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Utah State University

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THE EFFECT OF STATIC STRETCHING AND ORDER OF WARM-UP ON ISOKINETIC PEAK TORQUE OF THE KNEE EXTENSORS

by

Eric J. Sobolewski

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Health, Physical Education and Recreation

Approved:

Dale Wagner, Ph.D. Major Professor	Eadric Bressel, Ed.D. Committee Member
Dan Coster, Ph.D. Committee Member	Byron R. Burnham, Ed.D. Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2010

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ABSTRACT

The Effect of Static Stretching and Order of

Warm-Up on the Isokinetic Peak Torque

of the Knee Extensors

by

Eric J. Sobolewski, Master of Science

Utah State University, 2010

Major Professor: Dale Wagner, Ph.D.
Department: Health, Physical Education and Recreation

The purposes of these studies were to determine if an acute static stretch influenced isokinetic peak torque (IPT), and to examine if the order in which the warm up routine was performed affected peak knee extension torque. Twenty trained college male students performed maximal isokinetic knee extensions under four conditions: a control consisting of no stretching, a stretch only trial, jog then stretch, and stretch then jog conditions. Each stretch was held for a total volume of 360 s. Measurements were taken on a Biodex System 3 isokinetic dynamometer at speeds of 60^{o} s^{-1} and 300^{o} s^{-1}. Data were analyzed using t-tests to compare the stretch condition with the control. The results indicated that there was a significant difference between the stretch and the control at 300 ^{o} s^{-1} (p = 0.03 t = 2.42) but not at 60 ^{o} s^{-1} (p = 0.16). A 2 x 3 ANOVA (300 ^{o} s^{-1} x 60 ^{o} s^{-1}, and control x stretch then jog x jog then stretch) yielded no significance at either speed (p

> 0.05). Conclusions from this study indicate that stretching should not be the sole exercise in a warm-up routine as previous research confirms the decrease in IPT after stretching. Another finding of this study is that the negative effects of stretching can be diminished when combined with an aerobic activity such as jogging prior to performance. Further research is needed to determine the underlying factors that contribute to the post stretch decrease in IPT and the factors that lead to the restoration of force after aerobic activity. Caution is advised since these were controlled tests in a laboratory and results may vary with actual performance.

(49 pages)

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Eric J. Sobolewski

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CHAPTER I

INCLUSIVE INTRODUCTION

The primary goal of warm-ups prior to exercise is to increase core body temperature (45). In most cases "warm ups" include static stretching, in which minimal movement is being done, thus generating minimal thermal activity to heat up the body. The perceived need for stretching can be attributed to tradition and lack of knowledge of what stretching does to the body (31). Stretching has been shown to increase range of motion (ROM) (6), help prevent injury (3) and increase performance (54). Yet recent research, as reviewed by Shier (46), would disagree with stretching as part of a warm up because it has shown to decrease peak torque as produced by knee flexion (14) and extension, eccentric torque (16) electromyography (EMG) activity in active muscles during testing (18), vertical jump performance (11), and power output as measured by force, height, and time with a force platform (57).

The discrepancies in the research regarding the effects of stretching could be attributed to a lack of evidence demonstrating what happens physiologically during and after stretching. Since physiological effects of stretching have not been established, there is a need to examine kinematic and kinetic effects of stretching (46). Many of the presumed reasons for the previously seen effects, such as, an increase in ROM, loss of torque, EMG activity, jump performance, and power output (7) have been attributed to the visco-elastic components of the muscle-tendon unit. This would affect stiffness, the ability to resist force, and force production. If the elastic fibers in a muscle-tendon unit are stretched and remain in an elongated position a lag in the transfer of force is produced, thus compromising performance (31). Stretching may also alter the angle - torque relationship and/or sarcomere shortening velocity as speculated by Cramer et al (15). Another hypothesis is that stretching a muscle creates a neural inhibition that affects the motor units and limits the excitability of the muscle, as seen by a decrease in EMG activity (41). This decrease in EMG activity has culminated in a decrease in performance as observed in jump height (7).

Church et al. (11) found that stretching decreased jump height by 4 %. They examined six different stretches that focused on the knee and hip extensors. When performing a vertical jump, there are numerous muscles that create the motion. As observed by Church et al. (11), the main action in a jump is knee and hip extension. They maximized stretches targeting the hip and knee extensors and the hip adductors; this could explain the observed decrease in jump height.

Researchers that have found no difference in jump height (27, 48) stretched the hamstrings, gastrocnemeus, and quadriceps. However, Cornwell et al. (13) observed that an expanded stretch protocol that targeted the hip flexors, gluteals, and soleus as well as the hamstrings, gastrocnemeus, and quadriceps led to a decrease in jump performance.

From these aforementioned findings it may be suggested that the complexity of the vertical jump requires a more elaborate stretching protocol to target actively-used muscles. For a more controlled study, researchers may wish to isolate the active muscles using isokinetic torque as monitored by a dynamometer. These tests examine the knee flexors and extensors separately and also control the influence of muscle mechanics on muscle force production by controlling the speed of motion. Researchers have analyzed the isokinetic torque produced by the quadriceps due to the familiarity of leg extension exercise and its high correlation to sports performance (2, 4, 40).

With the focus constrained to just knee extensors several stretch test variables are possible including: type (static vs. dynamic), duration, intensity, speed, and angle. Zakas et al. (59) addressed the issue of duration. They found that a stretch duration of five minutes or more produced a loss in isokinetic peak torque (IPT), yet decreases have been seen in stretching as little as 30 s (47). Nelson et al. (35) concluded that negative effects of stretching are only observed in slower speeds, implying that the effects are velocity specific. However, recent research has found a decrease throughout the velocity spectrum of $30^{o}s^{-1}$ to $360^{o}s^{-1}$ (17). Also, there is evidence that force reduction is joint angle specific; some research indicates that it may only be seen at degrees closer to full (180º) knee extension (35). Papadopoulos et al. (41) showed decreased IPT only after static stretching; no difference was seen after dynamic stretches. More localized studies that used a dynamometer have shown a more consistent finding that stretching does decrease torque production (14-18, 35, 41, 47). All of the studies have shown some type of decrease in performance with little evidence refuting the idea that there is no effect when the force is isolated to knee extensors.

The only aspect of these aforementioned studies that is not addressed in the literature concerns the issue of what is being done with stretching as part of the warm up routine. Jogging, running, cycling (7), and an aerobic circuit (11) have been examined, yet there is little control of the criterion for what a warm up entails. In most cases after the participants had completed the stretching protocol they proceeded straight to testing

(57) except in one study (48) in which walking was used to warm the muscles up after stretching to prevent injury. In most pre-event warm ups athletes use stretching as a part of their routine which typically includes many other activities before and after stretching. There has been little control of the order of what takes place prior to testing that could alter the negative effects seen in prior studies. If the effects that decrease force production are attributed to muscle stiffness, then a jog could expand the decrease. If the effects are neurological then a post-stretch activity performed prior to testing could stimulate the neurons and offset the negative effect of stretching.

The purpose of this study was to determine if an acute static stretch influences isokinetic peak torque of the knee extensor muscles at speeds of 300 º s^{-1} and 60 º s^{-1}. A secondary purpose was to examine if the order in which the warm up routine was performed affects peak knee extension torque. The research hypothesis was that stretching will negatively affect isokinetic peak torque.

CHAPTER II

THE EFFECT OF STATIC STRETCHING ON ISOKINETIC PEAK TORQUE OF THE KNEE EXTENSORS

Introduction

The principle of a warm up prior to an athletic performance is to increase core body temperature (45). Traditionally, these "warm ups" have consisted of static stretching (56) which has been shown to increase range of motion (3, 31), help prevent injury (5), and improve sport performance (54). Although stretching as a part of a warm up is common practice among athletes and trainers alike (12, 59), the diminishing effects of stretching on performance have been observed in multiple studies (46).

Research has suggested that static stretching leads to a decrease in vertical jump performance (7, 11, 12, 57), running speed (22, 36), electromyography activity (18, 41, 55), isometric strength (7, 28, 42, 51), overall strength (29, 38, 39), and isokinetic torque (17, 32, 37). Deficits have shown to be joint angle specific (35) and even velocity specific (37). Even with substantial evidence showing the negative effects of static stretching there are still studies that show no ill effects of static stretching (27, 48). Studies that isolated the knee extensors have shown to be more consistent in finding deficiencies in performance (7, 17, 28, 32, 35, 37, 42, 51). Isokinetic measurements are the most commonly assessed (17, 32, 37, 41, 58).

Two hypotheses proposed to explain the deficiencies in strength after acute static stretching are: changes in the visco-elastic properties of muscle and neural inhibition. The theory is that stretching changes the visco-elastic components of muscle by increasing the length of the muscle-tendon unit, so it cannot properly transfer or produce force (51, 52). The other hypothesis of neural inhibition that occurs post stretching is that an increase in the autogenic inhibition of motor neurons leads to a decrease in force production (21, 26).

Isokinetic peak torque has been highly correlated to vertical jump performance ($r = .83$) and running speed ($r = .78$) at velocities of 60 ° s^{-1} and 300 ° s^{-1}, respectively (4, 8, 25, 40). Research has only evaluated the effects of stretching on speeds as high as 270 ºs^{-1} (58). Previous research is mixed on whether force inhibition is velocity specific. Cramer et al. (18) stated that deficiencies are seen at both 60º s^{-1} and 240º s^{-1}, but Nelson et al. (37) hypothesized that the effects are only seen at slower speeds.

The purpose of this study was to determine if the effects of static stretching were velocity specific because these velocities are correlated to sports performance at speeds of 60º s^{-1} and 300º s^{-1}. The research hypothesis was that the diminishing effects of stretching will be seen at both speeds.

Methods

Experimental Approach to the Problem

Two protocols, a stretch only and a no-stretch control, were performed in a random order, on different days, as a repeated measures test-retest design. Isokinetic tests of peak torque were conducted at two speeds that were assigned in a random order. Each participant performed five maximal repetitions at each speed the day of testing. Prior to testing, participants were introduced to the stretching techniques and testing procedures to familiarize themselves with the protocol to help diminish the learning effect. Tests were then conducted to determine the effects of stretching on isokinetic peak torque.

Participants

Twenty male college students volunteered to participate in this study. Recruitment of participants was done via word of mouth. Prior to the study they filled out an athletic questionnaire (Appendix A) in which they reported being free of knee pain and having no previous knee injuries. Participants' demographics were: age of 22.1 ± 2.4 yrs, height of 181.6 ± 1.8 cm, and mass of 82.3 ± 29.5 kg. All individuals agreed to maintain their current workout schedule yet refrain from leg exercises the day prior to and the day of the test. Participants were all similar in fitness level being active to very active as defined by performing physical activity four or more times per week. All participants read and signed an informed consent (Appendix B) approved by the institutional review board.

Procedures

Testing was performed at two speeds, 60º s^{-1} and 300º s^{-1}, speeds that correlate with vertical jump and sprinting performance, respectively (2, 4, 8, 25, 40). The test consisted of the participant performing five maximal isokinetic leg extensions at both speeds, which were randomly assigned. All tests were performed on the dominate leg (18). Five repetitions are optimal for determining peak torque (9). All five repetitions were done consecutively with a three min rest between each velocity to allow for maximum recovery (30).

Instrumentation

A Biodex System 3 isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY) was used to measure isokinetic peak torque. Participants were restrained with Velcro straps as recommended by the manufacturer. The axis of the dynamometer arm was aligned with the axis of the knee. Calibration and participant set up followed the instructions in the manufacturer's guide. An unpublished test of reliability of peak torque was done using the same equipment with an interclass correlation coefficient of $ICC = 0.95$.

Stretch Protocol

The stretching protocol consisted of four stretches, one unassisted and three assisted using a protocol from previously published research (17). Stretching procedures targeted the knee extensors exclusively. The unassisted stretch was a standing quadriceps stretch (Figure C.1). The participant stood arm's length away from the wall. The dominant knee was bent to 90º. With the opposite hand, the participant grabbed the foot and pulled it toward the buttock. The first assisted stretch the participant stood with his back to a table and the dorsal surface of his foot on a table (Figure C.2). For the second assisted stretch the participant laid prone on a padded table. The dominant knee was bent toward the buttock (Figure C.3). If the participant's foot reached the buttock and no stretch was felt, a 30º wedge was placed under the hip, causing a slight hyperextension of the hip. Pressure was applied to both the shoulder and the flexed knee. The final assisted stretch had the participant lay supine with his dominant leg hanging off the table (Figure C.4). The leg was then flexed and the hip slightly hyperextended by applying pressure to both the anterior part of the lower leg and the thigh. All stretches were performed until minor discomfort (25). All stretches were held for 30 s with a 15 s rest between stretches (6), stretch and rest time were monitored by an electronic timer. This was repeated three times for a total of 90 s per stretch exercise. The total volume of all four stretching exercises performed was 360 s, well above the minimum as determined by Zakas et al. (44). Each stretch was performed three straight times before moving on to the next stretch. Stretching order was randomly assigned. Immediately following the stretching protocol participants went directly to testing.

Statistical Analysis

A paired-sample experiment was designed using the stretching condition as the independent variable and the mean peak torque at both speeds as the dependent variables. A paired t-test was applied independently to each dependent variable to determine if there was a difference. Analysis was conducted using SPSS, version 17 (SPSS Inc., Chicago, IL). Significance was set at an alpha level of $p < 0.05$.

Results

Measurements of peak torque at both conditions are represented in Table 1. The paired t-tests revealed that there was a significant difference between the control and the stretching condition at 300 $^{\circ}$ s^{-1} ($t = 2.42$, $p = 0.03$) (see Figure 1). Significance was not found between the control and the stretching condition at 60 $^{\circ}$ s^{-1} ($t = 1.45$, $p = 0.16$) (see Figure 2).

Table 1 Control & Stretch Peak Toque Means ± SDs and Ranges for All Variables Tested

Condition	Angular Velocity	Mean (N m)	SD	Maximum	Minimum
Control	$300^{o}s^{-1}$	101.6*	24.3	149.4	66.6
Stretch		94.3	24.2	155.4	53.6
Control	$60^{o}s^{-1}$	205	49.1	280	128.3
Stretch		198.5	47.3	279.2	120.4

*Significant difference of mean value ($p < 0.05$) between the control and stretching at $300^{o}s^{-1}$

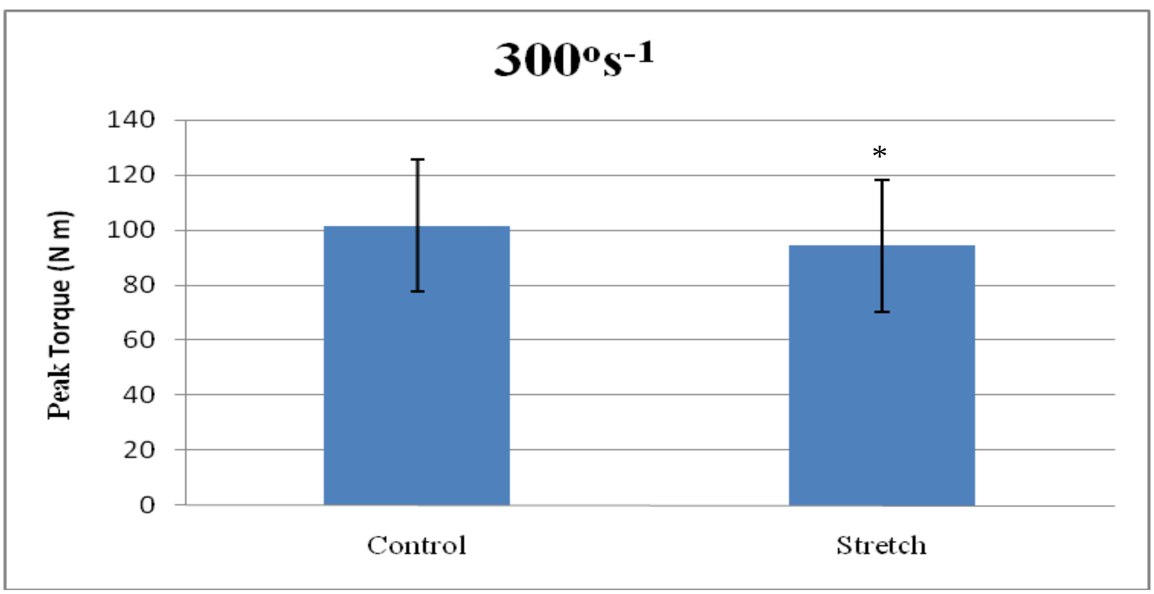

Figure 1. Isokinetic Peak torque at $300^{o}s^{-1}$ comparing stretching and the control conditions. *Significance of $p = 0.026$ t-value of 2.42.

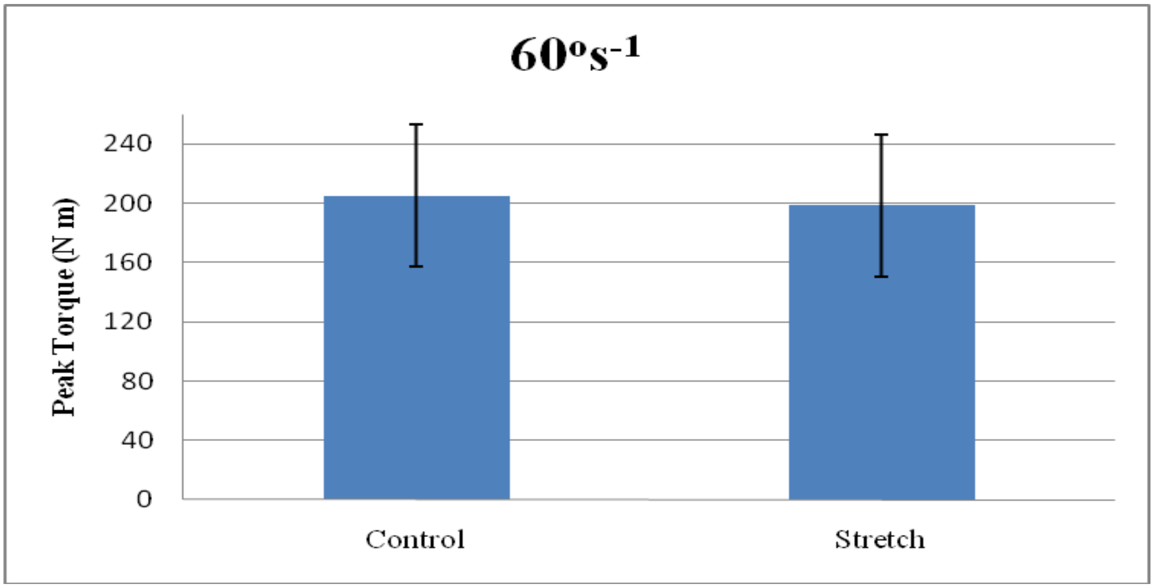

Figure 2. Isokinetic Peak torque at $60^{o}s^{-1}$ comparing stretching and the control conditions. No Significance of $p = 0.164$ t-value of 1.45.

Discussion

This study concurs with previous research findings that the torque of the knee extensors is acutely diminished at high speed, yet is not statistically different at the slower speed. Even though there was not statistical significance at $60^{o}\ s^{-1}$ in the present study, previous researchers (17, 58) who used a similar protocol found a significant diminishing effect ($p < 0.05$) at $60°s^{-1}$. This contradicts previous research that concluded that stretching is velocity specific (37). Zakas et al. (58) found the deficiency in men at speeds from $60^{o}\ s^{-1}$ to $270^{o}\ s^{-1}$ ($p < 0.001$). The peak torque measurements in the Zakas et al. study (209 ± 43.7 Nm at $60°s^{-1}$) were similar to the values found in the present study.

The new findings indicate that the negative effects of stretching on peak torque production are seen at velocities as high has $300^{o}\ s^{-1}$. The decrease of 7% on average in the 300º s^{-1} condition yielded a large enough decrease to become statistically significant. Even though only the faster velocity exhibited a significant difference in this study, Cramer et al. (17) found a decrease of 9% on average at 60º s^{-1}. The inhibitory effects seen at these two speeds (Figures 1 and 2) and their high correlation to sprint speed and jump performance may be seen in actual performance. Applying the decrease in force production at 60º s^{-1} would result in a vertical jump of 91.5 cm (36 in) decreasing to 83.2 cm (33 in), and at 300º s^{-1} a 40 m sprint time would increase from 4.5 s to 4.8 s. This may not seem like a lot, but when competitions are won and lost by one one-hundredth of a second or an inch, everything counts.

The deficits observed in research using actual sprint times (22, 23, 36) and jump performances (7, 9, 13, 57) indicate that impairments seen in the controlled environment of the laboratory can be linked to actual sports performance. This could lead to further research done in laboratories with actual performance validity. Further research needs to be done to analyze the speeds through the velocity spectrum that relate to different sports performances. This could lead to a higher external validity of laboratory tests.

This study failed to shed any light on the theories behind the deficits associated with stretching. These deficits contribute to changes in the stiffness of the muscle-tendon unit and neural inhibition. Studies have suggested that a change in the length of muscle-tendon unit could lead to a greater distance a sarcomere has to contract to produce force (21). This theory of lengthening in the muscle-tendon unit (MTU) alters the force-length curve leading to a decrease in force production. Stretching is believed to alter the MTU so that the muscle is not at optimal length for force production (51, 52). Stretching increases the length of the MTU creating slack. This inhibits the MTU to transfer force effectively. This loss in elastic energy could negatively affect the stretch shortening cycle which has been shown to produce high amounts of force (24). Neural inhibition is a commonly held belief that contributes to the desensitization of the Golgi tendon organs that initiates the stretch shortening cycle (5, 26). It may even impair the excitability of muscle units diminishing their potential to produce force as seen in decreased EMG activity (7). This study did not include addressing theoretical issues, and therefore cannot validate any of the underlining theories attempting to explain the negative effects of stretching. Future research may be aimed at determining these factors.

The limitations of this study are the extensive stretching protocol, which is highly unlikely to be part of a warm-up routine, decreasing the external validity. Even though there are high correlations between IPT and sports performance, laboratory procedures can never imitate actual sports performance and should be taken into consideration (34).

Practical Applications

This study confirms Shrier's review (46) that static stretching can negatively affect force production, but this study only found significance at 300 ° $s^{-1}$and not at the slower speeds. Therefore, it is advised that static stretching not be incorporated in a warm up routine prior to a performance that requires maximal force production and power output. Static stretching may be detrimental to the performance. Static stretching post performance can still yield all the benefits cited earlier, and should not be completely eradicated from an athletic training program. The research hypothesis was supported because static stretching significantly reduced isokinetic peak torque, yet only at 300 º s^{-1}.

CHAPTER III

EFFECT OF ORDER OF STATIC STRETCHING PAIRED WITH JOGGING ON ISOKINETIC PEAK TORQUE OF THE KNEE EXTENSORS

Introduction

Warm-ups have been routinely used prior to performances. The main objective of a warm-up is to increase the core body temperature (45). The approach to warm ups is varied; for example, some use static stretching, dynamic stretching, aerobic activity or any combination. One main staple of the warm up has been static stretching (56); it has been shown to help prevent injury (19, 52), increase range of motion (3, 31) and improve sports performance (44).

As research into sports performance has grown, the concept of static stretching has become a focal point (12, 46). Research has demonstrated that static stretching may decrease vertical jump performance (7, 11, 12, 58), EMG activity (18, 41, 55), running speed (22, 23, 36, 53), isokinetic torque (18, 32, 37, 41), isometric strength (7, 28, 42) and maximal voluntary contraction (38, 39). Research examining the effects of stretching commonly includes a warm up activity prior to testing and stretching. Typical warm up activities include riding a cycle ergometer (12, 29) or jogging (58). This practice is consistent with a warm-up as a goal to increase core body temperature. Studies have focused on using active warm-ups combined with passive stretching to evaluate the effects of stretching (10, 49, 50). These studies indicate that activity combined with stretching off sets the negative effects that stretching may cause. These studies used varied warm up protocols and used vertical jumps and sprints as the outcome performance measures. They only did the warm up pre-stretch or post-stretch but did not take into consideration either the order or the warm up routine.

The negative effects of stretching are attributed to two theories; neural inhibition (26, 33) and/or changes in the visco-elastic properties of the muscle-tendon unit (43). Research has demonstrated that static stretching results in a decrease in EMG activity (7), implying that it likely has something to do with motor units. Neural inhibition is a commonly held belief that stretching contributes to the desensitization of the Golgi tendon organs, which initiate the stretch shorting cycle (5, 26). The theory of lengthening in the muscle-tendon unit which leads to a decrease in force production is a result of the force-length curve not at an optimal length (51). Stretching has been shown to increase the length of the MTU creating slack, thereby inhibiting the MTU to transfer force effectively (53). This loss in elastic energy could negatively affect the stretch shorting cycle which has been shown to produce high amounts of force (24).

Stretching is most often paired with some type of activity in a warm-up routine. Taking this into consideration, jogging was paired with stretching to determine the effects on isokinetic peak torque (IPT). Warming up the body through jogging may diminish the negative effects of stretching. If jogging is done before stretching then the MTU may be less susceptible to change, and/or the nerve system may be excited, making it hard for desensitization to occur. If jogging is done post stretching then the MTU may return to is normal length and/or the nerves may be “awakened” by the jogging, reducing the negative effects of stretching.

This study aims to determine if an aerobic activity can diminish the negative effects of static stretching observed in previous research using isokinetic peak torque as a measurement for muscle strength. Isokinetic peak torque is commonly used to assess isolated strength, and is highly correlated to jump height (4, 25) and sprint speed (8, 40) at 60 ° s^{-1} and 300 ° s^{-1}, respectively. Previous studies have shown a decrease in IPT at both of these speeds. Thus, the purpose of this study was to determine what effect the order of warm-up has on the IPT of the knee extensors at 60° s^{-1} and 300° s^{-1}.

Methods

Experimental Approach to the Problem

A repeated measures analysis design was applied to this study with multiple tests done on the same participants through multiple conditions. Three conditions were evaluated: a stretch then jog, jog then stretch, and a control in which the participant only tested. The three conditions were performed at random. The main focus of the test was to determine if order of warm-up had an effect on IPT.

Participants

Twenty male college students volunteered to participate in this study. Recruitment of participants was done via word of mouth. Prior to the study they filled out an athletic questionnaire (Appendix A) in which they reported being free of knee pain and having no previous knee injuries. Participants' demographics were: age of 22.1 ± 2.4 yrs, height of 181.6 ± 1.8 cm, and mass of 82.3 ± 29.5 kg. All individuals agreed to maintain their current workout schedule, yet refrain from leg exercises the day prior to and the day of the test. Participants were all similar in fitness levels being active to very active as defined by performing physical activity four or more times per week. Participants were brought in prior to testing to familiarize themselves with the testing procedure to reduce the learning effect. All participants read and signed an informed consent approved by the institutional review board (Appendix B).

Procedures

Testing was performed twice a week for 2 weeks with a minimum of 48 h of rest between sessions. Participants performed one of the three protocols: jog for five minutes then stretch, stretch then jog, or simply testing without any warm up. Isokinetic testing was performed at two speeds, 60^{o} s^{-1} and 300^{o} s^{-1}. In this test the participant performed five repetitions of the leg extension exercise at both speeds while IPT was measured. A maximal contraction of the knee extensors was requested for each repetition. All five repetitions were done consecutively with a 3 min rest between each speed condition to allow for recovery (30). Five repetitions is the optimal number for determining peak torque (9). Peak torque was the highest measurement recorded during the five repetitions. Isokinetic peak torque was recorded for each speed and condition, and the data were used for analyses.

Instrumentation

A Biodex System 3 isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY) was used to measure IPT. Participants were restrained with Velcro straps as recommended by the manufacturer. The axis of the dynamometer arm was aligned with the axis of the knee. Calibration and participant set up followed the instructions in the manufacturer's guide. An unpublished test of reliability of peak torque was done using the same equipment with an interclass correlation coefficient of *ICC* = 0.95.

Stretch/Jog Protocol

The stretching protocol consisted of four stretches, one unassisted and three assisted using a protocol from previous research (17, 32). Stretching procedures performed targeted the knee extensors. The unassisted stretch was a standing quadriceps stretch (Figure C.1). The participant stood arm's length away from the wall. The dominant knee was bent to 90º. With the opposite hand, the participant grabbed the foot and pulled it toward the buttock. The first assisted stretch the participant stood with his back to a table and the dorsal surface of his foot on a table (Figure C.2). For the second assisted stretch the participant laid prone on a padded table. The dominant knee was bent toward the buttock (Figure C.3). If the participant's foot reached the buttock and no stretch was felt, a 30º wedge was placed under the hip, causing a slight hyperextension of the hip. Pressure was applied to both the shoulder and the flexed knee. The final assisted stretch had the participant lay supine with his dominant leg hanging off the table (Figure C.4). The leg was then flexed and the hip slightly hyperextended by applying pressure to both the anterior part of the lower leg and the thigh. All stretches were performed until minor discomfort (12). All stretches were held for 30 s with a 15 s rest between stretches, stretch and rest times were monitored by an electronic timer. This was repeated three times for a total of 90 s per stretch exercise. The total volume of all four stretching exercises performed was 360 s, well above the minimum as determined by Zakas et al.

(59). Each stretch was performed three straight times before moving on to the next stretch; sets of stretches were randomized.

Jogging was chosen for the aerobic (warm-up) activity for ease of testing and participants' familiarity with this type of activity. Jogging speeds were determined based on individual performance. Speeds varied due to individual difference with the average speed being 5.5 mph. Running speed was determined by the participants running in their aerobic zone as described in the *ACSM Guidelines for Exercise Testing and Prescription* (1). Jogging speed increased every two minutes until the heart rate, measured by a Polar monitor (Polar Electro Oy, Kempele, Finland), was steady in the aerobic zone (60-70% of age-predicted heart rate max). This procedure to determine appropriate jogging speed was done prior to the study trials at the familiarization day. The two protocols which required jogging used this predetermined speed in their 5 minute jog. All jogging was done on a Nordic-track 3200 treadmill (Icon Health and Fitness, Logan, UT). All participants went immediately from one protocol to the next with little or no rest.

Statistical Analysis

A 2 x 3 ANOVA was applied with testing speed ($60^{o}\ s^{-1}$, $300^{o}\ s^{-1}$) and the conditions (control x stretch then jog x jog then stretch) as the independent variables. Peak isokinetic torque was the dependent variable. In the event of significance, comparisons were made using Tukey's post hoc test. Analysis was conducted using SPSS version 17.0 (SPSS Inc., Chicago, IL). Significance was set at an alpha level of $p < 0.05$.

Results

Measurements of peak torque at both conditions are represented in Table 2. The 2 x 3 ANOVA yielded no statistically significant difference for the conditions (F = 0.14, p = 0.87), or the interaction of speed (60º s^{-1}, 300º s^{-1}) and condition (control x stretch then jog x jog then stretch) (F = 0.08, p = 0.93). The differences between testing conditions are visually represented in Figures 3 and 4.

Table 2 Control, Jog Then Stretch & Stretch Then Jog Peak Torque Means ± SDs and Ranges for All Variables Tested

Condition	Angular Velocity	Mean	SD	Maximum	Minimum
Control	$300^{o}s^{-1}$	101.6	24.4	149.7	66.6
Stretch then Jog	$300^{o}s^{-1}$	94.7	22.6	152.8	64.1
Jog then Stretch	$300^{o}s^{-1}$	95.8	22.5	173.9	62.9
Control	$60^{o}s^{-1}$	205	49.1	280.5	128.3
Stretch then Jog	$60^{o}s^{-1}$	204.9	47	299.9	128.3
Jog then Stretch	$60^{o}s^{-1}$	202.6	50.3	294.5	128.1

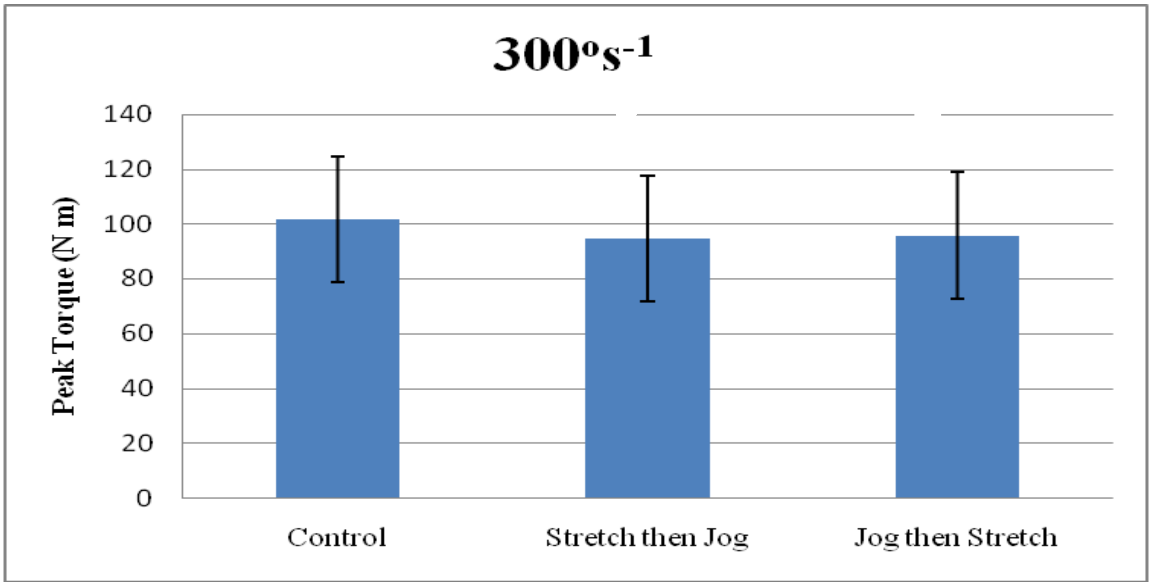

Figure 3. Isokinetic Peak torque at 300°s^{-1} comparing the Control, Stretch then Jog, and Jog then Stretch conditions.

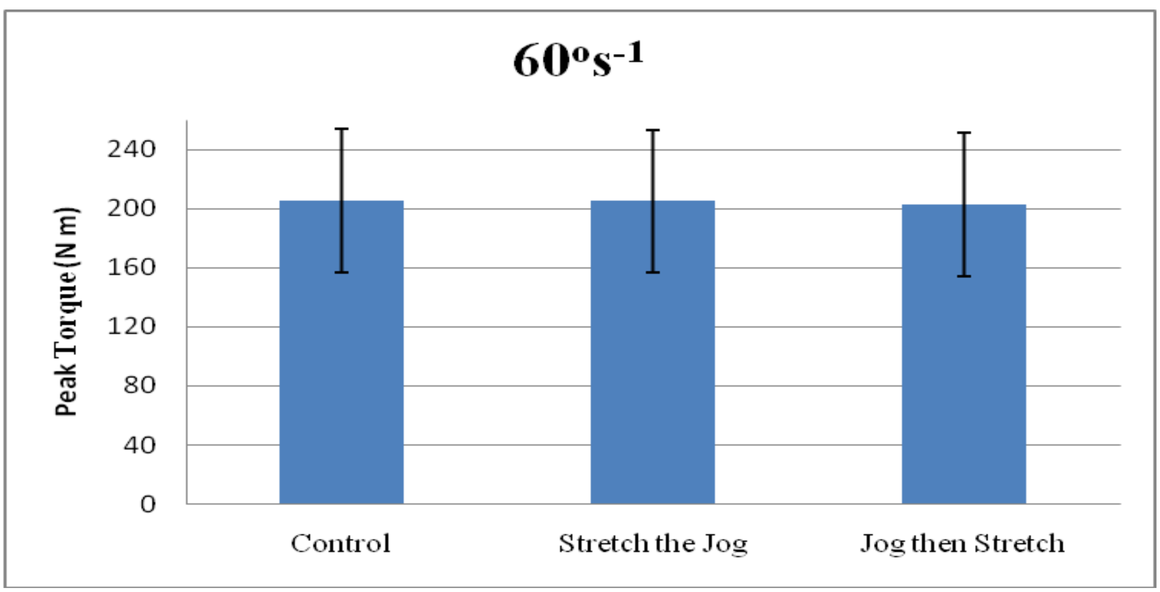

Figure 4. Isokinetic Peak torque at 60°s^{-1} comparing the Control, Stretch then Jog, and Jog then Stretch conditions.

Discussion

The main focus of this study was to determine if jogging before or after stretching reduces the negative effects of stretching. This study found that at 60º s^{-1} there was no significant difference between the control and the two warm-up conditions, validating the hypotheses. This study also concluded that there was no significant difference at the 300º s^{-1} condition. Previous research indicated that at 60º s^{-1} and 300º s^{-1} there were significant reductions in IPT (17, 59) after stretching. These studies used a cycle warm up prior to testing, but included the cycling in the control group. This indicates that jogging may reduce the effects of stretching at both speeds. In jogging the knee extensors absorb, transmit, and produce force. This activity of the knee may diminish the negative effects of stretching when the knee extensors are used to produce these forces.

Jogging post stretching was aimed to bring insight into the underlying factors that lead to force loss. Force loss has been attributed to changes in the MTU and neural inhibition (26). Jogging after stretching was addressing the issue that an aerobic activity may tighten up this “slack” (43). Jogging prior to stretching may make the MTU less susceptible to change because of the aerobic activity and the “warm-up of the muscle.” The other possible explanation of the neural inhibition principle regarding electromyography reduction was also evaluated with the idea that jogging post stretching would “wake up” the muscle units so that they can fire properly and reactivate the Golgi tendon organ to be a joint proprioceptor (33). Aerobic activity prior to stretching may stimulate the nervous system enough that stretching does not inhibit neural transmission. This study was not aimed to specifically target which of these two possible explanations were the underlining factors in force loss, just to determine if an aerobic activity can reduce the negative effects of stretching. Since there was not a significant decrease in force from the control to the two test groups at either speed, this indicated that an aerobic activity when paired with stretching either pre or post stretch may decreases the negative effects seen with static stretching.

The basis of this study was the numerous current research that indicates that there is a negative effect of stretching on IPT, yet this study sought to discover if there was a way to reduce these negative effects and concluded that an aerobic activity when paired with stretching can reduce the negative effects seen with static stretching prior to performance. The limitations of this study are that even though there are correlations between IPT and sports performance, anything done in the lab lacks external validity (34); yet stretching has decreased sprint times (53). There is not a perfect laboratory test to simulate a competitive environment. Another limitation is that the stretching protocol would not normally be incorporated into a warm-up routine, based on the volume of stretches. Future research is needed to determine if the level of intensity of activity prior to or post stretching can alter the negative effects seen. Also, research can continue to try to understand the underlying principles that lead to this loss in performance.

Practical Applications

This study discovered that the negative effects of stretching, as demonstrated in previous research, can be reduced by jogging. Although static stretching reduces force production, when stretching is used as part of a complete “warm-up” routine that contains other activities like jogging, the negative effects may be reduced. Caution is still advised when using prolonged static stretches prior to performance since the underlying factors are still not known, but should not be avoided completely; the positive effects of stretching can be utilized as part of a complete training program.

CHAPTER IV

INCLUSIVE SUMMARY

This study further validates previous research (46) that stretching negatively affects IPT. Although this study did not find statistical significance at 60º s^{-1}, statistical significance was found at 300º s^{-1}, further validating that the negative effects are seen at high speeds (17). The secondary objective of this study was to determine if stretching combined with some type of aerobic exercise (in this case jogging) would affect IPT. Jogging may reduce the negative effects of static stretching seen in previous research. The conditions of 60º s^{-1} and 300º s^{-1} yielded no significant difference and in this case that is a good thing, meaning that jogging may offset the negative effects of stretching as seen in both conditions.

The order of stretching and jogging was aimed to bring insight into the underlying factors that lead to force loss. Force loss has been attributed to changes in the MTU and neural inhibition (26). The idea that stretching affects the MTU relies on the idea that stretching elongates the MTU (51), decreasing its ability to transfer force due to "slack" (52). Jogging after stretching was addressing the issue that an aerobic activity may tighten up this "slack" (43). Jogging pre stretch was aimed at the idea that jogging would make the MTU less susceptible to stretching, thus maintaining the right angle - torque relationship (15).

The principle of neural inhibition (5) regarding electromyography reduction was also not evaluated, yet it is believe that jogging post stretching "wakes up" the muscle units so that they can fire properly and reactivate the Golgi tendon organ to be a joint proprioceptor (33). Since there was no EMG analysis this theory cannot be tested; thus, future research is needed to see if EMG analysis changes with aerobic activity. This study showed that an aerobic activity prior to and post stretching reduces the negative effects of stretching, but did not determined the underlying factors on why the negative effects were diminished.

The hypothesis that stretching would negatively affect isokinetic peak torque was validated, further adding to the research that stretching negatively affects peak torque (18, 32, 37, 41). This study also validates the second hypothesis that stretching when paired with an aerobic activity would diminish the negative effects of stretching. It did show that an aerobic activity can be beneficial to reducing the negative effects, yet further research needs to be done in this area to determine the specific reasons why. Overall the study confirmed prior ideas that stretching leads to a decrease in performance, and showed that the negative effects may be diminished through aerobic activity.

Even though there is a high correlation of isokinetic measurements to actual sports performance (4, 25), tests done in the laboratory are not actual performance measures. Therefore caution is recommended when reviewing research that is not sports specific. Also, further research has indicted that a trained population like college athletes may be less susceptible to the negative effects of stretching (20). This research has validated that stretching decreases IPT when done prior to performance. Stretching still needs to be part of a training program as it has many positive effects (54). Further research is needed to determine the underlying factors that contribute to the force loss as well as the level of intensity of activity that is required to offset the negative effects of stretching.

CHAPTER V

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APPENDICES

Appendix A

Initial Athletic Participation Questionnaire

Participant Name______________________ ID #_______________________

Height _____________cm Mass _____________ kg Dominate Leg______

Have you ever had a diagnosed knee Injury (torn ACL, cartilage, and or surgery?)
- ☐ No
- ☐ Yes, Please Explain____

How often have you participated in physical activity in the past week?
- ☐ 0
- ☐ 1-2
- ☐ 3-4
- ☐ 5+

If you could rate you activity level what would it be?
- ☐ Don't work out
- ☐ Moderate
- ☐ Strenuous
- ☐ Very Strenuous

How would you describe your exercise program?
- ☐ Cardio training only
- ☐ Cardio training and weight training
- ☐ Weight training only
- ☐ I do not exercise

On average how long do you spend exercising each time?
- ☐ 0-15-min
- ☐ 15-30 min
- ☐ 30-45 min
- ☐ 45+

How often do you participate in leg training exercises (running, squatting, leg press)?
- ☐ 0-1 time per week
- ☐ 2-3 times per week
- ☐ 3 or more times per week

Do you have knee pain when you perform leg training exercises?
- ☐ No
- ☐ Yes, Please explain____

Would you be willing to restrain from leg training exercises the day before and the day of testing?
- ☐ Yes
- ☐ No

Appendix B

Informed Consent

Health, Phys. Ed. & Recreation
7000 Old Main Hill
Logan UT 84322-7000
Tel: (435) 797-1497

Date Created: June 22, 2007;
Page **37** of **49**
USU IRB Approved 06/22/2007
Approval terminates 06/21/2008
Protocol Number 1824

INFORMED CONSENT

The Effects of Static Stretching and Order of Warm-up on the Isokinetic Peak Torque of the Knee Extensors

Introduction/ Purpose Professor Eadric Bressel in the Department of Heath, Education and Physical Recreation at Utah State University (USU) and Eric Sobolewski, a student researcher, are conducting a research study to find out more about the effects of stretching on human performance. You have been asked to take part because you are male and between the age of 18 and 27 years. There will be approximately 20 participants asked to participate in this research.

Procedures If you agree to be in this research study, the following will happen to you. Your isokinetic torque will be tested four times by a simple leg extension exercise on a Biodex 3 dynamometer. Each test will be conducted on different days for a total so you will be asked to return for testing four different times. These four days will span a three week period with a minimum of 24 hours between tests. The first day you will be asked to walk at a moderate pace of two mph for four minutes, and then you will be tested at two speeds five repetitions at each speed 10 total using a leg extension exercise. A simple jogging test will then be performed using a heart rate monitor worn around the diaphragm will determine your aerobic training zone, speed will be increase every two minutes until the heart rate reached 60% of max. The next three days you will perform one of three stretch/jog protocols. The first protocol requires you to perform four stretches that will be held three times for 45 s with a 15 s rest in between. The stretches will be performed until mild discomfort not pain is felt, and then the leg extension tests will be conducted. The second and third require the same stretches but includes jogging at the predetermined speed in the training zone on a treadmill, then the same leg extension tests. Each testing session should last 15-30 minutes to complete.

New Findings During the course of this research study, you will be informed of any significant new findings (either good or bad), such as changes in the risks or benefits resulting from participation in the research, or new alternatives to participation that might cause you to change your mind about continuing in the study. If new information is obtained that is relevant or useful to you, or if the procedures and/or methods change at any time throughout this study, your consent to continue participating in this study will be obtained again.

Risks Participation in this research study may involve some added risks or discomforts. These include: Over-stretching a muscle may lead to some temporary muscle soreness. You will be encouraged to stretch to a point of slight discomfort but not pain. This method should reduce the risk of over-stretching a muscle. Some soreness may also occur during the testing procedure, this may be due to contraction of the muscle to perform the task which may be strenuous to some but not all. However, it should be noted that as with any study there may be some unforeseen risks that could occur that are not described above.

Benefits There may or may not be any direct benefit to you from these procedures. The researcher's however, may learn more about how stretching influences isokinetic peak torque. Also, the information gained from this study may be helpful to coaches and athletes who prescribe/participate in stretching programs prior to athletic performance.

Voluntary nature of participation and right to withdraw without consequence
Participation in research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits. You may be withdrawn from this study without your consent by the investigator.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only the investigator will have access to the data which will be kept in a locked file cabinet in a locked room. Your name will be replaced with a code throughout this study. The code and data collection will be kept separate in a locked file cabinet and room of Dr. Bressel. Only the researchers will have access to this information. Personal, identifiable information will be kept until the data analyses are completed. Then, all personal identifiable information will be destroyed.

IRB Approval Statement The Institutional Review Board for the protection of human participants at USU approved this research study. If you have any questions or concerns about your rights, you may contact them at (435) 797-1821.

Copy of consent You have been given two copies of this Informed Consent. Please sign both copies and retain one copy for your files.

Investigator Statement "I certify that the research study has been explained to the individual, by me or my research staff, and that the individual understands the nature and purpose, the possible risks and benefits associated with taking part in this research study. Any questions that have been raised have been answered."

______________________________ _______________________________

EadricBressel, Ph.D. Eric Sobolewski
Principle Investigator Student Researcher
(435) 797-7216

Signature of Participant By signing below, I agree to participate.

_________________________ _________________________

Participants signature Date

Appendix C

Pictures of Stretching Protocol

Figure C.1

Figure C.2

Figure C.3

Figure C.4