Maximal Strength, Number of Repetitions, and Total Volume Are Differently Affected by Static-, Ballistic-, and Proprioceptive Neuromuscular Facilitation Stretching

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ABSTRACT

Barroso, R, Tricoli, V, dos Santos Gil, S, Ugrinowitsch, C, and Roschel, H. Maximal strength, number of repetitions, and total volume are differently affected by static-, ballistic-, and proprioceptive neuromuscular facilitation stretching. J Strength Cond Res 26(9): 2432–2437, 2012—Stretching exercises have been traditionally incorporated into warm-up routines before training sessions and sport events. However, the effects of stretching on maximal strength and strength endurance performance seem to depend on the type of stretching employed. The objective of this study was to compare the effects of static stretching (SS), ballistic stretching (BS), and proprioceptive neuromuscular facilitation (PNF) stretching on maximal strength, number of repetitions at a submaximal load, and total volume (i.e., number of repetitions × external load) in a multiple-set resistance training bout. Twelve strength-trained men (20.4 ± 4.5 years, 67.9 ± 6.3 kg, 173.3 ± 8.5 cm) volunteered to participate in this study. All of the subjects completed 8 experimental sessions. Four experimental sessions were designed to test maximal strength in the leg press (i.e., 1 repetition maximum [1RM]) after each stretching condition (SS, BS, PNF, or no-stretching [NS]). During the other 4 sessions, the number of repetitions performed at 80% 1RM was assessed after each stretching condition. All of the stretching protocols significantly improved the range of motion in the sit-and-reach test when compared with NS. Further, PNF induced greater changes in the sit-and-reach test than BS did (4.7 ± 1.6, 2.9 ± 1.5, and 1.9 ± 1.4 cm for PNF, SS, and BS, respectively). Leg press 1RM values were decreased only after the PNF condition (5.5%, p < 0.001).

All the stretching protocols significantly reduced the number of repetitions (SS: 20.8%, p < 0.001; BS: 17.8%, p = 0.01; PNF: 22.7%, p < 0.001) and total volume (SS: 20.4%, p < 0.001; BS: 17.9%, p = 0.01; PNF: 22.4%, p < 0.001) when compared with NS. The results from this study suggest that, to avoid a decrease in both the number of repetitions and total volume, stretching exercises should not be performed before a resistance training session. Additionally, strength-trained individuals may experience reduced maximal dynamic strength after PNF stretching.

KEY WORDS training, skeletal muscle, range of motion

INTRODUCTION

Stretching exercises have traditionally been incorporated into warm-up routines before training sessions and sport events. Its practice has been associated with performance improvements, decreased risk of injuries, and even reduced delayed onset of muscle soreness (35).

However, recent research indicates that the effects of stretching on performance seem to depend on the mode of stretching employed (2,3,12,13,27,28,37). For instance, it has been demonstrated that both the static and the proprioceptive neuromuscular facilitation (PNF) stretching may reduce not only maximal strength production (2,3,12,27,37) but also the number of repetitions performed with a submaximal load (12,13,28). Conversely, the literature has shown that sprinting and agility performance (23), isokinetic power (24), and vertical jump height (6) seem to be acutely improved after a ballistic-stretching (BS) protocol. These findings are difficult to reconcile. Nevertheless, data from previous studies suggest that BS might result in different neuromuscular adaptations than those of static stretching (SS) and PNF stretching. In fact, it has been demonstrated that SS and PNF may negatively affect the motor unit activation and the structural properties of soft tissues.
(i.e., muscles and tendons), which may, at least partially, explain performance decrements after SS and PNF (18,21).

Despite the increasing number of research studies dedicated to investigate the effects of different stretching protocols on several parameters of neuromuscular performance (6,12,13,18,21,27,28), not much attention has been given to the evaluation of the effects of stretching protocols on the number of repetitions performed at a submaximal load. Further, the few studies (12,13,28) that investigated the acute effects of stretching on such a parameter adopted single-set experimental designs. However, there seems to be a consensus that multiple sets are necessary to maximize training adaptations throughout a resistance training program (31).

Considering that the negative effects of stretching are transient (11), there is a gap in the knowledge regarding the effects of stretching on the number of repetitions performed with a submaximal load in a more realistic multiple-set training program design.

Additionally, stretching may affect the total volume performed during a resistance training bout. The term total volume takes into account both the number of repetitions performed and the weight lifted (i.e., repetitions × load [kilograms]). Moreover, total volume is thought to affect long-term adaptations to resistance training (i.e., hypertrophy and strength gains) (15,16,19,29,32), which warrants further studies on the effects of stretching not only on the number of repetitions but also on the total volume performed.

Therefore, the aim of this study was to compare the acute effects of SS, BS, and PNF stretching on maximal strength, number of repetitions, and total volume performed during a multiple-set resistance training bout. We hypothesized that the SS and PNF would greatly affect neuromuscular performance when compared with the BS protocol.

**METHODS**

**Experimental Approach to the Problem**

To evaluate the effects of 3 different stretching protocols on neuromuscular performance, all the subjects underwent 3 familiarization sessions. Afterward, each subject attended the laboratory on 8 separate occasions, all at the same time of the day. The subjects were also instructed to ingest a light meal and fluids before the experimental sessions. Each session comprised an evaluation of the range of motion (ROM) using the sit-and-reach test followed by a general warm-up (i.e., 5 minutes of treadmill running at 9 km h⁻¹). Then, 1 of the 3 stretching protocols (i.e., SS, BS, or PNF) or a control no-stretching condition (NS) took place. After treatment (i.e., stretching), an additional evaluation of the ROM was performed to determine the efficacy of the stretching protocol employed. Finally, 1 of the 2 neuromuscular tests was performed (i.e., a maximal strength test [1 repetition maximum (1RM)] or a number of repetitions test performed at 80% of 1RM). Figure 1 gives a pictorial view of the experimental design.

Four of the experimental sessions included a 1RM assessment after the 3 different stretching protocols (i.e., 1RM-SS, 1RM-BS, 1RM-PNF) and a control session with no stretching applied (1RM-NS). The remaining 4 experimental sessions consisted of a test to obtain the maximal number of repetitions performed with 80% of 1RM after the same stretching protocols (i.e., REP-SS, REP-BS, REP-PNF, and REP-NS). Except for the 1RM-NS session, which was always performed first, all the other experimental sessions were performed in a randomized order at least 72 hours apart. This design was adopted because we needed a baseline 1RM value (1RM-NS) to determine the external load applied to the number of repetitions tests. During the NS conditions, the participants sat for 10 minutes between the end of the general warm-up and the sit-and-reach test, which corresponded to the time necessary to perform the stretching protocols.

**Subjects**

Twelve young strength-trained men (20.4 ± 4.5 years, 67.9 ± 6.3 kg, 173.3 ± 8.5 cm) volunteered to participate in this study. All the subjects were currently engaged in upper and lower-limb strength training for at least 12 months before the investigation (16.2 ± 4.9 months). Training frequency varied between 3 and 5 workout sessions a week. They were free from any lower-limb musculoskeletal injuries and neuromuscular disorders. The investigation was approved by an institutional review board for use of human subjects, and all the participants signed an informed consent form before participation.

**Familiarization**

Before the experimental procedures, all the subjects completed 3 familiarization sessions on separate days at least 72 hours apart from each other. During the familiarization sessions, the subjects performed a general warm-up consisting of 5 minutes of running at 9 km h⁻¹ on a treadmill followed by 3 minutes of whole-body light stretching exercises. After warming-up, the subjects were familiarized with the leg-press 1RM testing and with the 3 different stretching protocols (SS, BS, and PNF). Body position and foot placement were recorded and reproduced throughout the study. The subjects were also familiarized to the sit-and-reach test.

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**Figure 1.** Pictorial view of the experimental design.
Different Stretching and Neuromuscular Performance

Table 1. Acute changes in flexibility after the stretching protocols in each neuromuscular test.*

<table>
<thead>
<tr>
<th>Test day</th>
<th>Acute changes in flexibility (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1RM-NS</td>
<td>0.5 ± 0.8</td>
</tr>
<tr>
<td>1RM-SS†</td>
<td>3.9 ± 1.7§</td>
</tr>
<tr>
<td>1RM-PNF‡</td>
<td>4.7 ± 1.6§</td>
</tr>
<tr>
<td>1RM-BS‡</td>
<td>2.9 ± 1.5§</td>
</tr>
<tr>
<td>REP-NS</td>
<td>0.6 ± 0.7</td>
</tr>
<tr>
<td>REP-SS†</td>
<td>3.8 ± 1.6§</td>
</tr>
<tr>
<td>REP-PNF‡</td>
<td>4.5 ± 1.5§</td>
</tr>
<tr>
<td>REP-BS‡</td>
<td>3.3 ± 1.7§</td>
</tr>
</tbody>
</table>

*NS = no-stretching condition; SS = static-stretching condition; PNF = proprioceptive neuromuscular facilitation stretching condition; BS = ballistic-stretching condition; 1RM = 1 repetition maximum.
†p < 0.05 compared with NS.
‡p < 0.05 when compared with BS.
§p < 0.05 when compared with prevalues.

Maximum Strength Test (1 Repetition Maximum)

Three days after the last familiarization session, the 1RM test for the lower limbs was assessed using a conventional inclined (45°) leg-press machine (Nakagym model NK5070, São Paulo, Brazil). The testing protocol followed the guidelines proposed by Brown and Weir (7). In brief, the subjects performed 8 repetitions with 50% of the estimated 1RM (obtained during familiarization sessions). After a 2-minute interval, the participants performed the second set with 3 repetitions with 70% of the estimated 1RM. The subjects then rested for 3 minutes and had up to 5 trials to achieve the 1RM load (i.e., maximum weight that could be lifted once with the proper technique), with a 3-minute interval between trials. The tests were conducted by 2 experienced researchers, and strong verbal encouragement was provided during the lifts. The same testing procedure was used during the 1RM-NS, 1RM-SS, 1RM-BS, and 1RM-PNF experimental conditions.

Number of Repetition Test

A multiple-set resistance training bout was used to obtain the number of repetitions. The test consisted of 3 sets until failure in the leg press using a submaximal load (80% of 1RM). Body positioning, knee and hip angles, and foot placement were reproduced according to the records made during the familiarization sessions. The number of repetitions performed in each set was recorded, and a 2-minute interval was allowed between sets. The sum of the repetitions performed in the 3 sets was used for statistical purposes. Total volume was calculated as the product of the number of repetitions completed and the load lifted (number of repetitions × weight [kilograms]). Only repetitions performed with the proper technique were considered valid.

Sit-and-Reach Test

The subjects sat with their heels pressed against the testing board. The knees were extended, and the right hand was placed over the left. Then, the participants were asked to reach and hold as far as possible along the measuring board, on the fourth bobbing movement (3). Three trials were performed, and the best result was used for statistical analysis.

Stretching Protocols

During stretching sessions, the participants stretched the main muscle groups used during the leg-press exercise (gluteus maximum and quadriceps), and the hamstring muscles. The stretching exercises used included the supine knee flex, the side quadriceps stretch, and the sitting toe touch. Baechle and Earle (4) offer a more detailed explanation of the stretches. During the stretching exercises, the subjects were assisted by an experienced researcher.

Three sets of each stretching exercise were performed. The SS was performed by holding the stretching position for 30 seconds followed by a 30-second interval before the next set. For the BS protocol, the same procedures were followed, but instead of holding the stretching positions for 30 seconds, the subjects had to bob in 1:1-second cycles for 1 minute. For the PNF protocol, the hold-relax technique was used. The subjects performed a passive stretch and held the stretching position for approximately 5 seconds. Then, they performed a 5-second near-maximal isometric contraction (34), relaxed, and passively held the stretching position for another 20 seconds.

Statistical Analyses

Data are presented according to descriptive statistics (mean and SD). Normality was assured by a Shapiro-Wilk test. The ROM data (pretest to posttest absolute change) were analyzed by a 1-way analysis of variance (ANOVA)
procedure. Changes between the control condition (NS) and the other stretching protocols (i.e., BS, SS, and PNF) for all of the remaining variables (i.e., maximal strength [1RM], number of repetitions, and total volume) were compared using a 1-way ANOVA. Whenever a significant F value was obtained, a Tukey post hoc test was performed for multiple comparison purposes. The significance level was set at \( p \leq 0.05 \). Further, intraclass correlation coefficient values were calculated for 1RM and sit-and-reach tests with values of 0.92 and 0.96, respectively.

**RESULTS**

**Range of Motion**

The results are presented in Table 1. No differences were observed between prestretching values across the experimental conditions (data not shown). As expected, no changes were observed in the sit-and-reach scores in the NS conditions. The PNF significantly improved ROM when compared with either SS or BS as measured by delta changes in ROM before the 1RM and the maximal number of repetitions tests.

**Maximal Strength, Number of Repetitions, and Total Volume**

Leg-press 1RM values significantly decreased after the PNF stretching protocol (233.3 ± 40.5 kg) when compared with NS (246.7 ± 40.8 kg, \( p = 0.01 \)) but were similar to those of SS (241.7 ± 40.0 kg, \( p = 0.81 \)) and BS (240.8 ± 42.3 kg, \( p = 0.82 \)). Figure 2 shows SS, PNF, and BS leg-press 1RM changes compared with NS and ROM delta change data.

In regard to the number of repetitions test, all the 3 stretching protocols negatively affected performance when compared with NS (Figure 3). The subjects performed 36 ± 42 repetitions during NS; 27.8 ± 4.1 during PNF (\( p < 0.001 \)); 28.5 ± 5.7 during SS (\( p < 0.001 \)); and 29.6 ± 4.9 during BS (\( p = 0.001 \)). Total volume was also negatively affected by all the 3 stretching protocols (5,702.7 ± 1,784.1 kg, \( p < 0.001 \); 5,535.3 ± 1,456.6 kg, \( p < 0.001 \); 5,860 ± 1,536.4 kg, \( p < 0.001 \) for SS, PNF, and BS, respectively) when compared with NS (7,137.3 ± 1,698.5 kg) (Figure 4).

**DISCUSSION**

The objective of this study was to compare the acute effects of different lower-limb stretching protocols on maximal strength, number of repetitions, and total volume performed in the leg-press exercise. The main and novel finding of this study is that not only SS and PNF but also BS impaired the number of repetitions and the total volume (i.e., number of repetitions × external load) performed after stretching when compared with NS. Additionally, we demonstrated that in strength-trained individuals, only the PNF stretching mode impaired the maximal strength production.

Reports on the acute effects of different stretching protocols on the number of repetitions are scarce. Nonetheless, previous studies have shown that either SS or PNF significantly reduces the number of repetitions performed in a single set of a resistance exercise (12,13,27). Our results extend this knowledge to BS protocols as well (Figure 3) and to multiple-set resistance training bouts. Despite evidence showing that BS does not affect maximal strength (3) and may even improve sprinting and agility (23) and vertical jump performance (6), our investigation is the first to investigate the acute effects of BS on the number of repetitions, demonstrating that a BS protocol significantly reduces the number of repetitions performed in the leg-press exercise at a submaximal load (80% of 1RM).

Total volume, which affects short- and long-term responses to strength training (3,14–16,32), is positively related to myofibrillar protein synthesis (8), anabolic hormones release (14,15,36), strength gains, and skeletal muscle hypertrophy (15,16,19,29,32). Our results demonstrated that total volume was reduced after the 3 proposed stretching protocols.
Different Stretching and Neuromuscular Performance

It suggests that stretching before training may negatively impact resistance training-induced adaptations in strength and muscle mass. However, caution should be exercised when interpreting and generalizing these findings because we have not evaluated the effects of stretching on long-term adaptations to resistance training.

In regard to the 1RM data, it is important to note that the scores obtained in the sit-and-reach test indicate that all the stretching protocols were effective in increasing ROM. Despite the previous reports associating acute increments in ROM (through SS and PNF stretching) with decreased maximal strength performance (3), our data show that only the PNF protocol significantly affected 1RM. In fact, the literature is still controversial regarding the acute effects of SS and PNF stretching on neuromuscular performance. For instance, Molacek et al. (26) and Egan et al. (9) reported no effect of SS and PNF stretching on the maximal torque and muscle power output. Conversely, SS and PNF have been shown to decrease vertical jump (6) and maximal strength (2,25,26,28).

Interestingly, Molacek et al. (26) and Egan et al. (9) suggested that training status could affect individual susceptibility to the detrimental effects of stretching on maximal strength performance. In accordance with this suggestion, Beedle et al. (5) showed that in highly trained subjects, neither BS nor SS affected maximal strength performance. Our results support this concept, because the strength-trained subjects of our study were not affected by either SS or BS. On the other hand, PNF induced an approximately 5.5% decrease in the 1RM in our study, supporting previous suggestions (9,26) that stretching should be of greater intensity (i.e., PNF) to affect strength in trained subjects.

The mechanisms underlying maximal strength decrements after stretching are based on reduced musculotendinous stiffness (1,11,33) and decreased motor unit activation (10,18,21,22). Our sit-and-reach scores indicate that despite improvements in the ROM after any of the stretching protocols, PNF was more effective in acutely augmenting ROM (Table 1), thus suggesting that PNF may greatly affect musculotendinous stiffness (18). It is important to note that sit-and-reach tests were used to evaluate changes in ROM but the muscles assessed (hamstrings) were different from those used during leg-press lifts (quadriceps and gluteus), but this test was used to evaluate stretching protocol efficacy. Because 1RM was reduced only by the PNF protocol, it is tempting to speculate that there might be a threshold in stiffness reduction to affect maximal strength. Additionally, it is also possible that autogenic inhibition was greater after PNF thus reducing neuromuscular activation and muscle strength.

At the moment, the events related to stretching that act upon the maximal number of repetitions are unknown. It is interesting to note that both the SS and BS protocols did not affect maximal strength but induced a decrease in the number of repetitions performed with a submaximal load. This suggests that mechanisms other than the viscoelastic properties of the musculotendinous unit and the reduced motor unit activation might play a role. It has been suggested that blood flow through a muscle can be reduced during stretching (20,30,38), which could at least partially explain the results. The partial ischemia-induced reduction in strength is attributed to a low-oxygen supply and impaired removal of metabolic by-products (17). The number of repetitions test was performed after the stretching protocol, so one may argue that blood flow was likely back to normal by then. However, it is possible that ischemia during stretching could have elevated the concentration of metabolites, which may have impaired testing performance. Despite the lack of data regarding mechanical properties, motor unit activation, and metabolic parameters regarding different stretching protocols, our results warrant further investigations evaluating such parameters and their relation to the number of repetitions performed.

In summary, the 3 stretching protocols acutely increased ROM and decreased the number of repetitions and the total volume performed, demonstrating for the first time that BS can also compromise neuromuscular performance. Additionally, we demonstrated that in strength-trained individuals, only PNF reduced the maximal dynamic strength.

Practical Applications

Stretching exercises as part of a warm-up routine are a common practice among trainers and athletes. Trainers should be aware that not only the stretching protocol performed but also the training statuses of the athletes play a role in its effect upon the neuromuscular performance. Strength-trained athletes are less prone to the negative effects of acute stretching on maximal strength and hence should avoid high-intensity protocols such as the PNF in their maximum strength training sessions.

However, when the training session includes multiple sets of resistance exercise (i.e., hypertrophy-oriented training sessions), trainers should avoid any stretching protocol, including the BS because stretching may result in a reduced number of repetitions performed with a submaximal load and lower total volume (i.e., number of repetitions × external load), thus affecting long-term resistance training adaptations.

References


