Effects of Proprioceptive Neuromuscular Facilitation Stretching and Static Stretching on Maximal Voluntary Contraction

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Abstract

Miyahara, Y, Naito, H, Ogura, Y, Katamoto, S, and Aoki, J. Effects of proprioceptive neuromuscular facilitation stretching and static stretching on maximal voluntary contraction. *J Strength Cond Res* 27(1): 195–201, 2013—This study was undertaken to investigate and compare the effects of proprioceptive neuromuscular facilitation (PNF) stretching and static stretching on maximal voluntary contraction (MVC). Thirteen male university students (age, 20 ± 1 years; height, 172.2 ± 4.6 cm; weight, 68.4 ± 6.7 kg; mean ± *SD*) completed 3 different conditions on 3 nonconsecutive days in randomized order: static stretching (SS), PNF stretching (PNF), and no stretching (control, CON). Each condition consisted of a 5-minute rest accompanied by one of the following activities: (a) control, (b) SS, or (c) PNF stretching. The hip flexion range of motion (ROM) was evaluated immediately before and after the activity. The MVC of knee flexion was then measured. Surface electromyography was recorded from the biceps femoris and vastus lateralis muscles during MVC tests and stretching. Although increases in ROM were significantly greater after PNF than after SS ($p < 0.01$), the decreases in MVC were similar between the 2 treatments. These results suggest that, although PNF stretching increases ROM more than SS, PNF stretching and SS is detrimental to isometric maximal strength.

Key Words flexibility, hamstring muscles, knee flexion, isometric contraction, warm-up

Introduction

Stretching is widely used by many athletes before exercise training and competition (33,34) because it increases range of motion (ROM) and it is commonly believed that increased ROM contributes not only to injury prevention but also to improved athletic performance (1). Although stretching of various kinds such as static stretching (SS), ballistic stretching, dynamic stretching, and proprioceptive neuromuscular facilitation (PNF) stretching are known (19), only PNF stretching includes contraction of target muscles and the anatomical antagonist and stretching of target muscles. The purpose of the procedure in PNF stretching is to decrease the excitability of the motor neuron pool by autogenic inhibition and reciprocal inhibition (12,15). It is believed that the greater motor pool inhibition reduces muscle contractibility, makes muscles more compliant, and provides greater potential for muscle lengthening than common SS does (12). The PNF methods of 2 kinds are well known. One is called "Contract or Hold Relax Agonist Contract" (CRAC or HRAC), which includes both autogenic and reciprocal inhibitions. Another is called "Contract or Hold Relax" (CR or HR), which includes mainly autogenic inhibition (20). However, the additional effect of PNF being superior to SS was not confirmed in earlier studies. Some reports have described that PNF stretching increased ROM more than SS did (11,32). Other reports have described that although ROM is increased, the effect of PNF stretching is similar to that of SS (6,8,14,16,17,22). Although many reasons for the conflict are proposed, such as differences of PNF methods used, target muscles, types of contraction, and characteristics of subjects, the conflict is not well explained because only performance data are available in some study.

Although stretching has a positive effect on ROM improvement, it is often reported to have a detrimental effect on muscular performance (2–5,9,10,13,21,24,26–28,31,36). For example, SS decreased 1-repetition maximum (1RM) (21), maximal voluntary contraction (MVC) (4,13,28), jump performance (5,9), and sprint performance (27). Stretching-induced impairment of muscular performance seems to be partly associated with lowered stiffness and lengthening of the target muscle (2,36). Therefore, it is postulated that PNF stretching also impairs muscular performance. In fact, some studies have demonstrated decreased capability in vertical

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27(1)/195–201

Journal of Strength and Conditioning Research
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jumping after CR (5) and CRAC (7) and in isokinetic concentric muscular strength after CR (24). However, one study showed that CR did not change concentric or drop jump performance (39). In addition, if PNF stretching can provide greater increase of ROM, then the detrimental effects of PNF stretching on MVC would be greater than those of SS. However, no data related to this point are available. It is important to resolve this problem to expand knowledge about the effects of PNF stretching on muscular performance. Marek et al. (24) recently reported that the ROM of the knee joint increased and that the isokinetic strength of the quadriceps muscles decreased after CR and SS. However, the improvements of ROM were slight and were not different between the types of stretching. To expect greater changes in the ROM, we selected hamstring muscles (hip joint) as target muscles and used the CRAC method, which is expected to cause both autogenic and reciprocal inhibitions. Furthermore, we recorded neuromuscular activities of the biceps femoris muscle as a target muscle and the vastus lateralis muscle as the antagonist during stretching procedures and muscular contractions.

Methods

Experimental Approach to the Problem

We used a counterbalanced, within-subjects experimental design to assess the acute effects of 2 conditions of stretching on MVC, integrated electromyography (iEMG), and ROM (Figure 1). Seven days before the experiment, all the subjects were familiarized with the experimental protocol. The subjects completed 3 different conditions: nonstretching (control, CON), SS, and PNF stretching (PNF). The order in which conditions were measured was assigned randomly on 3 nonconsecutive days to rule out order effects.

When the subjects reported to the laboratory, they rested on a chair for 5 minutes. Then, each subject completed 4 activities: (a) prestretching ROM measurements, (b) nonstretching (rest) or static or PNF stretching, (c) poststretching ROM measurements, and (d) MVC measurements. The iEMG was measured for activities in (b) and (d). All measurements were conducted using the subject's dominant leg: the leg used to kick a soccer ball. The average room temperature and the relative humidity of the laboratory were, respectively, 21.5 ± 0.4° C and 48.5 ± 4.9% (mean ± *SD*).

Subjects

Thirteen healthy male students (age, 20 ± 1 years; height, 172.2 ± 4.6 cm; weight, 68.4 ± 6.7 kg; mean ± *SD*) volunteered to participate in this study. All the subjects were active in approximately 2–3 hours of recreational and competitive sports training or competition 3–4 times per week. None reported any current or recent injury. Appropriate consent was obtained from each patient pursuant to Japanese law. Each subject was fully informed of the experimental purposes, procedures, and possible risks of the study. Each signed informed consent forms before testing. This study was approved by the Juntendo University Human Ethics Committee in accordance with the Declaration of Helsinki.

Stretching Procedures

For all treatment procedures, the subjects were supine on a padded table. The subjects of the control group rested supine with both legs straight for 5 minutes. For the SS group, we followed the protocol used by Behm et al. (4) and Power et al. (31). Briefly, the pelvis of each subject was fixed to the padded table with a band. Then hamstring muscles of the dominant leg were stretched by a skilled investigator to the point at which the subject first reported pain. This position was maintained for 45 seconds; it was followed by a 15-second relaxation period during which subjects placed both legs straight. For the PNF group, stretching was conducted according to the methods described by Holcomb (18), specifically the CRAC method. To begin, the subject's hamstring muscles were passively stretched for 10 seconds by the same skilled investigator. The subjects then performed maximal isometric contraction of the hamstring muscles for 6 seconds. Finally, a concentric contraction of quadriceps muscles and passive stretching of the hamstring muscles were performed simultaneously for 30 seconds,

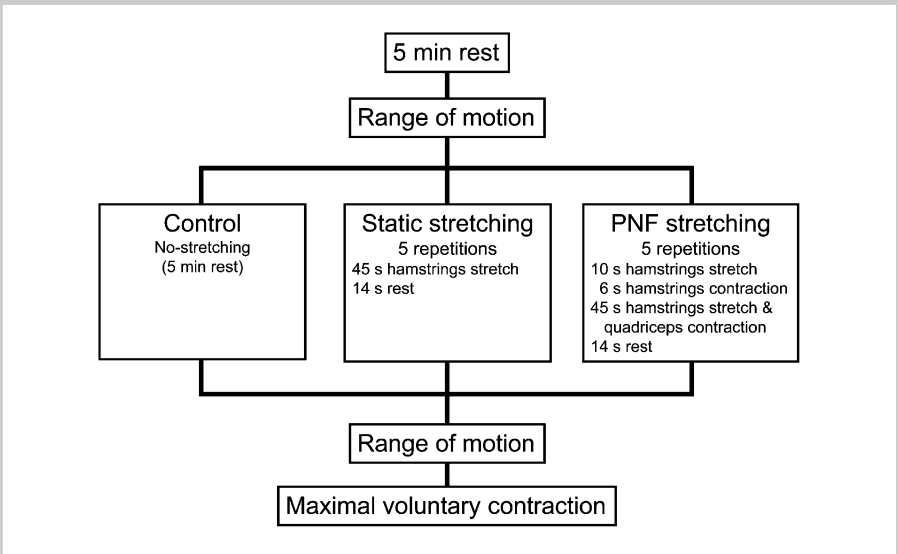

Figure 1. Scheme of experimental design. PNF = proprioceptive neuromuscular facilitation.

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followed by a 14-second relaxation period. Then SS and PNF were repeated, respectively, 5 times.

Range of Motion

The ROM of the hip flexion was evaluated using a Leighton flexometer according to procedures described by Hartley-O'Brien (17). Each subject was supine with both legs straight on a padded table. The pelvis was fixed with a band. A Leighton flexometer, strapped to the lateral thigh of the dominant leg, was adjusted to zero. The subjects were then required to raise the dominant leg to its limit slowly, without swinging or bouncing, while the investigator held the opposite leg firmly in contact with the padded table. The test was conducted 3 times. The highest value was used for analyses. In this test, the intraclass correlation coefficient (ICC) R of the 3 serial measurements was 0.998 (95% confidence interval [CI]; 0.996–0.999) and the ICCR of the prestretching in 3 days was 0.938 (95% CI; 0.855–0.979).

Maximal Voluntary Contraction

The MVC measurement method described by our previous study (28) was used, with modifications. The previous study (28) demonstrated that the ICCR of the 3 serial measurements in this test was 0.87 (95% CI; 0.62–0.96). The test–retest correlation (Pearson's r) of MVC was 0.92. Briefly, the subjects were restrained by a nylon belt on a chair. The ankle of the dominant leg was connected to the load cell (RTB-100K; Showa Sokki Co. Ltd., Japan) via a wire. The subjects crossed their arms in front of the chest. The knee angle of the dominant leg was set to 90°. When the investigator signaled to start, the subject flexed the knee with maximal effort for approximately 4 seconds, followed by a 60-second rest period. Each subject repeated this sequence 3 times. The force for a 1-second period of steady state was averaged, and the highest value of the 3 trials was used for analysis. The signal from the load cell was amplified by a carrier amplifier (AP-621G; Nihon Kohden Corp., Japan) and stored in a computer via an A/D converter (sampling rate, 2,000 Hz, Maclab; AD Instruments Pty. Ltd.). In this study, the ICCR of the 3 serial measurements was 0.921 (95% CI; 0.869–0.955) and the ICCR for the 3 days was 0.798 (95% CI; 0.581–0.926).

Electromyography

Surface electromyographic recording electrodes (Ag/AgCl, 5-mm diameter) were placed approximately 2.5 cm apart over the midportion of the biceps femoris muscle (long-head) and the vastus lateralis muscle. A ground electrode was secured on the fibular head. The placements of electrodes were marked as the identical position across 3 conditions. Thorough skin preparation for all electrodes included removal of dead epithelial cells around the designated areas with subsequent cleansing using an isopropyl alcohol swab. The EMG signals were amplified (time constant, 0.03, AB-621G; Nihon

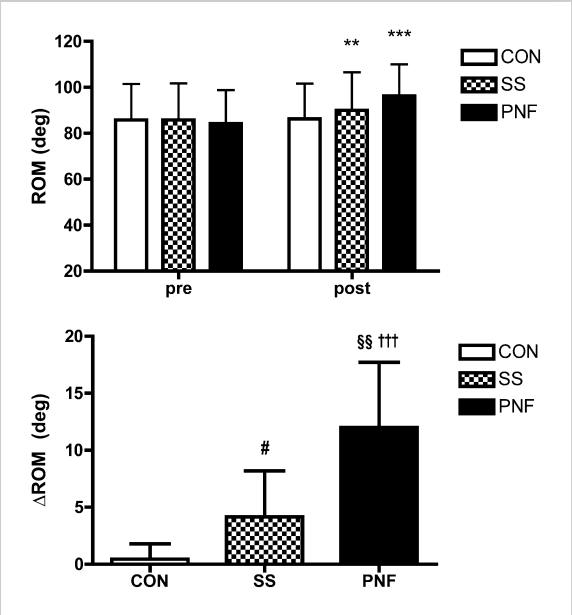

Figure 2. Upper: range of motion (ROM) before (pre) and after (post) nonstretching (CON), static stretching (SS), and PNF stretching (PNF). Lower: ΔROM (post-pre) in CON, SS, and PNF. Significantly different from pre: $^{**}p < 0.01$, $^{***}p < 0.001$. Significantly different from CON: $\#p < 0.05$, $\dagger\dagger\dagger p < 0.001$. §§Significantly different from SS, $p < 0.01$. Values are expressed as mean ± *SD*.

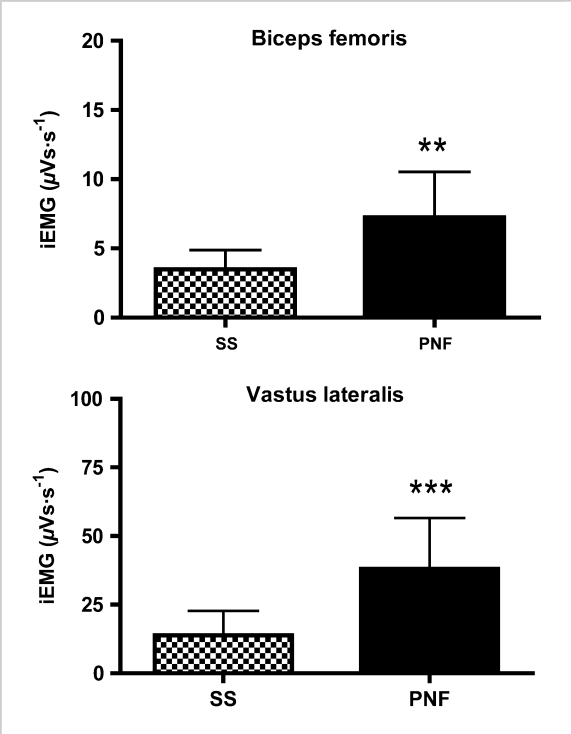

Figure 3. The integrated electromyography (iEMG) in the biceps femoris (upper) and vastus lateralis (lower) muscles during the stretch phase in static stretching (SS) and the final stretch phase in PNF stretching (PNF). Significantly different from pre: $^{**}p < 0.01$, $^{***}p < 0.001$. Values are expressed as mean ± *SD*.

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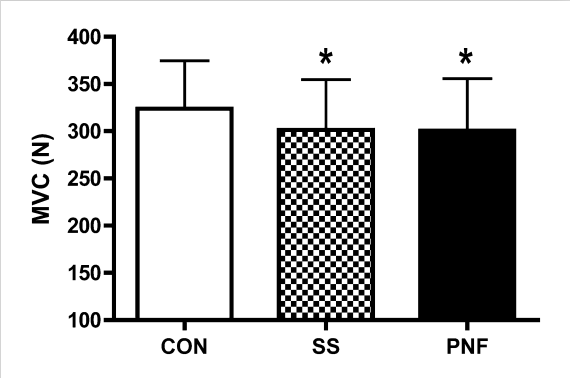

Figure 4. Maximum voluntary contraction (MVC) after nonstretching (CON), static stretching (SS), and PNF stretching (PNF). *Significantly different from CON, $p < 0.05$. Values are expressed as mean ± *SD*.

Kohden Corp., Japan), rectified, and stored in a computer via an A/D converter (sampling rate, 2,000 Hz, MacLab; AD Instruments Pty. Ltd.). The integrated EMG (iEMG) was calculated from the EMG over a 1-second period while at a steady state of MVC using a computer software program (Chart ver. 3.4; AD Instruments Pty. Ltd.). The EMG during stretching was also measured. The iEMG was calculated from the EMG during the stretch phase for SS and the final stretch phase for PNF. The ICCR of 3 serial measurements in the iEMG for the biceps femoris and the vastus lateralis MVC were, respectively, 0.892 (95% CI; 0.824–0.939) and 0.824 (95% CI; 0.724–0.896). The ICCRs over 3 days were 0.802 (95% CI; 0.588–0.928) and 0.531 (95% CI; 0.203–0.802).

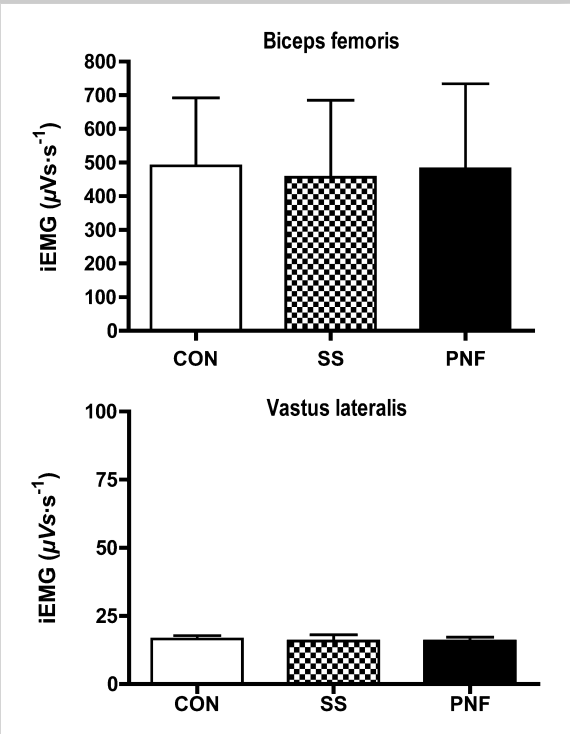

Figure 5. The integrated electromyography (iEMG) of biceps femoris (upper) and vastus lateralis (lower) muscles during maximum voluntary contraction (MVC) after nonstretching (CON), static stretching (SS), and PNF stretching (PNF). Values are expressed as mean ± *SD*.

Statistical Analyses

Differences in iEMG during the stretch phase between SS and PNF were evaluated using paired *t*-tests. The ROM was tested using 2-way repeated analysis of variance (ANOVA) among the 3 treatments. The change in ROM from pre- to post-, MVC, and iEMG during MVC were tested using 1-way repeated measures ANOVA among the 3 treatments. When a significant *F* ratio was detected, a Bonferroni test was conducted as a post hoc analysis. Statistical significance was inferred for $p < 0.05$. All data were expressed as mean ± *SD*.

Results

Range of Motion

Both SS and PNF significantly increased the ROM ($p < 0.01$ and $p < 0.001$, effect size = 0.26 and 0.83, respectively). The respective increases of ROM in the CON, SS, and PNF groups were 0 ± 1°, 4 ± 4°, and 12 ± 6°. The improvement of ROM was significantly greater in the PNF group than in the SS group ($p < 0.01$, effect size = 1.42) (Figure 2).

Integrated Electromyography During the Stretch Phase

The iEMG in the vastus lateralis muscle during the stretch phase was significantly greater for the PNF group than for the SS group ($p < 0.05$, effect size = 1.46). Similarly, the iEMG in the biceps femoris muscle, although slight, was significantly greater for the PNF group than for the SS group ($p < 0.05$, effect size = 1.30) (Figure 3).

Maximal Voluntary Contraction

Results of the MVC tests are presented in Figure 4. The MVC values for both the SS and PNF groups were significantly

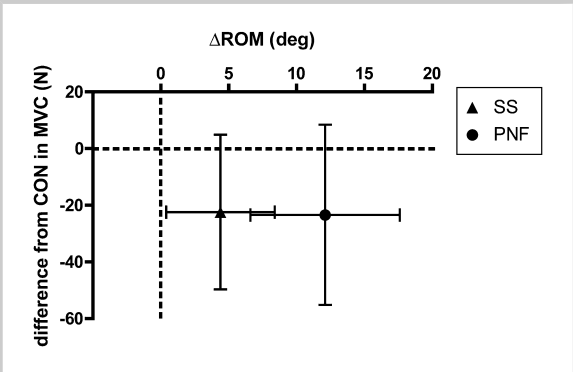

Figure 6. Relation between ΔROM (range of motion; post-pre) and difference from CON in maximum voluntary contraction (MVC; CON-SS, CON-PNF): CON = nonstretching; SS = static stretching; PNF = PNF stretching.

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lower than that of the CON group value, by 6.9 and 7.1%, respectively ($p < 0.05$, effect size = 0.44 and 0.46). No significant difference in MVC was found between the SS and PNF groups (effect size = 0.02).

Integrated Electromyography During Maximal Voluntary Contraction

Figure 5 presents the iEMG values obtained during MVC. In the biceps femoris muscle, the iEMGs for the SS and PNF groups were not significantly lower than that of the control group (effect size = 0.17 and 0.05, respectively). The iEMG for the vastus lateralis muscle did not differ significantly among the 3 groups.

Discussion

We investigated the acute effects of PNF stretching on ROM and MVC of hamstring muscles compared with those of SS. The main finding of this study is that although PNF stretching increased ROM more than SS, the extent of the decrease of MVC is similar between PNF and SS (Figure 6).

A clear consensus on the effectiveness of PNF stretching has not been reached. Some reports have presented that PNF stretching increased ROM more than SS did (11,32). Some studies have shown that although ROM is increased, the effect of PNF stretching resembles that of SS (6,8,14,16, 17,22). In this study, although both PNF and SS increased the ROM involving the hamstring muscles, PNF stretching increased ROM more than the SS did (effect sizes = 0.83 and 0.26, respectively).

Although previous reports have described that both PNF and SS reduced the excitability of the alpha-motoneuron pool controlling the stretched muscle by autogenic inhibition in originating Golgi tendon organs and reciprocal inhibition (8,12,15), we observed a higher level (about twice) of iEMG in the stretched biceps femoris muscle during PNF stretching than during SS (Figure 3). Such muscle activation might be associated with the actual force generation during stretching. The hamstring muscles stretched by the PNF might produce higher levels of neuromuscular activity than SS does. However, it is not surprising and similar results were reported earlier in the literature (8,25,29,30). For example, it was reported that the quadriceps contraction during final stretch phase in the CRAC method induced contraction of the hamstring muscles to keep maximal extension of the knee and the hamstring muscles under considerable tension, although CRAC increased ROM more than CR and SS (29,30). It was also reviewed that the CR method was enhanced tolerance to stretch and thereby CR increased ROM above that observed with SS although this technique reduced musculotendinous stiffness of stretched muscles and static (23). These findings suggest that the additional increase of ROM by the CRAC method used in this study might be attributable to the increased stretch tolerance or increased pain threshold rather than the reduced musculotendinous stiffness of the hamstring muscles. However, we did not directly measure musculotendinous stiffness. Further studies must be undertaken to clarify the mechanism of increased ROM in the same conditions used in this study.

In this study, we confirmed decreases of MVC after both static and PNF stretching from the control level. The results were in line with previous studies that showed decreases in MVC for knee extension (4) and 1RM for knee flexion and extension (21) after SS and which showed decreases in the isokinetic concentric strength (24) and dynamic performance such as vertical jumping (5,7) after PNF stretching. Moreover, our study has shown that the reduction of MVC after the CRAC was similar to that after the SS. This result resembles those reported for a previous study by Marek et al. (24), which showed that CR of the vastus lateralis muscle resulted in similar deficits in isokinetic muscular strength and power output to those of SS. However, the decreases were very small compared with those found in this study. In addition, in their study, improvements of ROM were very small (effect size: <0.1), showing no difference between CR and SS.

It has been suggested that stretching-induced impairment of muscular performance is associated with lowered stiffness of the target muscle and neuromuscular activity during muscle force generation. Several reports have described that reduced musculotendinous stiffness following stretching engenders decreased MVC (2,13,26,36). Wilson et al. (37) reported that stiffness of musculotendinous units was positively related to isometric and concentric bench-press performance. However, as discussed above, the additional increase of ROM by the CRAC method might be caused by the increased stretch tolerance in this study, although results suggest that increased ROM after stretching is attributable to decreased musculotendinous stiffness (23,35) and that ROM is negatively associated with musculotendinous stiffness (38). Therefore, although the ROM was increased more than that by SS, a decrease of MVC after the CRAC method is expected to be equivalent to that after SS.

However, the influence of stretching on neuromuscular activity during muscle force generation has not been sufficiently established. Fowles et al. (13), using the interpolated twitch (ITT) technique, found that decreased MVC after stretching was accompanied by decreased motor unit activation. Furthermore, Behm et al. (4) reported that measures in both iEMG and ITT during MVC were decreased after SS. In contrast, Weir et al. (36) found that motor unit activation was not decreased after SS. Nevertheless, MVC was lowered. We observed in this study that both PNF and SS showed a similar degree of decrease in iEMG in the biceps femoris muscle during MVC to that of the nonstretching condition. In addition, the CRAC method used in this study, which requires 5-times maximal isometric contraction of target muscle for 6 seconds, might induce fatigue not only in neuromuscular activities but also in the target muscles themselves. These factors might confound the results of measured parameters.

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Consequently, more research is necessary to draw conclusions about the acute effects of stretching on neuromuscular activities during muscle force generation.

In summary, our findings suggest that stretching-increased ROM is partly involved in decreased muscular strength, whereas a greater increase of ROM after PNF stretching might not be attributable to the decrease of isometric maximal muscular strength.

Practical Applications

Results of this study demonstrated that the increase in ROM is significantly greater after PNF stretching than after SS for hamstring muscles. Nevertheless, the decreases in MVC were equal between the 2 treatments. The benefit of PNF stretching therefore may be highlighted in certain sports or clinical situations where improved ROM is more important than producing high isometric muscle force. However, the greater ROM with PNF stretching may partly be attributed to increased pain threshold and thus hyper-ROM injuries such as strain might result. A risk-to-benefit assessment should be carefully applied to stretching and a caution should be taken when using PNF stretching for sports preparation.

Acknowledgments

This work was supported by grants from the Graduate School of Health and Sports Science, and Institute of Health and Sports Science and Medicine, Juntendo University.

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