angle of the hamstrings (mean ± SD) before (Pre) and after (Post) 8-week flexibility training for the control (CON), static stretch (SS), and proprioceptive neuromuscular facilitation (PNF) groups.

	Pre	Post	Percentage Δ
CON (n = 10)	73.7 ± 17.0 Nm	74.5 ± 18.7 Nm	1.3 ± 2.0%
SS (n = 10)	74.5 ± 19.1 Nm	84.2 ± 18.9 Nm*	13.2 ± 14.5%*
PNF (n = 10)	71.3 ± 20.8 Nm	83.4 ± 19.2 Nm*	16.8 ± 15.8%*

*Significantly higher than CON (P < 0.05); no significant difference was found between SS and PNF (P > 0.05).

3.3 Correlations between a shift in OA toward a longer muscle length and enhanced ISO after flexibility training

There was a direct positive correlation between the shift in OA toward a longer muscle length and the percentage by which peak ISO improved after training for the SS (r = .69, P < 0.05) and PNF (r = .78, P < 0.05) groups, respectively.

4. Discussion

The results of the present study showed that following the 8 weeks of training, the SS and PNF groups both experienced a significant increase in ISO and in P-ROM of the hips, and a clear shift of the OA toward a longer muscle length (Tables 1–3). No significant difference was seen between the SS and PNF groups for any of the abovementioned three variables (Tables 1–3). Moreover, there was a positive correlation between the magnitude of ISO increase following SS and PNF training and the extent of the shift of OA to a longer muscle length (Tables 2–3). Therefore, these data supported our hypothesis that SS and PNF training can improve flexibility and strength, and alter the angle-torque relationship of muscles.

Passive hamstring muscle stiffness had been reported to correlate with the maximum SLR P-ROM test [31]. Although the measurement of the SLR P-ROM is inherently subjective, and may be affected by subjects' ability to tolerate the discomfort of passive stretching, this type of test was easy to administer. It also had a high application value and was generally considered to be a very good test of flexibility. Therefore, the present study used the SLR P-ROM test to evaluate the flexibility and extensibility of subjects' hamstrings before and after the 8 weeks of SS and PNF training. Results of this study showed that the 8 weeks of training did indeed significantly improve hip flexibility (SS: 25º; PNF: 31º; Table 1). These results supported the findings of previous studies [4,6,16,30,32], that long-term SS and PNF training significantly enhanced flexibility, and provided further support of the positive effects of long-term SS and PNF training on joint flexibility.

The present study found that 8 weeks of SS and PNF training led to a marked increase in the ISO of both the SS (13%) and PNF groups (17%; Table 3). These results supported the findings of previous studies [4,6,16,32] that, "flexibility training can effectively enhance muscle strength." For example, Handel et al. [4] found that after athletes underwent 8 weeks of CR training (3 days/week, 10 mins/day) of the quadriceps femoris muscles and the hamstrings, the isokinetic eccentric strength of both the quadriceps femoris muscles (23%) and hamstrings (18%) saw a significant increase, as did the isometric strength of hamstrings (11%), and ISO of hamstrings (9%). Kofotolis et al. [30] found that following 8 weeks of PNF training (3 days/week) of the lower limb muscles (3 sets × 30 maximal resistance), the ISO of subjects' quadriceps saw a marked increase (10–14%). Kokkonen et al. [6] found that after untrained subjects underwent 10 weeks (3 days/week, 40 mins/day) of SS flexibility training of various muscle groups of the lower limbs, there was a significant improvement in both knee flexion (15%) and knee extension 1-RM (32%). Thus, the results of the present study and those mentioned above suggested that long-term SS and PNF training had the same effects as resistance training in terms of increasing muscle strength.

As for why long-term flexibility training improves muscle strength, one possible explanation could lie in the adaptations such as training causes in muscle structure or cells. Handel et al. [4] reported a significant increase in leg circumference (8 mm) in humans after 8 weeks of CR training. It has been reported that when soleus muscles are stretched three times (40 minutes) per week for 3–4 weeks, muscle mass increases by 13% and fiber area by 16–30% in animal models [33,34]. Similar findings were reported by Cox et al. [27], who found that incrementally applied static stretching over 3 weeks resulted in a 72% increase in the weight of the in situ latissimus dorsi muscle, a 130% increase in the protein content, and a 30% increase in the cross-sectional area of type I fibers in rabbits. Further human study is needed to determine the actual mechanisms behind the ability of long-term flexibility training to enhance muscle strength.

Another possible explanation for the ability of flexibility training to boost muscle strength could be the resulting increase in the number of sarcomeres in series. It has been reported that a shift of OA toward a longer muscle length is probably caused by increases in sarcomere number in series, suggesting that increases in sarcomere number in series are associated with the protective effect [23-25]. The present study found that following 8 weeks of SS and PNF training, both the SS and PNF groups experienced a significant shift of the OA toward a longer muscle length (SS: 9°, PNF: 10°; Table 2). In addition, a positive correlation was found between the increase in ISO and the shift of the OA toward a longer muscle length (r = .69–.78). Currently no other data exist comparing the relationship between long-term flexibility training in humans and changes in OA, against which we can compare our findings. However, studies on animals [27] can provide some initial support for the present study's findings about the logic behind the shift in OA toward a longer muscle length. Cox et al. [27] found that incrementally applied static stretching over a 3-week period of the latissimus dorsi muscle in rabbits resulted in a 25% increase in the number of sarcomeres in series. These results would suggest that part of the reason why flexibility training leads to an increase in ISO might be related to an increase in sarcomere numbers in series. When sarcomere numbers increase, this might cause the tension that occurs when a muscle performs an eccentric contraction to be smaller than prior to flexibility training. This decreased tension would reduce the occurrence of muscle damage, or reduce the severity of muscle damage when such damage does occur [25]. Furthermore, Brockett et al. [26] found that the smaller OA of previously injured hamstrings makes them were prone to damage from eccentric exercise than uninjured hamstrings, and this may account for the high re-injury rate in athletes. Thus, the results of the present study and those mentioned above may serve as proof that long-term SS and PNF training not only improve muscle strength, but also might be a way to prevent or reduce the muscle damage that results from exercise. Further studies are needed to explore whether the protection effect, which is produced as a result of long-term flexibility training, would prevent the muscle damage caused by maximal eccentric exercise.

5. Conclusion

The results of the present study showed that 8 weeks of SS and PNF training could significantly improve flexibility and muscle strength, and could cause a shift of the OA toward a longer muscle length. These results may provide more information concerning the benefits of incorporating an SS or PNF training program into a person's weekly activities. Therefore, it is concluded that regularly performing long-term flexibility exercise provides more physical benefits than just an increased joint ROM. Further studies can explore the protection effect after a long-term flexibility training program against the subsequent muscle damage caused by maximal eccentric exercise.

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