Effect of Potentiation and Stretching on Maximal Force, Rate of Force Development, and Range of Motion

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ABSTRACT

PURPOSE: The purpose of this investigation was to compare the effects of stretching versus performing three sets of maximal effort leg presses (potentiation) on subsequent maximal force and rate of force development capabilities in an isometric squat and joint range of motion. METHODS: Ten male collegiate track & field athletes participated as subjects in this study. Subjects were tested during three separate sessions that involved joint range of motion (ROM) measurements of the lower body and isometric squat trials on a force plate to determine peak force (PF) and rate of force development (RFD) values. One session was preceded by 10 minutes of quiet sitting (C), one with a 30 minute lower body stretching protocol (S) and one with three sets of a leg press exercise using 90% of the subjects previously determined one repetition maximum (P). Three repetitions were performed for each of the three sets with a three-minute rest period between each set.

RESULTS: PF in the isometric squat was not significantly different following any of the three conditions (C - 100.0% ± 0.0, S - 101.2% ± 6.5, P - 98.6% ± 6.2). However, RFD was significantly lower in P (87.5% ± 12.8) in comparison to both C (100.0% ± 0.0) and S (102.6% ± 18.5). Significant improvement in ROM only occurred following P.

CONCLUSION: It appears the potentiation protocol used in the current investigation may actually have had fatiguing effects instead of potentiating effects, but did manage to result in some significant increases in ROM. Furthermore, stretching did not appear to have a negative or positive effect on PF or RFD, however, stretching did not significantly alter ROM. Future experiments investigating the possibility of potentiation should most likely involve a lower number of sets or repetitions to avoid the possible onset of fatigue.

INTRODUCTION

Prior to an activity, most persons will perform some kind of active warm-up (WU) because it is commonly thought to enhance performance and prevent injury. There are multiple ways to perform active WU, the most common being jogging or biking. Stretching and sub-maximal sets are also commonly included in WU protocols. The goal of WU is to increase muscle temperature and other physiological responses.

Stretching in the active population has become a traditional WU practice performed without question. Many studies have looked at the effect of stretching on performance and have found confounding results. A number of studies have concluded that stretching enhances performance (Worrell et al, 1994) and prevents injuries (Shellock and Prentice, 1985; Smith, 1997). In contrast, a few studies have not found any correlation between stretching or flexibility and injury (Gleim and McHugh, 1997; Shrier, 1999). Recently, stretching has come under question when performed just prior to strength or power activities due to the negative effect it has shown with these movements (Kokkonen, Nelson, and Cornwell, 1998; Behm et al, 2001; Church et al, 2001; Nelson and Kokkonen, 2001; Young and Elliot, 2001; Cornwell, Nelson and Sidaways, 2002; Young and Behm, 2002).

A relatively new form of WU, potentiation (also called postactivation potentiation), has begun to receive an increased amount of investigation. Sale (2002) defined potentiation as an increase in muscle twitch and low-frequency tetanic force after a “conditioning” contractile activity. Sale went on to classify these conditioning activities, including a series of evoked twitches, an evoked tetanic contraction, or a sustained maximal voluntary contraction (MVC) (Sale, 2002). Although the mechanisms of potentiation have been studied in the past, recent interest has been given to its effects on athletic performance such as in the bench press and vertical jump (Güllich and Schmidtbleicher, 1996; Young, Jenner, and Griffiths, 1998; Young and Elliot, 2001).

Therefore, the purpose of this study was to compare the effects of acute static stretching versus potentiation from a MVC in a leg press on peak force (PF) and rate of force (RFD) in an isometric squat and active joint range of motion (ROM). Through this it is hoped that there will be an increased mechanistic understanding concerning the effects of stretching on strength and information on potentiation leading to better WU practices for athletes.

METHODS

Experimental Approach to the Problem

Each subject was exposed to two treatment protocols and acted as their own control group. A rest period of at least two days was given between sessions to allow for adequate recovery. The primary research hypothesis was that the stretching protocol would reduce PF and RFD, and that the potentiation protocol would increase performance in these activities. Athletes usually have a fairly good knowledge of what a good stretch feels like and how it should be done. Athletes also tend to know how to give their maximal effort. For these reasons, we used athletes to perform this research in hopes of reducing any learning effect. This research was approved by the Institutional Review Board.

Subjects

Ten healthy male collegiate track & field (sprints, jumps, pole vault) and footballers (age 20.6 $\pm$ 1.5 years, height 181 $\pm$ .4 cm, weight 83.4 $\pm$ 14.1 kg) gave their written consent to participate as subjects in this study. All subjects indicated that they had no significant history of recent musculoskeletal injury. Since the participants were athletes, they were instructed to continue with their current exercise regimen. Each subject performed a one repetition maximum (1RM) on the leg press during a familiarization session prior to performing the treatment protocols. Subjects were selected to proceed through the three treatment protocols, stretching (S), potentiation (P), and control (C); in a random order. After each treatment, subjects were tested using an isometric MVC in a squatting position against a force plate.

Range of Motion, One Repetition Maximum, & Familiarization

During the first session, subjects were familiarized with the procedures that would take place during the following sessions. Upon arrival, each subject's range of motion (ROM) measurements were taken. This was done through four tests: active straight leg hamstring (ASLH), active bent let hamstring (ABLH), active prone quadriceps (APQ), and gravity hip flexor (GHF). All tests proceeded left leg first followed by the right leg. Measurements were taken with a handheld goniometer. The ASLH test was completed by the supine subject raising their leg straight towards their head while keeping their contralateral leg flat on the ground. This measurement was controlled by three anatomical landmarks; the axilla, greater trochanter, and lateral condyle. The ABLH test was completed by having the examiner place and hold the supine subject's hip at 90° and then instructing the subject to extend their knee through contraction of the quadriceps. The APQ test was completed by having the subject contract their hamstring, thus pulling their heel towards their gluteal muscles. Subjects were instructed to keep the anterior aspect of their hip as close to the ground as possible for this test. These measurements of the ABLH and APQ were controlled by three anatomical landmarks; the greater trochanter, lateral condyle, and lateral malleolus. The last test, the GHF test, was the only non-active ROM measurement. The test was completed by the subject lying on a table with the superior portion of their gluteal muscles on the edge of the table. Subjects were then asked to grab their knee and bring it as far to their chest as possible and relax the opposite leg. Measurements were controlled by the same procedures as the ASLH test. Active ROM measurements were used to reduce tester error. These ROM measurement protocols were used to test ROM immediately prior to the treatments and following the performance testing.

For the 1RM testing protocol, each subject was asked to estimate their 1RM on a leg press. Each subject used their estimated 1RM (272.7 $\pm$ 60.2 kg) as a guideline for warming up. Subjects completed 10 repetitions at 50%, 6 repetitions at 70%, and 3 repetitions at 90% of their estimated 1RM. A repetition was considered full when the subject lowered the weight in a cotrolled fashion down to just short of causing posterior pelvic tilt. After the warm-up, the subject's actual 1RM (376.6 $\pm$ 81.3 kg) was assessed in 3-5 sets by completing a singe repetition of a given weight. Each set was separated by a three minute rest period to allow for recovery. This 1RM weight is used to estimate the potentiation weight.

After the completion of the 1RM, each subject was given two unmeasured trials of the performance testing to familiarize them with this protocol. This familiarization is thought to reduce confounding data from any learning curve.

Stretching Protocol

The stretching protocol consisted of four stretches. The four stretches consisted of a straight leg hamstring (SLH), gluteus medius (GM), prone quadriceps (PQ), and hip flexor (HF) stretch. For the SLH stretch, the examiner moved the subject's leg towards their head while maintaining a straight knee and a neutral foot position. For the GM stretch, the subject's hip was flexed, externally rotated, and adducted. The subject's foot was then placed on the opposite leg and passively moved towards the head of the subject. The subject's leg was then further adducted in the current position. For the PQ stretch, the subject's lower leg was moved towards their gluteal muscles while a downward pressure was applied to the posterior hip in order to counteract any subsequent hip flexion. For the HF stretch, the subjects assumed the same position as the GHF test. A downward pressure was applied to the superior portion of the knee while the lower leg was kept perpendicular to the floor. The subjects were passively stretched by the examiner, moving the limp until the subject instructed the examiner that they had reached the point just before the stretch became painful. Subjects were athletes with knowledge of stretching and it was assumed that the stretch elicited strain in the plastic range. Each stretch was held in place by the examiner for 30 seconds with a rest time of 20 seconds (total time 23.3 ± 1.8 minutes). The stretch time of 30 seconds was chosen because of its proven ability to adequately increase flexibility (Bandy). This was repeated three times for each limb.

Potentiation Protocol

The potentiation protocol consisted of 3 sets of 3 reps at 90% of the subject's 1RM on the same leg press as the 1RM was performed (potentiation weight 338.8 ± 73.1 kg). Each set was separated by a 3 minute rest period.

Control Protocol

The control protocol consisted of 10 minutes of quiet sitting with the knees and hips in a relaxed 90° position.

Performance Testing

Following each treatment, subjects completed 6 iMVCs (3 PF and 3 RFD) in a random fashion with 3 minutes rest between each trial. Subjects were placed in a Smith squat rack where they were set at approximately a fixed 90° hip and knee position. A force plate, place under the subjects feet, was used to measure force. For the PF testing, the subjects were asked to start off pushing against the bar slowly but with gradually more force, peaking at the end of the 5 second trial. For the RFD testing, the subjects were instructed to start off by exploding as fast and hard as possible into the bar and to maintain that force for the 5 second trial. Force resulting from these trials was sent to a computer through an amplifier where it was converted to digital data.

Statistical Analysis

An ANOVA with repeated measures model was used to determine whether there was significant differences in PF and RFD between the treatments groups. Each control performance was considered to be 100% of the individual subject's maximal performance. Performances from the treatment groups were converted to percentages of the control. The null hypothesis was that the treatments would have no effect on PF and RFD. For each session, body part stretched and side of the body, a paired sample t-test was performed subtracting the post-treatment measurement from the pre-treatment measurement. In all analyses, statistical significance was defined by $p<0.05$. Results are summarized as means ± standard deviations (SD).

Table 1. Peak force (PF) & rate of force development (RFD) values (mean ± SD) in Newtons (N) and Newtons/second (N/s) respectively.

Treatment	Peak Force (N)	RFD (N/s)
Control	2646 ± 471	4931 ± 1283
Stretching	2670 ± 468	4976 ± 1127
Potentiation	2605 ± 465	4254 ± 1052 *

* Significant at $p < .05$.

RESULTS

ANOVA showed that there was no significant difference (see Table 1) in PF (C mean 100.0% ± 0.0, S mean 101.2% ± 6.5, P mean 98.6% ± 6.2) between groups (F=.779, p=.474). RFD (C - 100.0% ± 0.0, S - 102.6% ± 18.5, P - 87.5% ± 12.8) was significantly lower (F=3.865, p=.040) than the control group (see Figure 1). There was no significant difference (see Figure 2) between stretching and potentiation groups for RFD (p=.187).

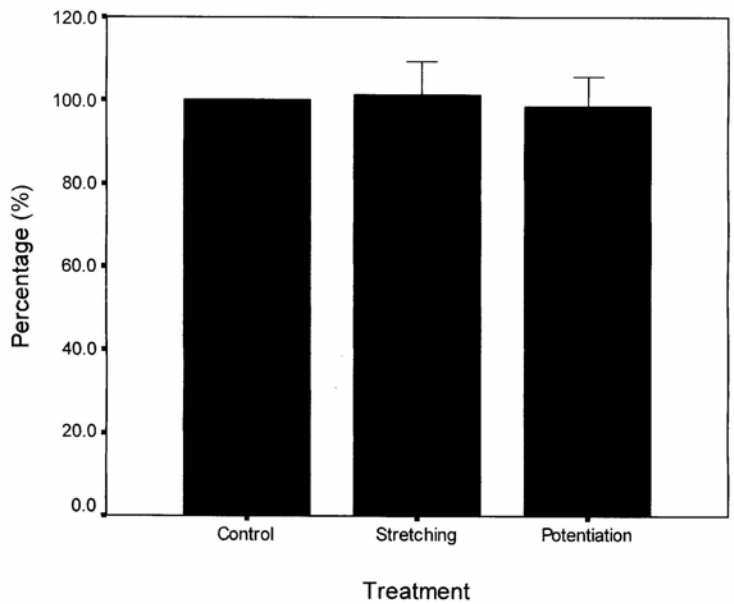

Figure 1. Peak force (PF) for each treatment group shown as a percentage of the control group.

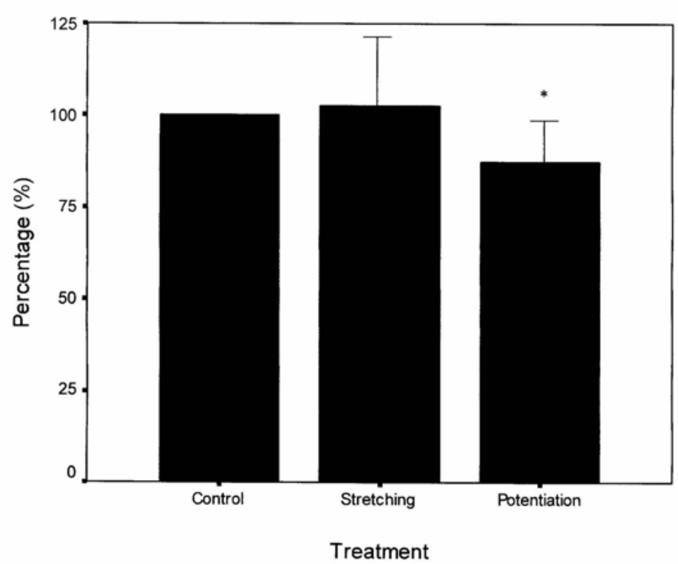

Figure 2. Rate of force development (RFD) for each treatment group shown as a percentage of the control group. Significance (*) at p < .05.

Significant changes in ROM were only seen in a few areas. Significant increases (5.9 ± 7.3 and 3.2 ± 4.4 degrees respectively) were observed in the left leg of the ABLH potentiation group (t=2.544, p=.032) and the right leg of the GHF potentiation group (see Table 2).

Table 2. Range of Motion (ROM) changes (mean ± SD) shown as differences (pre-test value – post-test value) in degrees.

	ASLH		ABLH		APQ		GHF	
Treatment	Left	Right	Left	Right	Left	Right	Left	Right
Control	2.5±7.6	2.1±6.8	-0.6±4.1	-1.5±6.3	0.4±3.4	-0.4±4.1	1.4±5.6	2.8±3.7*
Stretching	2.6±8.2	0.2±5.8	-1.0±7.1	0.1±8.5	0.8±4.3	0.0±3.1	1.9±4.3	4.0±3.6*
Potentiation	0.5±5.8	0.1±6.9	-5.8±7.3*	-2.7±7.6	0.5±3.3	2.0±4.2	-0.8±6.2	-3.2±4.4*

* Significant at $p < .05$.

DISCUSSION

The purpose of this study was to compare the effects of static stretching and potentiation on PF, RFD and ROM. One major finding of this study was that the stretching protocol did not have a detrimental or beneficial effect on performance. The other major finding was that the potentiation protocol seemed to have a fatiguing effect instead of a potentiating, performance enhancing effect. These findings were, in fact, unexpected and came as a surprise because they contradict some prior research. A finding which did not come as a surprise was that there were limited significant changes observed in ROM. Much research has shown that this is fairly normal for similar stretching protocols.

Recently, an increasing amount of research has been given to the effect that stretching has on different variables of athletic performance. In 1998, Kokkonen et al. looked at the effects of static stretching on knee flexor and extensor strength. They found that both knee flexion and extension strength was reduced following the stretching protocol as compared to the control. The researchers attributed this strength loss to a reduction in stiffness of the musculotendinous unit. An increase in muscle stiffness has been correlated with increased concentric performance in a bench press exercise (Wilson et al, 1994). Further more, Taylor et al. (1990) showed an increased muscle length, which may negatively affect force development by placing the contractile components at a less than desired point on the force-length curve. Cornwell, Nelson and Sidaway (2002) compared countermovement and static vertical jumps after an acute bout of static stretching (3 times for 30 seconds on the gastrocnemius and soleus). They found that the static stretching did not affect the static jump (SJ) but significantly decreased jump height in the countermovement jump (CMJ). They also found a decreased active stiffness of the muscle/tendon unit. The CMJ utilizes the stretch-shortened cycle (SSC) in which stored elastic energy may have been reduced due to the stretching protocol. It may be assumed then that the stretching protocol in the present study did not elicit an increase in muscle/tendon unit compliance due to the insignificant increases found in PF and RFD for the stretching group.

The results found in this study do not coincide with the results found with previous studies that investigated the effect of pre-activity contractions on performance. Güllich and Schmidtbleicher (1996) found that the used of three MVCs prior to a vertical jump test resulted in an increase in the subsequent jump height. These investigators also observed the effects of this type of potentiation in a bench press like movement. They found significantly positive effects on explosive force. These effects were greatest when the MVCs used a 5 minute rest interval. Young et al (1998) used a 5RM barbell squat as the preceding bout to elicit potentiation. An increased mean jump height (5 jumps) using a 19 kg load was observed. A 4 minute rest period was used to allow adequate recovery. One study (Gossen & Sale, 2000) did result in a similar outcome as the present study. These researchers used a 10 second MVC as their potentiating protocol followed by maximal dynamic knee extensions with 15%, 30%, 45%, and 60% loads. The testing was done approximately 15 seconds after the potentiation protocol was administered. Although no significant differences were shown, the general tendency was for peak velocity to be depressed. These findings suggest that insufficient recovery time was allowed to reduce fatigue. There are many factors that contribute to fatigue including metabolic, mechanical and neurological. Although none of these mechanisms were measured during this study, a reason behind the fatiguing effect may be inferred. One possibility might be that the rest period was not long enough between sets to allow the central nervous system recover properly (Sahlin et al., 1998).

Another mechanism of fatigue is decreased energy metabolism due to lactic acid build-up during high intensity activities (Sahlin et al., 1998).

Increases in ROM were seen in only two groups (left ABLH P and right GHF P). This finding is not unusual for an acute bout of stretching. One study showed that significant increases were only seen for three minutes when using an acute static stretching bout of four sets held for 30 seconds (DePino et al, 2000). Bandy (Bandy and Irion, 1994) found that a stretching time of 30 to 60 seconds was sufficient for increasing ROM, although a chronic protocol was used with the subjects stretching five days per week for six weeks. Three weeks of chronic stretching, five days per week and four sets of 15-20 seconds per day, was used as the protocol by Worrell et al (1994). They found that stretching increased peak isokinetic torque but had no significant effects on ROM. These studies differed from this one in that they only applied their stretches to one selected muscle group (i.e. knee extensors or flexors) whereas multiple muscle groups were stretched in this study. This may have attributed to reducing the effects that stretching may have had on performance in that by the time one muscle group was done being stretched; the other muscle groups had recovered from any mechanical strain. Another factor that may have contributed to minimal findings is the order of the protocols. If the ROM retesting was done immediately after the treatment protocols, before the performance protocol, it may have elicited significant increases.

Some future considerations may be drawn from the study's results. It may be concluded that the acute effects of stretching, including ROM, are not always elicited with a normal stretching protocol. Stretching protocols that resemble those used by most athletic individuals should be used. In the future, a more specified (i.e. stretching only those muscles that are used most) stretching routine might be used. A potentiation protocol with less sets and/or more recovery time might be optimal to elicit an increase in performance. ROM measurements should be taken directly following the treatment protocols to be sure that flexibility is not altered. The mechanisms behind stretching and potentiation both are still relatively unknown. Further research must be done to improve our understanding of this topic.

PRACTICAL APPLICATIONS

The information found in this study can be used to direct future researchers to use a lesser volume that what was used in this study. As we research more thoroughly the effects of different warm-up protocols on athletic performance variables, the most beneficial uses can be magnified. This increased understanding and more reliable utilization of the current information will help to enhance athletics, thus producing more efficient and productive athletes.

REFERENCES

1. BANDY, W.D. AND J.M. IRION. The effect of time on static stretch on the flexibility of the hamstring muscles. Phys. Ther. 74(9):845-852. 1994.
2. BEHM, D.G., D.C. BUTTON, AND J.C BUTT. Factors affecting force loss with prolonged stretching. Can. J. Appl. Physiol. 26(3):262-272. 2001.
3. CHURCH, B.J., M.S. WIGGINS, F.M. MOODE, AND R. CRIST. Effect of warm-up and flexibility treatments on vertical jump performance. J. Strength Cond. Res. 15(3):332-336. 2001
4. CORNWELL, A., A.G. NELSON, AND B. SIDAWAY. Acute effects of stretching on the neuromechanical properties of the triceps surae muscle complex. Eur. J. Appl. Physiol. 86:428-434. 2002.
5. DEPINO, G.M., W.G. WEBRIGHT, AND B.L. ARNOLD. Duration of maintained hamstring flexibility after cessation of an acute static stretching protocol. J. Athletic Training. 35(1):56-59. 2000.
6. GLEIM, G.W., AND M.P. MCHUGH. Flexibility and its effect on sports injury and performance. Sports Med. 24(5)289-299. 1997.
7. GROSSEN, E.R. AND D.G. SALE. Effect of postactivation potentiation on dynamic knee extension performance. Eur. J. Appl. Physiol. 83:524-530. 2000.
8. GÜLLICH, A., D. SCHMIDTBLEICHER. MVC-induced short-term potentiation of explosive force. New Studies in Athletics. 4:67-81. 1996.
9. KOKKONEN, J., A.G. NELSON, AND A. CORNWELL. Acute muscle stretching inhibits maximal strength performance. Res. Q. Exerc. Sport. 69(4):411-415. 1998.
10. NELSON, A.G., J.D. ALLEN, A. CORNWELL, AND J. KOKKONEN. Inhibition of maximal voluntary isometric torque production by acute stretching is joint-angle specific. Res. Q. Exerc. Sport. 72(1):68-70. 2001.

11. NELSON, A.G., J. KOKKONEN. Acute ballistic muscle stretching inhibits maximal strength performance. Res. Q. Exerc. Sport. 72(4):415-419.
12. SAHLIN, K., M. TONKONOGI, AND K. SODERLUND. Energy supply and muscle fatigue in humans. Acta. Physiol. Scand. 162(3):261-266. 1998.
13. SALE, D.G. Postactivation potentiation: role in human performance. Exerc. Sports Sci. Rev. 30(3):138-143. 2002.
14. SHELLOCK, F.G. AND W.E. PRENTICE. Warming-up and stretching for improved physical performance and prevention of sports-related injuries. Sports Med. 2:267-278. 1985.
15. SHRIER, I. Stretching before exercise does not reduce the risk of local muscle injury: a critical review of the clinical and basic science literature. Clin. J. Sports Med. 9(4): 221-227. 1999.
16. SMITH, C.A. The warm-up procedure: to stretch or not to stretch. A brief review. J. Orthop. Sports Phys. Ther. 19(1):12-17. 1994.
17. TAYLOR, D.C., J.D. DALTON, A.V. SAEBER, AND W.E. GARRETT. Viscoelastic properties of muscle-tendon units: The biomechanical effects of stretching. Am. J. Sports Med. 18(3):300-309. 1990.
18. WILSON G.J., A.J. MURPHY, AND J.F. PRYOR. Musculotendinous stiffness: its relationship to eccentric, isometric, and concentric performance. J. Appl. Physiol. 76(6):2714-2719. 1994.
19. WORRELL, T.W., T.L. SMITH, AND J. WINDEGARDNER. Effect of hamstring stretching on hamstring muscle performance. J. Orthop. Sports Phys. Ther. 20(3):154-159. 1994.
20. YOUNG, W.B. AND D.G. BEHM. Should static stretching be used during a warm-up for strength and power activities? Strength Cond. J. 24(6):33-37. 2002.
21. YOUNG, W. AND S. ELLIOT. Acute effects of static stretching, proprioceptive neuromuscular facilitation stretching and maximal voluntary contractions on explosive force production and jumping performance. Res. Q. Exerc. Sport. 72(3):273-279. 2001.
22. YOUNG, W.B., A. JENNER, AND K. GRIFFITHS. Acute enhancement of power performance from heavy load squats. J. Strength Cond. Res. 12(2):82-84. 1998.