Acute Effects of Static, Dynamic, and Proprioceptive Neuromuscular Facilitation Stretching on Muscle Power in Women

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Abstract

Manoel, ME, Harris-Love, MO, Danoff, JV, and Miller, TA. Acute effects of static, dynamic, and proprioceptive neuromuscular facilitation stretching on muscle power in women. *J Strength Cond Res* 22(5): 1528–1534, 2008–The purpose of this study was to investigate the acute effects of 3 types of stretching–static, dynamic, and proprioceptive neuromuscular facilitation (PNF)–on peak muscle power output in women. Concentric knee extension power was measured isokinetically at 60°·s^{-1} and 180°·s^{-1} in 12 healthy and recreationally active women (mean age ± *SD*, 24 ± 3.3 years). Testing occurred before and after each of 3 different stretching protocols and a control condition in which no stretching was performed. During 4 separate laboratory visits, each subject performed 5 minutes of stationary cycling at 50 W before performing the control condition, static stretching protocol, dynamic stretching protocol, or PNF protocol. Three submaximal warm-up trials preceded 3 maximal knee extensions at each testing velocity. A 2-minute rest was allowed between testing at each velocity. The results of the statistical analysis indicated that none of the stretching protocols caused a decrease in knee extension power. Dynamic stretching produced percentage increases (8.9% at 60°·s^{-1} and 6.3% at 180°·s^{-1}) in peak knee extension power at both testing velocities that were greater than changes in power after static and PNF stretching. The findings suggest that dynamic stretching may increase acute muscular power to a greater degree than static and PNF stretching. These findings may have important implications for athletes who participate in events that rely on a high level of muscular power.

Key Words flexibility, post activation potentiation, isokinetic power, explosive strength

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Introduction

Stretching activities before exercise are believed to prepare the body for physical activity and athletic events by improving joint range of motion, thus promoting improved performance and reducing the incidence of injury (2,26,28,30). Consequently, athletes and coaches regularly include stretching exercises in both training programs and in pre-event warm-up activities (16). Several recent review articles have questioned the proposed benefits of stretching in the warm-up, notwithstanding its widespread acceptance and use (16,18,19,29,31). Some studies have shown that stretching, especially static or passive, can actually produce a significant acute decrease in various maximal muscular performances, including force or power production (3,9,13,15,20,23,24), vertical jump performance (7,8,34), and running speed (22). These effects have implications for athletes involved in activities that require strength and power production, such as gymnastics and football, and have led some researchers to recommend against the practice of static stretching before such events. This paradox between accepted dogma and current research represents a dilemma for coaches, athletes, and the common fitness enthusiast. Should potentially injury-preventing stretching exercises be included in pre-event activities at the expense of optimal athletic performance?

To address this issue, professionals have turned their attention to forms of stretching that could be used without a concurrent decrease in performance. Strength and conditioning coaches have adopted various forms of active or dynamic warm-ups to prepare athletes for the physical demands of their sport (17). Although several variations of dynamic warm-up protocols exist, most incorporate continuous and rhythmic movements. These types of exercises have been shown to improve performance in the vertical jump (35) and to increase leg extension power (33). However, these findings conflict with those of Nelson et al. (24), who found that dynamic stretching reduced maximal knee flexion and extension strength to the same extent as static stretching. Thus, a clear consensus for the effect of dynamic stretching on muscle performance has not been achieved.

Another form of stretching commonly used is proprioceptive neuromuscular facilitation (PNF). While research on the acute effects of PNF on muscle performance is limited, interesting results have been obtained from a few recent studies. Acute bouts of either PNF or static stretching caused similar deficits in knee extension power, measured by isokinetic dynamometry (11). In contrast, another study examining the effects of both static and PNF stretching on hamstring torque concluded that increasing hamstring flexibility through either protocol was an effective method for increasing hamstring torque concentrically and eccentrically (32).

Based on a review of the available literature, there is still disagreement among many authors concerning the effects of different stretching protocols on muscle performance. Studies have used different variables for stretching interventions (e.g., number of repetitions, stretch time, and body position) and testing procedures (e.g., isokinetic, 1 repetition maximum, and vertical jump). In addition, most previous studies have concentrated on static stretching, while few have tested 2 or more types of stretching on 1 population sample. To the authors' knowledge, this study is the first to compare static, dynamic, and PNF stretching in 1 population sample. This was done in the hopes of eliminating some of the existing variability among the different study protocols. Furthermore, a single-joint, isokinetic testing protocol was incorporated. This was done to ensure that any differences seen between treatment groups were due to the stretching protocol itself and not to a practice effect that might be seen with less sensitive indicators of power, such as vertical jumping or sprinting. Finally, the effects of acute stretching on muscle power in women have remained relatively unexplored. From the literature review, only 2 previous studies analyzed the effects of acute stretching on a sample of women (7,9). Therefore, the purpose of this study was to investigate the acute effects of 3 types of stretching–static, dynamic, and PNF–on muscle power output in women.

Methods

Experimental Approach to the Problem

The current study was performed in part due to conflicting findings in the existing literature regarding the effects of different types of stretching on skeletal muscle power. Comparisons of results between studies have proven to be difficult to interpret because of the large variability in stretching time, the type of stretching used, the type of power test used, and the subjects themselves. To address this issue, the current study is the first to examine the effects of static, dynamic, and PNF stretching in the same group of subjects. Furthermore, a single joint isokinetic testing procedure was incorporated to allow for maximal power measurement sensitivity throughout the entire range of motion of an isolated muscle group. The authors believe that this design will eliminate the possible alterations in intramuscular coordination that could lead to changes in measured power when multiple-joint movements, such as the vertical jump, are used as the measure of muscular performance.

Subjects

Twelve healthy and recreationally active women were recruited from The George Washington University campus located in Washington, DC (mean age ± *SD*, 24 ± 3.3 years). All subjects completed a Physical Activity Readiness Questionnaire (PAR-Q) and signed an informed consent statement approved by The George Washington University Institutional Review Board. No subjects reported a history of knee pain or problems.

Procedures

Subjects were available for testing on 4 separate days, with at least 48 hours between testing days to allow for full recovery. The isokinetic testing protocol was similar to the one described by Cramer et al. (9). On each testing day, each subject completed a 5-minute aerobic warm-up at 50 W on a stationary cycle ergometer before initial isokinetic testing. Each subject was then randomly assigned to perform 1 of 3 stretching protocols (i.e., static, dynamic, or PNF) or a no-stretch control condition. The order of conditions for subsequent data sessions was systematically varied for the 12 subjects. This variation ensured a minimization of order effects and allowed each subject to perform all 3 stretching protocols and the control condition by the conclusion of testing.

Before and after stretching exercises, concentric isokinetic power for knee extension of the dominant leg (i.e., based on kicking preference) was measured by using a calibrated Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY) at predetermined velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$. Three submaximal warm-up trials preceded 3 maximal efforts at each velocity. A 2-minute rest was allowed between testing at each velocity. There was a 4-minute rest between the stretching intervention and the poststretching power measurements. The number of maximal contractions and rest periods were chosen to avoid fatigue.

Subjects were placed in a seated position with a restraining strap over the pelvis and trunk in accordance with the Biodex Pro Manual (4). The dynamometer's input axis was aligned with the axis of the knee, while the nonworking leg was braced against the stabilization bar. In summary, each subject completed the following activities during laboratory visits: 5-minute aerobic warm-up; prestretching isokinetic assessment; static stretching, dynamic stretching, PNF stretching, or the control intervention (on different days); and poststretching assessment.

Stretching Interventions

Because isokinetic testing involved knee extension, the muscles targeted in the stretching protocols were those in the quadriceps group. For all stretching interventions, the researcher demonstrated proper technique before each routine and monitored subject movement to ensure correct performance.

For the static stretching intervention, the subject passively stretched the quadriceps until a point of mild discomfort, but not pain, was reported (9). The stretch was held at that position for 30 seconds and repeated 3 times. There was a 20-second interval between repetitions. The static stretch used was the standing unilateral quadriceps stretch, in which the subject stood upright with 1 hand against a wall for balance and then flexed the knee of the dominant leg to the position of stretch by grabbing the ankle with the ipsilateral hand.

The PNF stretching protocol consisted of the same motion and subject positioning as the static stretching intervention. However, it took the contract-relax form that involved a maximal isometric contraction against resistance from the primary investigator at the joint's end range of motion for 5 seconds followed by relaxation and then 15 seconds of passive stretch until mild discomfort was felt by the participant. This procedure was repeated 3 times with a 20-second rest between repetitions.

The dynamic stretch also involved similar leg positioning as the other stretching interventions, but the stretch was achieved through muscular activation and rhythmic movement. This consisted of the butt-kick exercise, which involved standing in place while individually bringing the heel of each foot toward the buttocks in a repetitive and alternating fashion as quickly as possible. This procedure was performed for 30 seconds and repeated 3 times. There was a 20-second interval between repetitions. In the CON condition (i.e., no-stretch), subjects were relieved from the Biodex restraining belts after the pretest and remained seated for a total of 2.5 minutes.

Statistical Analyses

Power analysis based on preliminary data established that with a sample size of 12 subjects, statistical power was approximately 35%. All torque measurements were recorded in newton meters and converted into power by multiplying torque measurements by velocity in radians per second. Values for power output were expressed as watts ± SEM. A 2 × 4 repeated-measures analysis of variance (ANOVA) was used to compare absolute levels of power output for prestretching, poststretching, and the 4 conditions. A 1-way repeated-measures ANOVA was also used to compare percentage changes in power output across the 4 conditions:

$$\text{percentage change} = 100 \times (\text{poststretching power} - \text{prestretching power})/(\text{prestretching power})$$

Post hoc tests were applied when appropriate based on the ANOVA results. The significance level for all analyses was set at $p < 0.05$.

Results

Reliability of the authors' isokinetic testing procedures has been previously established (4,9,10). Prestretching to poststretching testing resulted in Pearson linear correlations of 0.92, 0.90, 0.94, and 0.99 for static stretching, dynamic stretching, PNF stretching, and the control condition at $60°\cdot s^{-1}$, respectively, and 0.84, 0.93, 0.95, and 0.97 for static stretching, dynamic stretching, PNF stretching, and the control condition at $180°\cdot s^{-1}$, respectively. All correlations were significant ($p < 0.001$). Knee extension power was not significantly different when comparing prestretching to poststretching for all protocols combined (i.e., main effect) or for any of the individual stretching protocols (i.e., interaction effect) at both $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ (Figures 1 and 2). However, when the percentage increases in knee extensor power were calculated, pairwise post hoc analysis showed that the dynamic stretching protocol resulted in significantly larger percentage increases than for either of the other protocols or the controls at both $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ (Tables 1 and 2). There was no change in the joint angle at which peak muscle power or torque occurred after each protocol (data not shown).

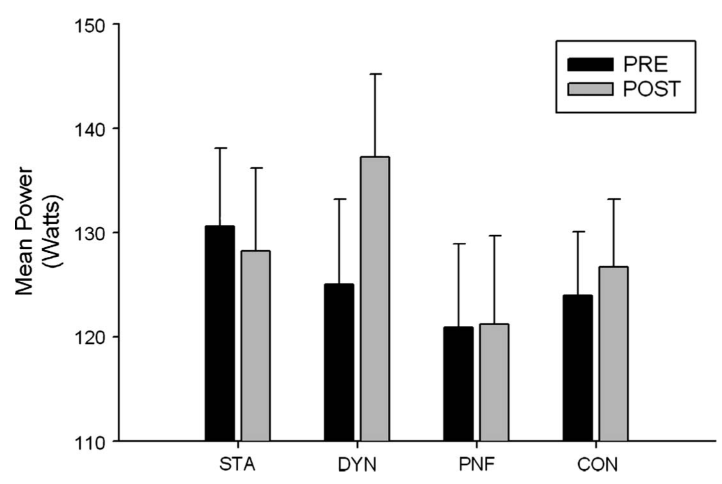

Figure 1. Average power values (W) at $60°\cdot s^{-1}$ velocity before and after static stretching (STA), dynamic stretching (DYN), proprioceptive neuromuscular facilitation (PNF) stretching, or the control (CON) condition. The bar denotes *SEM*.

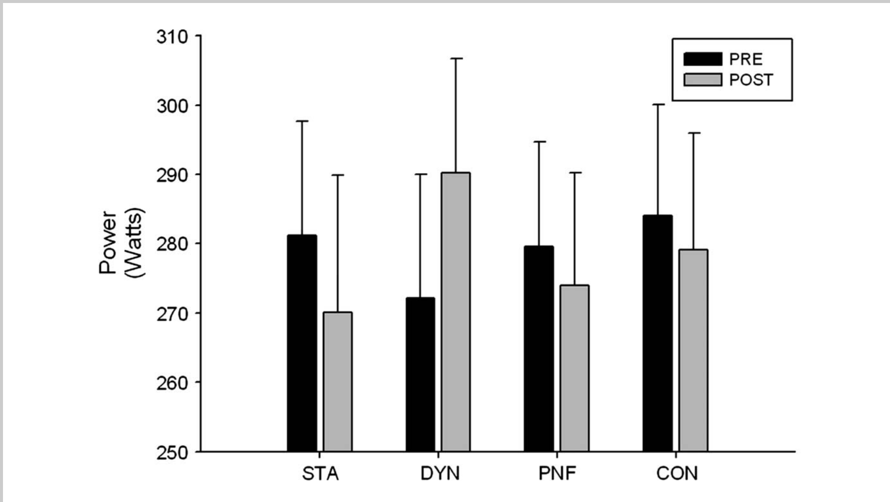

Figure 2. Average power values (W) at $180° \cdot s^{-1}$ velocity before and after static stretching (STA), dynamic stretching (DYN), proprioceptive neuromuscular facilitation (PNF) stretching, or the control (CON) condition. The bar denotes *SEM*.

Discussion

The purpose of this study was to compare the acute effects of static stretching, dynamic stretching, PNF stretching, and the control condition on isokinetic muscle performance in women and, in particular, to determine whether any of these techniques would lead to short-term changes in isokinetic power output of the knee extensors. The first analysis demonstrated that subjects were able to use these stretching techniques without a decrease in absolute levels of knee extensor power. When percentage changes in power output were analyzed, the dynamic technique resulted in a percentage change of almost 9%, which was statistically higher than the percentage change for all of the other stretching techniques. This was true for both $60° \cdot s^{-1}$ and $120° \cdot s^{-1}$. Percentage changes for the other techniques were either close to 0 or slightly negative, although low statistical power prevents the identification of these as decreases. The authors continue to have some reservations pertaining to the poststretching effects of static stretching, PNF stretching, and the control condition, but are confident that dynamic stretching does not have negative effects and may actually modestly increase output power.

Dynamic stretching is currently a popular technique, especially among competitive athletes (17). The current study demonstrates that dynamic stretching of the quadriceps muscle group may increase power for both slow and fast movements. This finding is consistent with previous studies. For example, Yamauchi and Ishii (33) found that there was no influence of static stretching on leg extension power but that dynamic stretching of the lower-limb muscles significantly increased leg extension power compared to nonstretching controls. Young and Behm (35) found that a warm-up consisting of submaximal running and practice jumps had a positive effect on explosive force and jumping performance, whereas static stretching had a negative influence. McMillian et al. (21) showed better power and agility scores after a dynamic stretching protocol compared to static stretching. Based on these findings and the current results, dynamic stretches appear to be effective for use in preactivity warm-ups to enhance muscular performance. It must be noted that the current study used an isokinetic testing modality, which does not mimic the types of external forces or muscle contraction patterns that would occur with activities such as running and jumping. Because performance in these kinds of activities could be greatly affected by, among other things, the subjects' technique and coordination, it can not be assumed that changes in performance that are seen through isokinetic testing will necessarily translate into increased performance in running, jumping, and other on-the-field activities.

Although the specific mechanisms by which acute dynamic stretching increases muscle power output is uncertain, 2 possibilities have been suggested (6,21). One is that temperature-related changes may be beneficial. Increases in muscle temperature have been shown to increase dynamic short-duration performance (5). Elevated temperatures occur primarily from increased

Table 1. Mean power values (W) ± *SEM* for $60° \cdot s^{-1}$ velocity ($n = 12$).

Protocol	Before	After	Change
Static stretching	130.6 ± 7.5	128.2 ± 8.0	−1.7%
Dynamic stretching	125.0 ± 8.2	137.2 ± 8.0	8.9%*
PNF	120.9 ± 8.0	121.2 ± 8.5	0.2%
Control	124.0 ± 6.1	126.7 ± 6.5	2.1%

PNF = proprioceptive neuromuscular facilitation.
*Significant difference from other protocols ($p < 0.05$).

TABLE 2. Mean power values (W) ± *SEM* for $180^{\circ}\cdot s^{-1}$ velocity ($n = 12$).

Protocol	Before	After	Change
Static stretching	281.2 ± 16.5	270.1 ± 19.8	−3.9%
Dynamic stretching	272.1 ± 17.9	290.2 ± 16.5	6.3%*
PNF	279.6 ± 15.1	274.0 ± 16.2	−2.1%
Control	284.1 ± 16.0	279.1 ± 16.9	−1.6%

PNF = proprioceptive neuromuscular facilitation.
*Significant difference from other protocols ($p < 0.05$).

intramuscular friction that occurs during exercise. Higher muscle temperatures increase the transmission rate of impulses, positively affect the force–velocity relationship, and increase glycogenolysis, glycolysis, and high-phosphate degradation (6). However, more recent findings have shown that passive heating of the quadriceps before dynamic knee extensor exercise does not influence muscle energy turnover from either aerobic or anaerobic pathways during exercise (14). Ferguson et al. (14) suggested that conflicting findings relating to temperature-dependent differences in muscle energy production may be related to the variation in muscle perfusion rates that occur with different forms of exercise. To the authors' knowledge, no studies to date have been conducted to compare alterations in muscle power after stretching-induced (i.e., static, dynamic, or both) and passive muscle heating. While it is clear that elevations in muscle temperature that occur after a dynamic warm-up will occur concomitantly with increases in muscle perfusion, it is unlikely that passive heating causes the same degree of increased muscle perfusion. Therefore, increases in performance that occur after a dynamic warm-up may be due to increases in perfusion and not increases in muscle temperature per se. In the current study, the dynamic warm-up consisted of 3 30-second bouts of repeated rapid contraction and relaxation of the upper leg musculature. The effect of this skeletal muscle pumping would be relatively large increases in muscle blood flow compared to the PNF and static stretching protocols.

The second possibility is that neuromuscular phenomena elicited from a dynamic stretch are contributing factors that lead to increased muscle power. Two of these mechanisms include postactivation potentiation and postcontraction sensory discharge (PSD). Postactivation potentiation is an increase in muscle force after a conditioning contractile activity, such as the butt-kicking exercise performed in this study, which can theoretically improve muscle power (21). However, optimal parameters to exploit this specific phenomenon have not been established (27). Similarly, the increased neural activity in spinal dorsal roots after muscular contractions (i.e., PSD) may lead to a more rapid and forceful response from the muscle being activated (12,21).

The finding of this study that static and PNF stretching protocols did not significantly change power performance may also be important. While the current findings support those of a recent study by Cramer et al. (10), who found that static stretching did not result in a performance decrease, they are in disagreement with past findings, in which both static and PNF stretching warm-ups have been shown to produce significant acute decreases in various maximal performances (3,7–9,13,15,20,22–24,34). Researchers have proposed 2 primary hypotheses to explain stretching-induced decreases in muscle performance: mechanical factors involving the viscoelastic properties of the muscle as it is stretched beyond the normal range of motion and neural factors such as reflex sensitivity and neural inhibition. Studies examining mechanical factors have postulated that an increase in muscle–tendon compliance after stretching leads to a reduced rate of force transmission from the muscle to the skeletal system, which leads to a decrease in muscle performance (15,23,24). The neural mechanism involves the acute response of muscle proprioceptors, such as Golgi tendon organs, to sustained stretching (1,20,28). Some stretching techniques may produce inhibition that diminishes the number of available motor units, thereby limiting force and power output.

Although viscoelastic change and altered muscle proprioceptor response from static and PNF stretching may explain stretching induced decreases in performance in previous studies, the static and PNF protocols did not produce significant decreases in power output. One possible explanation may be related to differences in the number of static stretching exercises and total stretching time used. In this study, subjects performed only 1 exercise for the quadriceps, repeated 3 times for a total stretching time of 90 seconds. In other studies, subjects performed between 2 and 5 different stretches for a muscle group for total stretching times that ranged from 100 seconds to 20 minutes (3,7,8,13,15,24). For example, Cramer et al. (11) had subjects perform a total of 4 stretching exercises for the quadriceps, each repeated 4 times and held for 30 seconds each time (11). These differences in stretching stimuli may have varied effects on the magnitude of viscoelastic change and muscle proprioceptor response for the stretched muscle. The static and PNF stretching protocols incorporated in the current study might not have been sufficient in duration to induce such mechanisms. However, there is also a possibility that the nonsignificant ANOVA results for static and PNF stretching may be due to inadequate statistical power of the study (power = 0.35). In this situation, the natural variability among the subjects approaches in size the variability between the prestretching and poststretching conditions. The conservative nature of ANOVA applied to raw scores then would not allow a significant finding across the different conditions or the interactions between conditions and time. Thus, if more subjects were available, these techniques might have resulted in significant decrements of performance. However, by testing percentage change of performance, the significant improvement in performance associated with dynamic stretching was able to be established (Figures 1 and 2).

Two additional factors pertaining to this study should be considered. First, due to the study design, how long the observed benefits of dynamic stretching were actually maintained could not be established. Rosenbaum (25) found that all decreases in force and power related to stretching returned to normal after only 10 minutes of running. This finding suggests that if there are indeed adverse acute effects of static and PNF stretching, they may be offset by performing dynamic movements before the event. Future studies should examine this possible interrelationship by using protocols that combine dynamic stretching with other types of stretching. Second, caution should be used when generalizing the results from this investigation to other populations. The subjects in this study were young, healthy, and recreationally active women. Less athletic or older individuals may respond differently to the stretching protocols used in this study.

Coaches, trainers, and other individuals working in the fields of strength, conditioning, and athletics often base general recommendations of which types of stretching to use on personal experience and equivocal previous research. However, questions remain as to the optimal parameters to be used in pre-event warm-ups for factors such as duration, intensity, and rest interval. Future research should further investigate the effects of various stretching protocols on samples from older and less athletic populations, additional body segments, and combination protocols. The association between dynamic stretching and injury incidence should be examined to determine whether these techniques are protective or detrimental.

Practical Applications

Based on the results of this study, it is suggested that including dynamic stretching as part of a pre-event warm-up may offer performance benefits not found with static and PNF stretching. An acute bout of dynamic stretching will not result in output power decreases, which have been associated with the other techniques, and can produce a positive percentage change in muscular power significantly greater than percentage changes associated with static or PNF stretching. The dynamic protocol used in this study may avoid eliciting the mechanical and neuromuscular drawbacks associated with acute static and PNF stretching. Furthermore, athletes who perform pre-event static or PNF stretches are advised to incorporate dynamic stretches in the later part of their warm-up program to benefit from this type of stretching. This information may be especially useful for athletes and coaches involved in sports requiring high amounts of power generation (i.e., rapid, forceful movements), such as football and weightlifting.

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