STRETCHING: TYPE AND TIMING FOR OPTIMAL BENEFITS

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ABSTRACT

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It is known that stretching is able to increase the compliance of human tendons and as a result increase the capacity of the tendon to absorb energy. Sports involving "explosive" type skills, with many maximal stretch-shortening cycle (SSCs) movements, require a muscle tendon unit that is compliant enough to store and release a high amount of elastic energy. When an individual's muscle-tendon unit (MTU) is less flexible, there exists a predisposing factor for exercise related injuries since the tendon is unable to absorb enough energy, which may lead to tendon and/or muscle damage. Therefore, increasing the compliance of the muscle tendon unit and increasing the temperature within the muscle unit is vital in avoiding injury and complementing athletic performance. However, there remains a great deal of confusion among coaches and professionals as to which type of stretching will elicit the greatest benefits to the exerciser.

Conflict remains as to which type of stretching is the best way to prepare the body for movement. However, by understanding the type of sport the individual is participating in and the physical demands required of the body (i.e. power output, flexibility, rehabilitation), coaches and professionals may be able to prescribe a more suitable warm-up and cool-down that will compliment activity opposed to hindering it.

Dynamic stretching appears to offer greater benefits to the athlete or individual exercising before competition. With movements and actions that mimic the sport or event, increasing muscle temperature may be the most desirable outcome before competition.

Sports or activities that rely heavily on explosive power, speed and strength may choose dynamic activity over static to avoid detrimental tendon elasticity and muscle compliance. It seems that static stretching produces impairments in muscle force production. This impairment may be associated with the stress relaxation explained further below. Including static stretching post-activity may offer greater benefits to the athlete long term in regards to greater flexibility gains acquired over time.

Proprioceptive neuromuscular facilitation (PNF) stretching offers athletes/individuals with the greatest gains in range of motion, a benefit that reduces the chance of muscle related injury. However, this type of stretching requires greater amount of time to complete. Including PNF stretching in a rehabilitation program may offer athletes the ability to see the greatest gains in range of motion (ROM), allowing them to return to competition sooner.

It is important to incorporate these types of stretching in various stages of preparation. Each type offers unique and some shared benefits to the user. However, it is important to understand the timing in which they will have the most success in benefiting the individual as opposed to hindering their performance.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

Stretching muscles and elevating their temperature has been an instrumental part of a proper warm-up and cool down since the earliest application of exercise. The proper format for the use of different stretching methods has been questioned even among professionals. There are four common stretching techniques: static stretching, ballistic stretching, dynamic stretching and proprioceptive neuromuscular facilitation stretching. This paper outlines the types of stretches, as well as reviews current research on which type of stretching is best to increase flexibility before, and following activity. By understanding the different types of stretching methods and what sports movements are being used, individuals may have a more beneficial stretching protocol before and following activity.

Statement of Purpose

There is still confusion among coaches, athletes, individuals, and sports professionals regarding what the best stretching method is to prepare the body for exercise. This paper reviews four different stretching methods and clarifies which type of stretching method is best suited to the athlete in their stage of activity: pre-exercise or post-exercise. The purpose of this review was to clarify confusion among stretching techniques currently being used among coaches and professionals today.

Specific Objectives

- To determine if static stretching is the most common form of post exercise recovery.
- To determine if stretching before a workout should include exercises that mimic the movement's athletes will experience during the activity.

- To compare and contrast four types of stretching techniques.

Methods and Procedures

A thorough review of the literature regarding the different types of stretching has been completed, and evaluated to identify which is the most commonly accepted form of stretching. Internet search engines such as Google Scholar, Ebsco host, Science Direct, and online journals such as PubMed Central were utilized to identify research-based studies focused on the effects of stretching. North Dakota State University online libraries were used, primarily the Ebsco host search engine. The *Journal of Strength and Conditioning* provided a solid base to this research. Key words such as stretching protocol, static stretching, ballistic stretching, PNF stretching, dynamic stretching, and muscle flexibility were used in the initial search of applicable journal articles. Additional key words or phrases found in the initial search were utilized to further develop the topic discussion. After adequate depth and breadth of data covering the effect of stretching was collected, a review of the literature was completed. The review of literature took approximately a year to complete following committee approval.

Definitions

PNF stretching: Proprioceptive neuromuscular facilitation (PNF) stretching was originally developed as part of a neuromuscular rehabilitation program designed to relax muscles with increased tone or activity. The most common PNF leg or arm positions encourage flexibility and coordination throughout the limb's entire range of motion. PNF techniques are usually performed with a partner and involve both passive movement and active (concentric and isometric) muscle actions. During the PNF stretches, three specific muscle actions are used to facilitate the passive stretch. Both isometric and concentric muscle actions of the antagonist (the muscle being stretched) are used before a passive stretch of the antagonist to achieve autogenic inhibition (relaxation that occurs in the same muscle experiencing increased tension). The isometric muscle action is referred to as *hold* and the concentric muscle action as *contract*. A concentric muscle action of the agonist, called *agonist contraction*, is used during a passive stretch of the antagonist to achieve reciprocal inhibition. Each technique also involves passive, static stretches that are referred to as *relax*. There are three basic types of PNF stretching techniques:

- Hold-relax
- Contract-relax
- Hold-relax with agonist contraction

The PNF techniques are completed in three phases. The first phase incorporates a passive pre-stretch of 10-s duration with each of the three techniques (Baechle & Earle, 2000).

Hold-Relax: The hold-relax technique begins with a passive pre-stretch that is held at a point of mild discomfort for 10 seconds (s). The partner applies a force and the athlete is instructed to "hold and don't let me move the limb" while the athlete "holds" and resists movement so that an isometric muscle action occurs and is held for 6 s. The athlete then relaxes, and a passive stretch is performed and held for 30 s. The final stretch should be of greater magnitude due to autogenic inhibition (Baechle & Earle, 2000).

Contract-Relax: The contract-relax technique also begins with a passive pre-stretch of the muscle that is held at the point of mild discomfort for 10 s. The athlete then extends the muscle against resistance from the partner so that a concentric muscle action through the full ROM occurs. The athlete then relaxes, and a passive muscle stretch is applied and held for 30 s. The increased ROM is facilitated due to autogenic inhibition (i.e. activation of hamstrings). It must be noted that an alternative description has been provided in which the athlete attempts to extend the hip but the partner does not allow the movement. Because this is essentially the same as the hold-relax technique, the contract-relax method described here is preferred (Baechle & Earle, 2000).

Hold-Relax with Agonist Contraction: The hold-relax with agonist contraction technique is identical to hold-relax in the first two phases. During the third phase, a concentric action of the agonist is used in addition to the passive stretch to add the stretch force. That is, following the isometric hold, the athlete flexes the hip, thereby moving further into the new ROM. With this technique the final stretch should be greater due to primarily reciprocal inhibition (i.e., activation of the hip flexors) and secondarily, autogenic inhibition (i.e., activation of the hamstrings) (Baechle & Earle, 2000; Rubini, Costa, & Gomes, 2007; Sharman, Cresswell, & Riek, 2006).

Static stretching: A static stretch is slow and constant with the end position held for 30 s. A static stretch includes the relaxation and concurrent elongation of the stretched muscle. Because it is performed slowly, static stretching does not elicit the stretch reflex of the stretched muscle; therefore, the likelihood of injury is less than the risk during ballistic stretching (Baechle & Earle, 2000).

Dynamic stretching: Consists of fast specific movement patterns that usually mimic sports activity. A dynamic stretch involves flexibility during sport-specific movements. Dynamic stretching is similar to ballistic stretching in that it utilizes speed of movement, but dynamic stretching avoids bouncing and includes movement's specific to a sport or movement pattern. In a sense, dynamic stretching is similar to a specific warm-up; the movements used to help prepare the athlete for competition by allowing him or her to increase sport-specific flexibility. It is most common among track-and-field athletes, but is also used in other sports, such as volleyball, soccer, golf, and baseball. (Baechle & Earle, 2000; Torres et al., 2008).

Ballistic stretching: A form of passive stretching or dynamic stretching in a bouncing motion. Ballistic stretches force the limb into an extended range of motion when the muscle has not relaxed enough to enter it. It involves fast, "jerky" movements where a double bounce is performed at the end range of motion (Samuel, Holcomb, Guadagnoli, Rubley, & Wallmann, 2008). Ballistic stretching is often used in the pre-exercise warm-up; however, ballistic stretching may injure muscles or connective tissues, especially when there has been a previous injury. Ballistic stretching usually triggers the aforementioned stretch reflex, not allowing the muscles to relax, which defeats the purpose of stretching.

Flexibility: Measured as the absolute range of motion in a joint or series of joints and muscles that is attainable in a momentary effort with the help of a partner or a piece of equipment (Nelson & Bandy, 2004).

Range of motion: Measurement of the achievable distance between the flexed position and the extended position of a particular joint or muscle group (Torres et al., 2008).

Muscle: Contractile tissue of the body. Muscle cells contain contractile filaments that move past each other and change the size of the cell. They are classified as skeletal, cardiac, or smooth muscles. Their function is to produce force and cause motion. There are two broad types of voluntary muscle fibers: slow twitch and fast twitch. Slow twitch fibers contract for long periods of time but with little force while fast twitch fibers contract quickly and powerfully but fatigue very rapidly (Proske & Morgan, 2001).

Physical exercise: Any bodily activity that enhances or maintains physical fitness and overall health. It is performed to strengthen muscles and the cardiovascular system, honing athletic skills, and weight loss or maintenance (O'Connor, Crowe, & Spinks, 2006).

Limitations

Within the research there are contradictions and varied beliefs as to which methods of stretching should be used as the standard. Studies regarding ballistic stretching are not as prevalent as those regarding static stretching. PNF stretching also has not had the amount of attention static stretching has. Small numbers of subjects within various studies may limit the validity of results.

Significance of Paper

There is still confusion among coaches, trainers, students and professionals as to which stretch or combination of stretches best prepares the body for exercise and decreases the risk for injury. This paper outlines the types of stretching as well as offers a review of the current research completed, to try and eliminate confusion from contradicting research results. This paper also identifies stretching methods that may increase the likelihood of injury, therefore contradicting its purpose in an athlete's preparation. Stretching practices date back to each individuals' experience doing them. For example, a coach may have his athletes stretch a certain way, because that is the way he was taught and did it as an athlete. Hopefully, by reviewing the current literature, this paper will reduce the common uncertainty of stretching techniques, and offer a more effective way to implement a proper warm-up protocol. Individuals are bound to do what they are comfortable teaching and have done themselves, however, this may not be the best way to prepare athletes for competition.

Document Organization

Chapter two provides an overview of the types of stretching, and the material used to draw a conclusion of which type of stretching technique should be used before competition/activity, and which type of stretching technique should be used after activity in order to increase flexibility and reduce the risk of injury. This consists of an extensive literature review of the references found, and research completed to outline the common misconception of stretching, and the proper way to choose a stretching program for individual athletes. Chapter three is comprised of a discussion on the research found, a conclusion based on the material and a portion of reflection based on the paper. This is followed by a list of references used in the paper.

CHAPTER 2. REVIEW OF LITERATURE

The purpose of this review was to clarify confusion among stretching techniques currently being used among coaches and professionals today. Stretching prior to activity has been a key step for some athletes before they perform their specific exercise. When preparing for activity a variety of stretches and movements can be used in order to achieve the following goals: increased flexibility, increased muscle temperature, and injury risk reduction, among others. What some athletes don't know is that these movements may actually hinder their ability to perform their best. Flexibility has been defined as the ability of a muscle to lengthen and allow one joint (or more than one joint in a series) to move through a range of motion (Baechle & Earle, 2000). Some of the proposed benefits of enhanced flexibility are reduced risk of injury, pain relief, and improved athletic performance (Kokkonen, Nelson, Eldredge, & Winchester, 2007; Nelson & Bandy, 2004). While stretching provides athletes with the ability to increase their flexibility, some researchers are still uncertain about the effect stretching has on other aspects of performance.

Athletes tend to rely on previous knowledge of stretches, or things they have done in the past to guide a warm-up. For example, a "retired" athlete may start off a jog or weight lifting session by performing a series of static stretches in order to start his/her workout. Most of the time, this is done simply because it is what they have been instructed to do in the past. A non-competitive exerciser may read about the benefits of stretching before they take their dog out for a walk. These individuals tend to not require the same ability to produce speed, force and power as trained athletes; therefore not experiencing some of the negative effects stretching has uncovered in the research.

Recently, research has questioned the positive effects of stretching on delayed onset muscle soreness (DOMS), increased flexibility, and the muscle's ability to produce force. It is suggested that pre-exercise stretching may temporarily compromise a muscle's ability to produce force. It is possible that the short-term effect of stretching on muscle force production may affect the performance of various rehabilitation-strengthening exercises (Marek et al., 2005). Understanding the different types of stretches and what type of activity an individual is preparing for may shape the effectiveness and necessity of the stretch.

Four types of stretching methods are commonly used by athletes and sports professionals to increase flexibility, reduce soreness, and increase muscle force production. These methods include static stretching, ballistic stretching, dynamic stretching and proprioceptive neuromuscular facilitation (PNF) stretching. There are other stretches that have been used for performance, but these remain the most commonly recognized types to increase performance. Static stretching, considered the gold standard for measuring flexibility, is elongating a muscle to tolerance and sustaining the position for a length of time. Ballistic stretching is a technique involving a rhythmic, bouncing motion. The bouncing uses the momentum of the extremity to lengthen the muscle. PNF involves the use of brief isometric contractions of the muscle to be stretched before statically stretching the muscle (Nelson & Bandy, 2004). Dynamic stretching is a form of stretching that uses sports-specific movements to warm-up the muscles and prepare the body for movement. There appears to be limited research on the effects of stretching on athletic performance directly. However, there are studies done on the different effects that arise from exercise, including, but not limited to, DOMS, reducing the risk of injury, and other factors that aide performance such as force, speed, and power.

Certain types of exercise have been determined to affect muscle soreness and increase injury potential more than others. These include but are not limited to, quick lateral movement, explosive speed and power output, and a variety of training methods. Resistance training and stretching have been commonly used for increasing aspects of performance. Although the resistance and stretching training regimens would affect the biomechanical properties of muscle and tendon, previous studies have shown changes in the dimensions and properties of the muscle component only (Kubo, Kanehisa, & Fukunaga, 2002; Woods, Bishop, & Jones, 2007). These researchers questioned if the viscoelastic properties of tendon structures were altered with resistance training alone or with resistance training coupled with stretching. While training, does stretching hinder performance or even increase risk for injury? Before looking further into the research, it is important to understand the types of stretching more in-depth and their physiological benefits.

Stretching

Stretching is defined in various studies in slightly different ways, with the protocol and timing varying as well. However, there tends to be a common understanding as to what stretching aims to accomplish both before and after exercise. Usually the purpose is to reduce muscle soreness (delayed onset) after exercising, to reduce the risk of injury, or to improve athletic performance (Herbert & Gabriel, 2002). Recent studies have shown that stretching programs can significantly influence the viscosity of the tendon and make it significantly more compliant, and when a sport demands stretch shortening cycles of high intensity, stretching may be important for injury prevention (Kubo et al., 2002). The goals of the pre-exercise warm-up should be to promote an increase in core body temperature and blood flow, to increase muscle tendon suppleness, and to enhance free coordinated movements, which in turn, help prepare the body for exercise (Herman & Smith, 2008).

Dynamic Stretching

Dynamic stretching is defined by Fletcher and Jones (2004) as "controlled movement through the active range of motion for each joint" (p.885). Dynamic stretching is not ballistic stretching, and it does not increase the risk of injury like ballistic stretching. The joint or limb is stretched with a movement that resembles part of a sports skill (Beedle, Rytter, Healy, & Ward, 2008). Dynamic stretching raises core body and deep muscle temperatures, stimulates the nervous system, decreases the inhibition of antagonist muscles, increases post activation potentiation, and possibly reduces the risk of injury (Jaggers, Swank, Frost, & Lee, 2008). Within many athletic settings, it is feasible to replace the typical static stretching warm-up with a more active, dynamic, and sports-specific stretching warm-up aimed at optimizing performance. It is plausible that doing so may eliminate the harmful effects on strength, speed, power and agility associated with static stretching.

A dynamic warm-up involves moving joints through a gradually increasing range of motion while increasing the speed of the movement. The goal of dynamic warm-ups is to "lead" or "lift" the limbs in a controlled movement through a full range of motion. Dynamic stretching is similar to ballistic stretching in that is uses movement, but dynamic stretching includes movements that may be specific to a sport or movement pattern. Using a dynamic warm-up may increase performance mainly as a result of the increase in muscle temperature (Christensen & Nordstrom, 2008).

Static Stretching

Static stretching is often referred to as slow or passive stretching. In this method, a slow, deliberate movement is used to achieve a lengthening of the muscle. Each stretch should be maintained for approximately 20 seconds to facilitate connective tissue elongation (Woods et al., 2007). The static stretch is a method in which the muscle is slowly elongated to tolerance (comfortable stretch, short of pain) and the position held with the muscle in this greatest tolerated length. Static stretching offers advantages over the ballistic stretching method. Exceeding the extensibility limits of the tissue involved is unlikely, and the technique requires less energy to perform while alleviating muscle soreness (Bandy & Irion, 1994).

Static stretching can increase flexibility, but it also appears to acutely impair muscular performance by reducing subsequent strength and power production. The mechanism for this deficit has not been fully uncovered, but could be due to mechanical factors, such as changes in viscoelastic properties of the musculotendinous unit, neuromuscular factors, including decreased motor unit activation, firing frequency, and altered reflex sensitivity. "Although the majority of studies show that static stretch has a negative impact on performance, others have observed that static stretching may not interfere with performance" (Torres et al., 2008, p.1280).

These contradictions appear to reside in the region of the body being stretched. For example, Knudson, Noffal, Bahamonde, Bauer, and Blackwell (2004) demonstrated that static stretching had no influence on muscular performance during a tennis serve. Findings on direct comparisons of different lower-body stretching modalities have found either no effect or a reduction in performance with static stretching (Faigenbaum, Bellucci, Bernieri, Bakken, & Hoorens, 2005). This could potentially explain the conflicts found in research. Because several of the muscles of the lower body are larger than the upper body, greater reductions in force may occur when testing lower body musculature.

Ballistic Stretching

The ballistic stretch uses bouncing or jerking movements imposed on the muscle to be stretched. The quick, jerking motion that occurs during the ballistic stretch can theoretically exceed the extensibility limits of the muscle in an uncontrolled manner and cause injury (Bandy & Irion, 1994). Ballistic stretching usually triggers the aforementioned stretch reflex, not allowing the muscles to relax, which defeats the purpose of stretching (Baechle & Earle, 2000).

PNF Stretching

PNF stretching techniques are commonly used in the athletic and clinical environments to enhance both active and passive range of motion (ROM) with a view in optimizing motor performance and rehabilitation. The terms 'contract relax', 'hold relax' and 'contract relax agonist contract' are commonly referred to in PNF stretching literature. Usually 'contract relax' and 'hold relax' represent a passive placement of the target muscle into a position of stretch, followed by a static contraction of the targeted muscle. The targeted muscle is then passively moved into a greater position of stretch (Sharman et al., 2006).

When a targeted muscle is held in a stretch position, passive torque and muscle stiffness decrease, that is, the muscle tendon unit demonstrates viscoelastic stress relaxation (Magnusson, 1998). PNF, along with static and ballistic stretching, is commonly used to lengthen the musculotendinous unit and as a result increase the range of motion (ROM) of a specific joint. A static (isometric) contraction of a stretched target muscle and/or a shortening (concentric) contraction of an opposing muscle to lengthen the target muscle, together with a slow and controlled approach to the stretch, are generally what differentiate PNF stretching from both static and ballistic alternatives.

Stretching Protocols

Stretching protocols may be the key in understanding the duration of appropriate stretches to use pre and post activity. Protocols vary in time of stretch, type of stretch, when to implement the stretch for the type of activity. There are a number of studies that use the same timing for certain types of stretches; however there are also varying lengths and results that occur throughout the research. Understanding the type of activity may be the best way to implement an appropriate type of stretch and when this should happen- pre or post activity. However, as explained further below, each type of stretch offers benefits and drawbacks to the individual.

Static Stretching- Benefits and Drawbacks

Static stretching remains a "go-to" type of stretch that may or may not be fully supported in the research. Bandy and Irion (1994) found that static stretching with a duration of 30 seconds is effective for enhancing the flexibility of the hamstring muscles. Researchers evaluated stretching durations of 15 seconds as well as 30-60 seconds. Results indicated that the most effective duration of stretching is 30 seconds. Costa, Graves, Whitehurst, and Jacobs (2009) examined the effects of different durations of static stretching on dynamic balance. Results revealed that a stretching protocol of 45-second hold durations does not adversely affect balance. Additionally, the study revealed that a moderate, 15-second stretching protocol induced significant improvements in dynamic balance performance by increasing postural stability.

Brandenburg (2006) also believes that studies with longer stretching protocols yield larger decrements in performance, whereas shorter protocols elicit smaller reductions in performance. A common thread appears to be present with static stretching of moderate durations produces either no significant change or a positive effect, particularly with performance based measures (Costa et al., 2009). Little and Williams (2006) found no detrimental effects from 30 seconds of stretching on performance measures, suggest that if static stretching is to be used, minimizing stretches to short durations may minimize decrements to performance.

Bacurau et al. (2009) states static stretching exercises produce a greater acute improvement in flexibility compared with ballistic stretching. According to Woods et al. (2007) stretching provides many benefits for an individual. Viscoelastic responses to stretching in a muscle are time and history dependent. For example, performing three-30 second repetitions of static stretch have been reported to lead to muscle lengthening. The ability to lengthen the muscle without damage may allow athletes to assume unusual positions that would otherwise result in injury.

However, Pope, Herbert, Kirwan, and Graham (2000) found that a typical muscle stretching protocol performed during pre-exercise warm-ups does not produce clinically meaningful reductions in risk of exercise-related injury in army recruits. These results are similar to Marek et al. (2005) in that both static and PNF stretching methods caused similar deficits in strength, power output, and muscle activation at both slow and fast velocities.

Previous authors have examined the effects of stretching on maximal strength (Kokkonen, Nelson, & Cornwell, 1998; Nelson & Kokkoynen, 2001), explosive force production, vertical jump performance, concentric isokinetic peak torque, isometric force production, and balance. According to Marek et al., (2005) only 2 previous groups have compared the effects of static and PNF stretching on human performance measures, with conflicting results. One group reported that vertical jump heights after PNF stretching were lower than after static stretching and/or control conditions. The other group, however, demonstrated no significant differences in jump performances between the PNF stretching and control conditions but significant decreases as a result of static stretching. Therefore, according to these researchers, limited and inconclusive data are available regarding the effects of static and PNF stretching on muscle strength and power output (Marek et al., 2005).

Static stretching may not be recommended before athletic events that require high levels of force. Static stretching can increase flexibility, but it also appears to acutely impair muscular performance by reducing subsequent strength and power production. The mechanism for this deficit has not been fully elucidated but could be due to mechanical factors, such as changes in viscoelastic properties of the musculotendinous unit, and neuromuscular factors including decreased motor unit activation, firing frequency, and altered reflex sensitivity (Manoel, Harris-Love, Danoff, & Miller, 2008; Samuel et al., 2008; Sayers, Farley, Fuller, Jubenville, & Caputo, 2008; Torres et al., 2008; Witvrouw, Mahieu, Danneels, & McNair, 2004).

Dynamic Stretching-Benefits and Drawbacks

Dynamic stretching is currently a popular stretching technique, used especially by competitive athletes. A study conducted by Manoel, et al. (2008) demonstrates that dynamic stretching of the quadriceps muscle group may increase power for both slow and fast movements. This finding is consistent with previous studies. For example, Yamauchi and Ishii (2005) found that there was no influence of static stretching on leg extension power but that dynamic stretching of the lower-limb muscles significantly increased leg extension power compared to non-stretching controls. Young and Behm (2003) found that a warm-up consisting of submaximal running and practice jumps had a positive effect on explosive force and jumping performance, whereas static stretching had a negative influence.

McMillian et al. (2006) showed better power and agility scores after a dynamic stretching protocol compared to static stretching. Based on these studies and current results, dynamic stretching appears to be an effective means for warming-up and enhancing muscular performance. Length of the stretching protocol may have a greater bearing on observed results. Herman and Smith (2008) observed that a 4-week dynamic warm up intervention elicited improvements in the majority of performance measures that assessed power, speed, agility, endurance, flexibility and strength. Second, the observed performance improvements in the dynamic warm-up group were entirely absent in the active control group performing a static warm-up.

A review by Bishop (2003) and, more recently, the work of McMillan, Moore, Hatler, and Taylor (2006) show dynamic warm-up routines positively influence power, agility, and other performance measures. Bishop attributes these performance measures to both temperature and non-temperature physiological mechanisms. Proposed temperature related mechanisms include decreased stiffness, increased nerve-conduction rate, altered force-velocity relationship, and increased anaerobic energy provision. Temperature related mechanisms involve increasing the baseline temperature of the muscle prior to activity.

PNF Stretching-Benefits and Drawbacks

According to Franco, Signorelli, Trajano, and Oliveria (2008) PNF stretching generally leads to a force decrease. Marek et al. (2005) have reported decreases in peak torque and mean power output when comparing pre-stretching and post-stretching procedures. Franco et al. (2008) showed a reduction of muscle endurance after PNF stretching, even with a small duration and only one stretching exercise. Similarly, research done by Marek et al. (2005) found conflicting evidence that static stretching before exercise and through PNF provided benefits to those who performed the stretching properly. They concluded that both static and PNF stretching caused similar deficits in strength, power output, and muscle activation at both slow (60 degrees per second) and fast (300 degrees per second) velocities.

The theory of autogenic and reciprocal inhibition has been used to explain the larger range of motion gained by PNF when compared with others' methods. The autogenic inhibition mechanism refers to a decrease in the excitability of a contracted or stretched muscle, which reduces the efferent drive to the muscle and decreases motor unit activation. This suggests that a larger range of movement is associated with further decreased motor unit activation. However, in a rehabilitation setting, or where an athlete is primarily looking for greater ROM, PNF stretching may be the best way to accomplish that goal. According to Sharman et al. (2006) one repetition is sufficient to increase ROM with an expectant change in ROM from anywhere between 3 and 9 degrees, depending on the joint.

Investigations into the passive properties of the human musculotendinous unit (MTU) have found that there is an increase in passive torque (the passive resistance of the MTU to stretch) and muscle stiffness (change in torque divided by the change in joint angle) as elongation of the targeted muscle increases. When the passive torque response has been compared across static and PNF stretching, the PNF stretch not only yields greater gains in ROM but also greater passive torque measures at end ROM.

It is important to understand how the muscle operates and responds, in response to an increase in demand, to further understand the importance of stretching and the type and timing to implement the best protocol.

Musculotendinous Unit (MTU)

Muscle-tendon systems may generate forces in two distinctively different ways: (1) as an elastic-like spring in stretch-shortening motion that occurs, for example, during jumping type activities; and (2) as converters of metabolic energy into mechanical work in predominantly concentric contractions, such as cycling, jogging and swimming. In the first role, an eccentric muscle action is immediately followed by a concentric action. It is well known that if an activated muscle is stretched before shortening, its performance is enhanced during the concentric phase. This phenomenon is the result of strain energy stored in the tendon and muscle structures (Witvrouw et al., 2004).

Sports involving bouncing and jumping activities with high intensity of stretch-shortening cycles (SSCs) [e.g. soccer and football] require a muscle tendon unit that is compliant enough to store and release the high amount of elastic energy that benefits performance in such sports. If the participants in these sports have an insufficient compliant MTU, the demands in energy absorption and release may rapidly exceed the capacity of the

MTU. This may lead to an increased risk for injury of this structure. Consequently, the rational for injury prevention in these sports is to increase the compliance of the MTU (Witvrouw et al., 2004).

A muscle and its tendon have both viscous and elastic mechanical properties. The viscous properties within a MTU will elongate in response to a slow sustained force and will resist rapid changes in length. While the MTU is under stretch, the amount of force generated by the viscous material resisting the elongation decreases over time ('stress relaxation'). The amount of force required to elongate the MTU is mostly dictated by the elastic properties of the MTU (Sharman et al., 2006).

Impact of MTU during movement

Activities like cycling, skating, and swimming rely on constant sustained movement and little opportunity exists for absorbing amounts of energy during the task or skill. A more compliant MTU allows for the effective storage and release of series elastic energy, but seems to be less suited for a task with this type of sustained movement. A study completed by Wilson et al. (1994) concluded that MTU stiffness was significantly related to isometric and concentric performance but not to eccentric performance. Researchers concluded, the stiffer subjects performed significantly better than the more compliant subjects on both the isometric tests and on the majority of the concentric tests, since the stiff muscles immediately transfer force to the muscle-bone junction. In contrast, compliant muscles generated less power due to the delayed transfer of energy through the MTU.

Therefore, it seems that different types of sports need different levels of MTU compliance. Many physical activities, such as cycling, swimming, skating, wrestling, and boxing, involve the rapid development of force in an isometric or concentric muscular contraction, and such performances could be enhanced through an increase in MTU stiffness. The stiffer the MTU, the faster the force is transferred to the bones, and the resulting movement of the joint is quicker.

Therefore, looking only at performance, it might be possible that in these sport activities there is no need for highly elastic muscle-tendon that acts like a spring. The aim of sports with a high amount of positive work-loops is to convert metabolic energy as fast as possible into mechanical work (Witvrouw et al., 2004). Positive work loops involve movements or activities that remain consistent in motion or energy use. For example, a swimmer or cyclist moves the body in a steady motion. There is little change in movement, or need for a storage of quick bursts of energy. Conversely, in sports with a high intensity SSC such as soccer and football, a more compliant MTU may be required for the storage and release of elastic energy. A MTU involved in such SSC's needs a high storage capacity for potential energy and must, therefore, be sufficiently compliant.

It should be considered that there may be an ideal level of compliance for a MTU during a task. This level can be influenced by structural characteristics of the unit (Witvrouw et al., 2004). Mechanical and neural factors influence the responses to stretching. Accordingly, changes in joint range of motion after static stretching reportedly cause changes in MTU stiffness or in pain tolerance (Sharman et al., 2006). Consequently, a less stiff MTU may increase the time for forces and signals to be transmitted between the central nervous system and skeletal system.

Young and Elliott (2001) have stated that a high level of MTU stiffness may ensure a fast transmission of muscular force to the bones. Similarly, Behm, Bambury, Cahill, and Power (2004), have suggested that a more compliant MTU has more slack on the connective tissue, hence affecting muscle activation, which could alter reaction and movement time, consequently affecting balance and stability, or the proprioception of a limb (Costa et al., 2009).

Sports with high SSC movements versus non-impact sports

Understanding the differences between stretching protocols, and the confusion that remains among professionals, may be related to results found during different types of activity. Pre-stretching a muscle just prior to concentric action can enhance force production during the subsequent contraction. The increase in force production is called stretch-shortening potentiation or, more commonly, the stretch-shortening cycle (SSC). This enhancement is most likely caused by the combined effects of the use of elastic energy in the muscle (primarily from stretching the myosin cross-bridges) and stretch-reflex potentiation (activation of the myotatic stretch reflex caused by a rapid stretch) of muscle. The SSC is a very important phenomenon in sport, since it occurs so frequently and is an integral component of activities such as running, jumping, throwing, and striking (Baechle & Earle, 2000).

Fletcher and Jones (2004) compared the detriment in running performance after a bout of stretching with the performance decreases in drop jump height found by Young and Elliott (2001). Sprinting requires a rapid transition from eccentric to concentric muscle action, as does performing a drop jump, albeit with the latter using a single stretch-shortening cycle, and the former using several in continuous fashion. Fletcher and Jones suggest that static stretching primarily affects the eccentric phase of the SSC. During this phase, the series elastic component (SEC) lengthens, storing elastic energy to be reused in the concentric phase of the SSC, when the SEC springs back to its original configuration.

However, after a bout of static stretching, the SEC may already be lengthened, thereby impeding the pre-activation of the MTU and decreasing its ability to store and reuse as much elastic energy during the SSC.

Shorten (1987) reports that the amount of elastic energy that can be stored in the MTU is a function of stiffness. Therefore, because static stretching reduces the stiffness of the MTU less energy can be retained and used after a bout of static stretching. This peripheral mechanism may have contributed to the decrease in overall sprint performance observed by Sayers et al. (2008).

Conflicts in Research

There still remains conflict in research about the type, timing and overall type of stretch to use before activity; however there are common recommendations for types of stretches to use prior to different activity. The effects of stretching exercises on muscle force capacity are contradictory. A common understanding appears to run throughout the research that adding a sports-specific warm-up prior to activity may elicit the greatest benefits to the individual.

Yamaguchi and Ishii (2005) have reported increased leg power after dynamic stretching. McMillian et al. (2006) found increased medicine ball throw, T-drill, and five step jump performance after dynamic stretching but not after static stretching. Similar results were obtained by Little and Williams (2006), who found that dynamic stretching was most effective to prepare for high-speed activities 10-m sprint, flying 20-m sprint, and agility; and that static stretching was not detrimental to performance.

Fletcher and Jones (2004) found a significant decrease in 20-m sprint performance after acute passive and active static stretch. They concluded that static stretching produces impairments in muscle force production. This impairment may be associated with the stress relaxation as mention above. The increased stress relaxation could impair muscle force production as a result of changes in the force-velocity and length-tension relationships (Bacurau, et al., 2009). Individuals looking to increase flexibility may benefit from static stretching routine stretching targeted muscles for duration of approximately 30 seconds. However, static stretching has also provided researchers with negative or no benefits to the individual performing the stretching routine. Decreases in power and strength output have been observed with the use of static stretching which would hinder volleyball, basketball, and athletes relying on jump height and quick power outputs to use this method of pre-activity stretching (Sayers et al., 2008; Samuel et al, 2008; Torres et al, 2008).

Marek et al. (2005) found a 2.8% decrease in peak torque and a 3.2% decrease in mean power output as a result of the static and PNF stretching exercises. The results of this study were unique in that the researchers observed decreases in muscle strength and power as a result of both static and PNF stretching exercises. Conflicting evidence exists regarding the effects of PNF stretching on jump performance. These conflicting results may be due to the differences between stretching protocols and or the types of jumping tests performed (vertical jump versus drop jump versus concentric-only jump).

Static stretching has been attributed to greater flexibility, therefore still serves a purpose in the athletic world. Perhaps implementing a static stretching routine post-activity may offer athletes flexibility improvement and greater range of motion without the upcoming need for power and strength production as a pre-game routine would require.

Ballistic stretching has not been researched as thoroughly as static, dynamic and PNF stretching methods. However, ballistic stretching has shown to increase flexibility such as static stretching has, yet ballistic stretching is commonly thought of as unsafe. Ballistic stretching does not allow the muscle to relax into a greater state of relaxation, which is the objective of stretching a muscle. The use of bouncing movements ballistic stretching is generally not recommended for individuals, and has been described to defeat the overall purpose of stretching (Baechle & Earle, 2000).

Stretching Recommendation

Athletes may require different types of stretching for their individual needs. For example, PNF stretching has been shown to elicit the greatest gains in ROM compared with other stretching protocols. However, PNF stretching has been responsible for decreases in strength and power performance. Therefore, PNF stretching may benefit those in a rehabilitation program looking to gain ROM to return to their sport. PNF stretching has commonly been used in rehab programs, where athletes work closely with trainers or therapists to get back to optimal shape for competition.

Understanding the type of activity the individual is preparing for may offer the best answer to coaches and professionals looking to ready their athletes for competitions. Sports such as volleyball, basketball, football, and soccer would benefit the most from a dynamic routine pre-activity that mimics sports movements without decreasing power and strength output observed with a static stretching routine. If these athletes do not have a compliant MTU, the demands in energy may exceed the capacity of the MTU resulting in increased risk of injury. Because these athletes also need a greater range of motion for muscle length, to also avoid injury, implementing a static stretching routine post-activity may accomplish the flexibility observed by researchers after a bout of static stretch. Reducing the time to a moderate amount of time (15-30 seconds) per targeted muscle may also reduce the occurrence of performance related deficits long-term.

Athletes that rely on a positive work-loop such as swimming, cycling, and skating, depend on the rapid development of force in an isometric or concentric muscular contraction. These types of athletes benefit further from a stiffer MTU, enabling the force to be transferred more rapidly to the bones, and the resulting movement of the joint quicker. Looking only at performance, it may be possible that in these sports activities there is no need for highly elastic muscle tendon that acts like a spring, storing mechanical energy for later work. The aim of sports with a high amount of positive work-loop is to convert metabolic energy as fast as possible into mechanical work (Witvrouw et al., 2004).

By including routine that compliments activity, the negative outcomes found in research following stretching may be limited or avoided. Athletes looking to use explosive type movements or change in direction may benefit more from a dynamic stretching routine that takes the body through movements that mimic their activity. Static stretching has proved its relevance in the athletic world through increased flexibility and muscle compliance. Including static stretching post-exercise appears to offer the individual with the safest means of observing these outcomes. PNF stretching is also a beneficial type of stretching offering its greatest rewards to those in a rehabilitation setting where individuals are observed and taken through a specific routine in order to return to competition. Ballistic stretching may present a mixture of positive and negative outcomes in research, however, it has taken a backseat to dynamic stretching, a type of stretch that is much safer for individuals to perform.

CHAPTER 3. DISCUSSION

The purpose of this review was to clarify confusion among stretching techniques currently being used among coaches and professionals today. While there still remains conflicting research, understanding the types of stretching methods as well as timing (pre or post exercise) may clarify some uncertainty when implementing a stretching routine. Sports involving "explosive" type skills, with many maximal SSC movements require a muscle tendon unit that is compliant enough to store and release the high amount of elastic energy. It has been shown that stretching is able to increase the compliance of human tendons, and as a result increase the capacity of the tendon to absorb energy (Sayers et al., 2008). When an individual's muscle-tendon unit is less flexible in these types of sports activities, there exists a predisposing factor for exercise-related injuries since the tendon is unable to absorb enough energy, which may lead to tendon and/or muscle damage.

When the sports activity contains no, or only low, SSC movements (cycling, jogging), all or most work is directly converted into external work. In these cases, there is little need for a compliant tendon since the amount of energy absorption remains low (Witvrouw et al., 2004). Findings on direct comparisons of different lower-body stretching modalities upon these sport activities have found either no effect or a reduction in performance with static stretching, compared to either no effect or improved performance following a dynamic stretching or warm-up. These findings indicate that sports relying on high lower-body power output, such as track and field, could benefit from as dynamic stretch or warm-up. The mechanism by which dynamic stretching improves muscular performance has been speculated by many to be due to elevated muscle temperature or postactivation potentiation in the stretched muscle caused by voluntary contractions of the antagonist (Torres et al., 2008).

According to Sharman et al. (2006), the literature supports PNF stretching as the most effective means to increase range of motion by way of stretching, particularly in respect to short term gains in ROM. Aside from being safe and time efficient, the dramatic gains in ROM seen in a short period of time may also promote compliance with the exercise and rehabilitation program. However, Marek et al. (2005) reported decreases in peak torque, mean power output, and EMG amplitude when comparing PNF pre-stretching and post-stretching procedures. Franco et al. (2008) reported a reduction of muscle endurance after PNF stretching, even with a small duration and with only one stretching exercise.

The theory of autogenic and reciprocal inhibition has been used to explain the larger range of motion gained by PNF when compared to other methods. The autogenic inhibition refers to a decrease in the excitability of a contracted stretched muscle, which reduces the efferent drive to the muscle and decreased motor unit activation. This suggests that a larger ROM is associated with further decreased motor unit activation. Thus, one might hypothesize that the same mechanism that involves PNF, which leads the muscles to gain a large range of movement, can negatively influence the endurance of the muscle. This hypothesis is in accordance with the idea that a PNF method is more likely responsible for the decrease on muscle strength than a static stretch. On the other hand, when a person intends to increase his or her range of movement, a PNF stretch is more likely beneficial than a static stretch (Franco et al., 2008).

A ballistic stretch typically involves muscular effort and uses a bouncing type movement in which the end position is not held. Ballistic stretching is often used as the pre-exercise warm-up; however, ballistic stretching may injure muscles or connective tissues, especially when there has been a previous injury. Ballistic stretching usually triggers the aforementioned stretch reflex, not allowing the muscles to relax, which defeats the purpose of stretching (Baechle & Earle, 2000).

Conflicting reports on the benefits of ballistic stretching to athletes remain. According to Samuel et al. (2008) significant declines in power occurred after both static and ballistic stretching. In various studies, vertical jump (VJ) was affected by a bout of stretching. This was not the case with Samuel et al. One potential explanation for this is that the VJ requires a certain amount of technique. Therefore, the VJ used in this study comprised of three factors: force, speed, and technique. It is speculated that stretching does not have any effects on VJ technique. In comparison, raw power involves only force and speed. Results of the Samuel et al. study reveal that acute static and ballistic stretching preformed pre-activity does not affect VJ and torque output of the quadriceps and hamstrings.

Coaches that use stretching as a part of the warm-up can continue to do so by limiting the duration of the stretching to 1.5 minutes per muscle group. However, because power was adversely affected, sports that require maximal power output should not proceed with acute static stretching. Static stretching can increase flexibility, but it also appears to acutely impair muscle performance by reducing subsequent strength and power production. The mechanism for this deficit has not fully been uncovered but could be due to mechanical factors, such as changes in viscoelastic properties of the musculotendinous unit, and neuromuscular factors, including decreased motor unit activation, firing frequency, and altered reflex sensitivity. Although the majority of studies show that static stretch has a negative impact on performance, it has been observed that static stretching may not interfere with performance (Torres et al., 2008). According to Bacurau et al. (2009), Static stretching produced a significant acute drop in force production compared with both ballistic and control (e.g., no stretch), but ballistic stretching did not affect force production. In addition, both stretching protocols produced acute increments in flexibility (sit-and-reach and hip joint ROM test). However, the static condition produced greater increments in flexibility.

Application

Therefore, when introducing a stretching protocol into a pre-activity and post-activity routine coaches and professionals should be wary about which type of stretch they are using. Dynamic stretching appears to offer greater benefits to the athlete or individual exercising before competition. With movements and actions that mimic the sport or event, increasing muscle temperature may be the most desirable outcome before competition. Sports or activities that rely heavily on explosive power, speed and strength may choose dynamic activity over static to avoid detrimental tendon elasticity and muscle compliance. It seems that static stretching produces impairments in muscle force production. This impairment may be associated with the stress relaxation reported above.

Including static stretching post-activity may offer greater benefits to the athlete long term in regards to greater range of motion acquired over time. A possible explanation for the greater increase in flexibility after the static exercise may be the viscoelastic stress relaxation that occurs when the muscle tissue is kept stretched in a fixed position. The stress relaxation seems attributable to increased tendon elasticity and a decreased muscle viscosity, which produces a decreased passive joint torque (Bacarau et al., 2009). There remains conflicting research on the negative effects static stretching has on athletes. A trend seems to exist whereby static stretching of moderate duration produces either no significant change, particularly with performance based-measures. Little and Williams (2006), who found no detrimental effects from 30 seconds of stretching on performance measures, suggests that if static stretching is to be used, minimizing stretches to short durations may minimize decrements in performance (Costa et al., 2009). This information seems promising, as coaches and professionals tend to rely heavily on static stretching as a means of warming up and improving flexibility before practice and competition.

Much of the literature supports that PNF is the most effective means to increase ROM by way of stretching. Aside from being safe and time efficient, the dramatic gains in ROM seen in a short period of time may also promote compliance with the exercise and/or rehabilitation program (Sharman et al., 2006). However, studies have also supported the idea that PNF stretching also leads to decrements in athlete's ability to produce force (Franco et al., 2008). However, Sharman et al. (2006) reports that one repetition of PNF stretching is sufficient to increase ROM with an expectant change in ROM from anywhere between 3 and 9 degrees, depending on the joint. Due to the continued contradiction in studies, with PNF offering individuals the greatest ROM, PNF stretching may greatly benefit those in a rehabilitation program over those warming up for competition. With most athletic events requiring some type of force production as well as flexibility to complete the tasks, PNF stretching may offer some benefits yet also some decrements.

When competition comes down to inches, stretching the smartest may make the final difference. By completing a warm-up routine that mimics the specific movements needed for the task, the athlete has the greatest ability to prepare the body in time for the event. Dynamic stretching appears to be the best way to increase muscle temperature and prepare the body for competition without some of the detrimental effects other modes of stretching tend to have on the body. However, it is important that some athletes maintain greater levels of flexibility to avoid injury. Therefore, static stretching appears to hold importance in the overall needs of certain types of athletes (depending on their sport and the demands placed on the body). Static stretching allows increased flexibility without placing the body through a high amount of stress in the joints and muscles. Timing for optimal benefits appears to be following competition or practice, where the athlete is not relying on strength and power output, but also looking to prepare the body for further competition after rest.

PNF stretching has also been researched to provide athletes with greater ROM, again reducing the amount of injury and added stress placed on the body. However, based on some sports' short amount of time before competition to prepare and warm-up, PNF stretching may hold its greatest benefits to those in a rehabilitation program looking to get back to where they were before injury. These athletes/individuals tend to have greater amounts of time to focus on stretching without the time constraints of a vigorous practice or game schedule.

Therefore, reviewing the research has uncovered some common ideas behind stretching; and the type and timing to implement before, and following exercise. After reviewing the four types of stretching techniques most commonly used by individual's there appears to be some importance as to the timing and type of stretch based on the type of activity being performed. Static stretching appears to hold a more valuable place in the athletic world post-exercise when the detriments are not seen in performance. Dynamic stretching has also been widely supported to offer individuals the greatest ability to warm-up the body in a safe manner before competition or activity. Sports specific movements allow the body to warm up in a more appropriate manner tailored to the individual's activity.

In conclusion, while research continues to vary and conflict, athletes and coaches still rely on a routine to prepare the body for competition or practice. Sports specific movements before activity and static stretching following may offer the individual the safest, most time efficient means of producing a maximal effort available to be successful in competition.

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