A Review of Stretching Techniques and Their Effects on Exercise

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Abstract

The role of flexibility in exercise performance is a widely debated topic in the exercise science field. In recent years, there has been a shift in the beliefs regarding traditional benefits and appropriate application of static stretching. Static stretching has previously been proposed to increase exercise performance and reduce the risk of injury, however recent research does not support this belief consistently and may even suggest conflicting viewpoints. Several types of stretching methods have also been promoted including proprioceptive neuromuscular facilitation (PNF) stretching, AIS, and dynamic, and ballistic stretching. The role of flexibility in exercise performance continues to be researched with hopes to discover how these techniques affect exercise both acutely and long term. It is important to understand the effects of the various stretching types and determine when each is most appropriate to maximize human motion and performance. The purpose of this thesis is to focus on reviewing each major form of stretching and to provide the reader with the most current research supporting or negating their implementation in the health and fitness fields.

A Review of Stretching Techniques and Their Effects on Exercise

In the world of physical fitness, flexibility continues to be a misunderstood component of physical health. It is considered one of the 5 major components of physical fitness, yet, from a physiological standpoint, there is still a great deal that is not fully understood. Flexibility, most simply, refers to the range of motion that a joint or body segment can move through (Alter, 2004). A variety of stretching techniques have been adapted into exercise programs and workouts attempting improve flexibility. But, the question, “What benefit does improved flexibility achieve during exercise?” often lingers without clear answers. In the past, it was believed that stretching before an exercise or activity helps to prevent injury and increase effective performance (Amako, Oda, Masuoka, Yokoi, Campisi, 2003; Robinette, 2007). In addition the phrase, “stretching prevents injury,” has also been repeated throughout the exercise science field for many years. Does research support these traditional declarations that many coaches, athletes, trainers, and educators continue to proclaim; does flexibility positively contribute to the prevention of injury? Another common claim is that greater range of motion in the joints improves an individual’s exercising capabilities (Stamford, 1984; Shellock & Prentice, 1985; Beaulieu, 1981). Does increasing flexibility beyond the range of motion necessary to perform activities of daily living actually result in improved physical performance in areas such as speed and power? If so, what form of stretching, how often, and at what time should it be done? Does everyone respond the same way to stretching or does it vary among individuals?

Physiological Mechanisms Involved in Stretching

In order to understand the relationship between stretching and performance, it is necessary to recognize the mechanisms involved in both skeletal muscle contractions and muscle lengthening. A thorough understanding of the physiological mechanisms of skeletal muscle will aid in the comprehension of the various stretching methods. Muscle stretching refers to purposeful lengthening of a muscle while muscle contraction is the shortening of the muscle to produce movement. Before we examine the stretching techniques, a review of muscle anatomy will be discussed, as well as the sliding filament theory and safety reflexes.

Anatomy of Skeletal Muscle

Skeletal muscle is composed of many parts. Each muscle in the body is comprised of muscle fibers that are bundled together in groups called fasciculi. Connective tissue called perimysium surrounds each fasciculus and endomysium connective tissue surrounds each of the muscle fibers. Each fiber consists of a membrane called the sarcolemma and can be broken down further into hundreds of myofibrils. Myofibrils are surrounded by the sarcoplasm where glycogen, fat particles, enzymes, and mitochondria are stored. Transverse tubules wrap perpendicularly around the muscle fibers and in between the myofibrils allowing a synchronized discharge of the action potential. Finally, each myofibril is organized lengthwise by sarcomeres, which are composed of protein filaments actin, myosin, and titin that enable muscular contraction and elongation. Figure 1 below provides a clear illustration of the major components of a muscle.

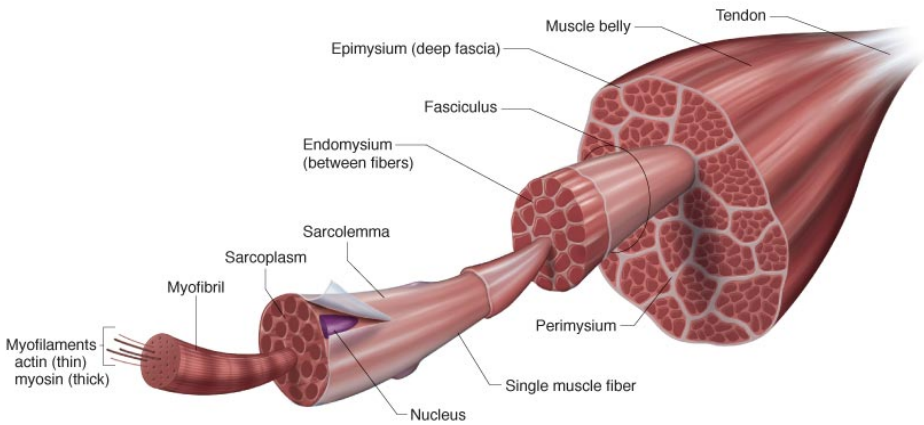

Figure 1. Muscle Anatomy Various sheaths of connective tissue- epimysium, perimysium, and endomysium- contribute to individual flexibility (Baechle & Earle, 2008).

Sliding Filament Mechanism

The sliding filament theory is thought to explain how sarcomeres within the myofibrils produce skeletal muscle contractions. As calcium is released in the sarcoplasmic reticulum actin binding sites are uncovered. The myosin heads of the thick filaments attach to the binding sites and the thin filament is pulled past the myosin towards the M-line resulting in a shortening of the sarcomere. Each myosin head that attaches to the actin filament creates a cross bridge. As the action potential continues to fire, all the sarcomeres within that motor unit continue to contract (All-Or-None Principle.) As the muscular contraction necessary to complete the task becomes greater, the number of cross bridges formed within the sarcomere increases. Figure 2 provides a visual representation of sarcomeres within the muscle.

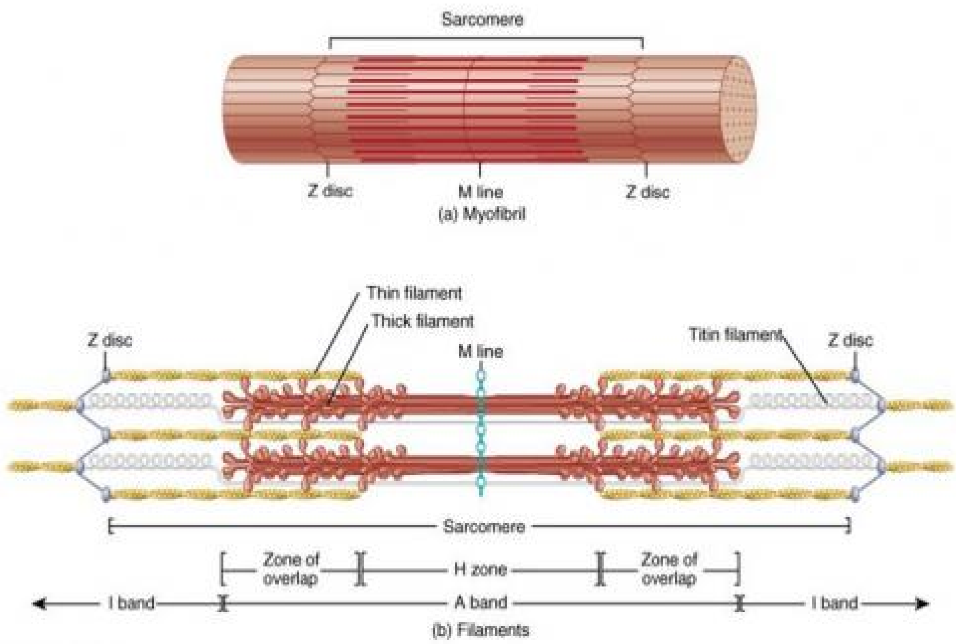

Figure 2. Sarcomere Anatomy Titin filaments within the sarcomere elongate during a stretch (Baechle & Earle, 2008).

In contrast, for a muscle that is stretched, the thin filaments are pulled away from the think filaments. In addition, literature supports the notion that titin filament takes up more and more of the displacement created by the actin and myosin during the stretch increasing tension within the myofibril (Labeit, Kolmerer, &Wolfgang, 1997). The titin filament is believed to be responsible for the sarcomere's extensibility and resistance to stretch (Tskhovrebova & Trinick, 2002). Stretching a muscle is not the same as an eccentric contraction in which an action potential is fired and the sarcomere is lengthened. Stretching a muscle is a passive motion in which body positioning causes a lengthening of the muscle. In an eccentric contraction, such as elbow extension while lowering a weight from a bicep curl, nerve impulses are being fired to control the speed of the motion. Force is being produced within the muscle fibers, but it is equal to less than the opposing force. Similarly, the muscle undergoes tension during a static stretch and is under the influence of Golgi tendon organ and muscle spindle reflexes for the prevention of injury.

One theory to explain the reason skeletal muscle strength may decrease directly following a stretching bout is that the muscle has not returned to its resting position and it remains slightly elongated. This means that within the sarcomere, the thick and thin filaments are further away from each other in a resting position. When the individual attempts to contract the muscle, fewer cross bridges can be formed because the myosin and actin are pulled away from each other (Huxley, 1969). The fewer cross bridges that are formed, the less force produced by the muscle.

Reciprocal Inhibition

The primary muscle used to allow a specific movement to occur is called the agonist. For example, the agonist muscles that concentrically contract to extend the knee are the quadriceps. The opposing muscles are called the antagonists. As the knee extends, the antagonists (the hamstrings) relax to assist the movement. Reciprocal inhibition refers to this contraction and relaxation that occurs between the agonist and antagonist muscle pairs; the antagonists are inhibited from contracting. The safety reflexes, designed to prevent individuals from a motion that would cause an injury within the muscle, utilize reciprocal inhibition.

Safety Reflexes

An important concept to consider in the discussion of stretching efficacy is the stretch reflex or the myotatic stretch reflex. As a muscle is stretched quickly, the rapid change in the length of the muscle is detected by the proprioceptors of the muscle spindle organ located within the belly of the muscle. This rapid change in length triggers the central nervous system, specifically the spinal cord, to generate muscular contraction in the agonist muscle. This reflex occurs to reduce a person's chance of injury by proceeding too far or too quickly into a stretch. When an individual slowly stretches a muscle, holding the stretch for a prolonged period, the muscle spindle has adequate time to become accustomed to the new muscle length and the stretch reflex does not occur (Morán, 2009).

The opposite occurs as a muscle is contracted too quickly or too far. The tendon reflex or the inverse myotatic reflex occurs when the Golgi tendon organ senses excessive rapid tension in the tendons due to muscular contraction. This reflex is a protective mechanism that prevents tendon and muscles from being torn away from their attachments by activation of the antagonistic muscles. The GTO sends an impulse to override the muscle spindle's signals to contract and the muscle relaxes (Baechle & Earle, 2008).

Static Stretching

Static Stretching is the most well known forms of stretching (Blahnik, 2013). It occurs when an individual moves his/her body in such a way that a muscle is slowly elongated and then held in that position for a period of time. For example, to statically stretch the hamstrings a seated person with legs straight can bend at the waist and reach for the toes. The individual holds the position for a length of time, usually between 15 and 60 seconds. The American College of Sports Medicine recommends 2-4 repetitions of stretches totaling 60 seconds per stretch to improve flexibility. The goal of static stretching according to the Encyclopedia of Sports Medicine, is to “desensitize tension sensors in the muscle,” and it is believed that when this happens, the muscle is capable of taking on more force before becoming damaged (Okragly, 2011).

There are two basic ways static stretching can be performed: active or passive. Active stretching occurs when the individual uses his/her own muscles to hold the stretching position. Active stretching is more beneficial in the development of active flexibility. In passive stretching, an external force holds the static stretching position for the individual. This external force can be an object or a person. Passive stretching eliminates the need for the opposing muscle to contract while stretching. In active static stretching reciprocal inhibition is applied so the opposing muscle groups are contracted whereas in passive static stretching both the antagonist and agonist muscles may be relaxed through the stretch. (Baechle & Earle, 2008)

For example, the quadriceps can be actively stretched by the contraction of the hamstrings to flex the knee. Flexion refers to the movement allowed by some joints of the skeleton that decreases the angle between 2 adjoining bones while extension indicates the motion that increases the angle (Baechle & Earle, 2008). The quadriceps are passively stretched by flexing the knee using a chair or object or pulling one’s ankle toward their buttocks. This allows both agonist and antagonist muscle to relax while stretching. Passive stretching is preferred when the elasticity of the muscles and connective tissues restrict flexibility and is commonly performed in rehabilitation settings. Since the muscles are in a relaxed state, there is an increased risk of muscle soreness if stretching is performed too aggressively. Active stretching may be more beneficial in improving ROM because it is more closely related to actual exercise movements by the utilization of reciprocal inhibition (Blahnik, 2013).

Effects on Injury Occurrence

There are many studies preformed past and present investigating causes and prevention of musculoskeletal injuries. Static stretching has been advocated as a legitimate technique to avoid the occurrence of various injuries. It was believed that stretching prior to physical activity was a necessary practice and that it was dangerous not to do so (Neuberger, 2001). Very few studies on static stretching convincingly investigate the effect on injury susceptibility yet many experts suggest that acute static stretching may increase injury potential (Macera, 1992; Van Mechelen, 1992; Knapik, Bauman, Jones, et al., 1991).

For example, Kieran O'Sullivan, exercise expert at the University of Limerick, Ireland, believes that, "when you stretch before exercising, your body may think it's at risk of being overstretched. It compensates by contracting and becoming tenser. That means you aren't able to move as fast or as freely, making you more likely to get hurt" (Cheng, 2010, para. 5). *The Encyclopedia of Sports Medicine* (2011) states, "Static stretching has long been used in "warm-up" routines by those engaging in sports activity. The common thought is that loose muscles are less likely to be injured. Multiple studies show that static stretching before an athletic contest may cause small tears in the muscle and make the muscle more prone to injury"(para. 3). In an article reviewing the necessity of static stretching prior to exercise, Dr. Malachy McHugh, the director of research for the Nicholas Institute of Sports Medicine and Athletic Trauma at Lenox Hill Hospital in New York and an expert on flexibility states, "You may feel as if you're able to stretch farther after holding a stretch for 30 seconds so you think you've increased that muscle's readiness. But typically you've increased only your mental tolerance for the discomfort of the stretch. The muscle is actually weaker" (Reynolds, 2008, para. 8).

In contrast, Dr. Paul Donohue encourages stretching on the basis of injury prevention. He says, "If joints, tendons, ligaments and muscles are too tight, they suffer from sprains (ligament and tendon tears) and strains (muscle tears). Intuitively, stretching ought to prevent such injuries" (Donohue, 2010, para. 3). Many experts continue to encourage static stretching for preventing injury when done other times than directly before exercising as it has been shown that flexibility is increased and overuse injuries are potentially reduced (Carrand, Gallagher, & Vardiman, 2010).

A study of 901 military recruits examined the prevalence of injury for those who stretched before and after exercise and those who did not stretch prior to exercise. It was found that the total injury rate was nearly the same for both groups, but incidences of muscle and tendon injuries and low back pain was found to be significantly lower for the stretching group. Bone and joint injuries were not decreased due to stretching (Amako et al., 2003). Another study of 1,538 army recruits revealed no significant injury occurrence difference between those who stretched prior to engaging in physical activity and those who did not. "In the Australian military, tendon injuries occurred in 20 of 735 (2.7%) subjects who stretched and 16 of 803 (2.0%) subjects who did not stretch" (Small, McNaughton & Matthews, 2008, p. 219).

In a systematic literature review of articles from 1990-2008 by Small, McNaughton, and Matthews, it was concluded that there was "moderate to strong evidence" that routine static stretching does not result in significant reductions in all-injury risk. However, "preliminary evidence" exists indicating that static stretching may decrease musculotendinous injuries (Small, McNaughton, & Matthews, 2008).

Acute Effects on Speed

La Torre recently investigated acute effects of static stretching on reaction time and balance and concluded that balance following stretching decreases. In addition, reaction and movement time decreased significantly post-stretching (La Torre, 2010). This is surprising because it would be expected that a greater range of motion in the joints would result in a greater speed and agility in movement. In contrast, other researchers observed the effect of a combined dynamic and static stretching protocol and found no detrimental effects on repeated sprint ability and/or change of direction results (Behm, Chaouachi, Lau, & Wong, 2011).

Acute Effects on Power Output

A wide range of research exists investigating static stretching and its acute effects on maximal exertion and power output. Debate exists regarding the recommended amount of time an individual should hold a static stretching position. To simplify this static stretching review, studies are divided and discussed based on the amount of time designated for stretches (≤30 seconds, 30-60 seconds, and >60-90 seconds.)

Static stretches ≤30 seconds. Few studies have been performed investigating the effect of such a short static stretching bout on maximal output. According to Kay and Blazevich's systematic review, stretching bouts under 30 seconds result in no significant disadvantageous effects on power. However, a 1 maximum repetition experiment paired with a routine of 3 repetitions of 15 second static stretching indicated that there was a significant decrease in maximal strength following stretching (Kokkonen, Nelson, & Cornwell, 1998). Many researchers have investigated the role of 30 second static stretching since 30 seconds is a common pre-exercise duration for stretching. Force development in squat jump was found to decrease significantly after a static stretching bout in which stretches were held for 30 seconds. This evidence suggests that the use of static stretching may not be recommended for activities of maximal power output at “knee angles near full extension” and force development is reduced in the squat jump (La Torre, 2010). Stretching for 30 seconds did not significantly affect vertical jump height, yet was found to decrease low-extremity power output in a study of static and ballistic stretching (Samuel, 2008).

Behm and Kibele investigated whether or not static stretching intensity played a role in jump performance, subjects completed three 30-second stretches and different levels of discomfort. Most stretching studies instruct participants to hold their stretch at the point of discomfort (POD), but in this particular study, participants stretched at 50%, 75%, and 100% of their POD to determine whether intensity played a role in their jump performance. All three stretching intensities were found to inhibit jump functioning by 3.5% (Behm & Kibele, 2007).

In 2011, Behm et al. evaluated the effect of shorter duration static stretching (10, 20, and 30 seconds) combined with a 90 second dynamic stretching routine on repeated sprint ability, change of direction, and the sit and reach test. The longer durations (20 and 30 second static stretching) had a significant positive effect on the sit and reach scores, while there appeared to be no significant difference on the repeated sprint times or change of direction results (Behm et al., 2011). This may suggest that a combination of both dynamic and static stretching before exercise may increase range of motion without inhibiting performance.

Static stretches 30-60 seconds. A systematic literature review in which over 4500 acute static stretching studies were reviewed revealed that no detrimental acute effects occur for static stretching durations less than 60 seconds (Kay & Blazevich, 2011). In addition, “overwhelming evidence” confirms that strength decreases after static stretching durations over 60 seconds (Kay & Blazevich, 2011). 45 seconds of static stretching may not reduce force production. This is supported by one study (Behm, 2004). Stretching 15-60 seconds has been found to increase an individual’s flexibility, though it has been demonstrated that these increases are merely short-term and muscle flexibility will return to its pre-stretched length after 10-20 minutes (Carrand, Gallagher, & Vardiman, 2010, ACSM, 2011). These flexibility gains are only temporary, however if done consistently, flexibility improves over time. Static stretches held from 30-60 seconds may decrease force production in some cases (Behm, 2004).

Static stretches >60-90 seconds. In 2006, a study took place that investigated muscle length and strength loss following static stretching. Participants performed isometric and isokinetic knee flexion contractions before and after a static hamstring stretching. The hamstring stretch was held for 90 seconds and was repeated 6 times and then strength was assessed at various knee flexion positions. It was discovered that strength decreased by 8%. At a shortened position strength decrease was 15% but at a lengthened position a decrease in strength did not occur. (McHugh & Johnson, 2006)

Chronic Effects on Speed and Power

Fewer researchers have investigated the long-term effects of routine static stretching can have on performance in the areas of speed, agility, and force production. It is believed that increased stretching over a period of time results in an increase in the number of sarcomeres in series onto the end of existing myofibrils: “Research has substantiated that an addition of sarcomeres is responsible for an increase in muscle length,” but additional research must be performed to confirm that the increase in sarcomeres is a direct result of a stretching program (Kay & Blazevich, 2011, para. 18).

La Roche et al. (2008) performed a study and found that a 4-week static hamstring stretching routine had little effect on optimal muscle length, work capacity, peak hamstring force, or power. These results are significant because due to lower reflex activity and reduced work absorption no detrimental results on force production were found. Though there appears to be no benefit to chronic stretching for performance, it is important to note that there was no apparent negative result on power. Based on this study, the authors conclude that stretching can continue to be used as a means of increasing range of motion and alleviating muscle soreness without decreasing performance (LaRoche et al., 2008). In a separate study, a 6-week static hamstring stretching protocol was administered to 21 women’s track and field athletes to determine its influence on sprint time and vertical jump. Four repetitions of 45-second static hamstring stretching took place 4 days a week for 6 weeks. No significant difference was found after the stretching protocol (Bazett-Jones, Gibson, & McBride, 2008).

A study by Stone in 2006 found small performance enhancements (3-4%) in maximum strength and explosive strength after chronic static stretching. The author suggested that muscle hypertrophy might occur as a result of chronic stretching. This has been observed in some animals as “chronic stretch causes some muscle damage and chronic reflexive activity” (Stone, 2006, para. 17). However, the author concluded it unlikely that enough muscle tissue damage occurs in the way athletes utilize routine static stretching to result in muscular hypertrophy, therefore the mechanisms causing the slight performance improvements remains unclear (Stone, 2006). Continued research needs to be performed in order to confirm these findings, establish the optimal time to do static stretching, and ascertain the appropriate length of static stretching routine to produce favorable results on exercise performance.

Optimal Utilization

Most research does not support the traditional belief that static stretching prior to exercise enhances an individual’s athletic capacities. In fact, the overwhelming majority of studies have come to the opposite conclusion (McHugh & Johnson, 2006; Kay & Blazevich, 2011; Behm & Kibele, 2007). Force production, strength, reaction time, and speed all appear to suffer when directly following a static stretching bout. Therefore, it may be advisable to discontinue static stretch routines that take place prior to physical activity involving these skills. In addition, no conclusive evidence exists confirming the notion that static stretching prior to exercise prevents injury. However, chronically, static stretching increases flexibility and no decisive research was found indicating that long-term static stretching routines inhibit power or speed. Though the mechanisms involved remain elusive, static stretching at times other than prior to exercise, may be advantageous and certainly is not harmful to athletic functioning. Since the optimal time to stretch (other than stretching prior to exercise) is uncertain, a study examining static stretching timing -immediately following exercise or hours afterward- to determine when an individual could reap the greatest benefit.

Ballistic Stretching

Ballistic stretching is a technique that involves a bouncing or bobbing motion during a stretch. Instead of holding a position as in static stretching, the individual moves in and out of the stretch over and over. It uses the momentum of the body part to force a greater ROM in the joint. Ballistic stretching promotes the stretch reflex reaction to the rapid lengthening of the muscle and has been contraindicated in many textbooks (Morán & Arechabala, 2009, p. 12). *The Oxford Dictionary of Sports Science and Medicine* deems it a “potentially injurious type of stretching,” as ballistic stretching increases the risk of muscle tears. In addition, Kent reports that the risk of tissue damage increases because the rapid, bouncing motion may carry the joints beyond their maximum ROM (Kent, 2006). Unlike dynamic stretching, (described in detail in the following section) ballistic stretching is erratic and uncontrolled and is rarely recommended for the use of the general population (Blahnik, 2013).

Despite the negative connotation of ballistic stretching, it has been shown to improve flexibility in some cases (Mahieu, McNair, Muynck, et. al., 2007). In addition, one particular study revealed that ballistic induced significantly less muscle soreness than static stretching (Smith et al., 1993). Several other studies have also investigated ballistic stretching and its effects on performance.

Acute Effects on Performance

Much like static stretching, ballistic stretching has been shown to acutely decrease force output in some cases. A study investigating ballistic stretching and how it influences 1-repetition maximums in knee flexion and extension found a significant reduction in both 1RMs (Nelson & Kokkonen, 2001). Another study found that lower body power output significantly decreased due to ballistic stretching while vertical jump height remained unchanged. The ground reaction forces from a force plate measured power during the vertical jump test (Samuel et al., 2008).

Ballistic stretching has also been shown to have no significant effect on performance. A study investigating vertical jump after ballistic stretching showed no significant difference in vertical jump height from not stretching (Jaggers et al., 2008). Another study of 16 actively trained women found no significant difference in vertical jump height after a ballistic stretching protocol. Subjects performed quadriceps, hamstring, and calf stretches by bobbing up and down at a pace of one bob per second. Subjects bobbed for 15 seconds and then rested for 20 before repeating the stretch again (Unik et al., 2005).

One study of 43 subjects investigating the effects of ballistic stretching combined with basketball activity on vertical jump (VJ) height discovered that VJ increased significantly (Woolstenhulme et al., 2006). Subjects completed a ballistic stretching routine of 2 repetition of 1 bob per second for 30 seconds followed by 20 minutes of basketball play. Vertical jump height was then recorded and found to be significantly higher than vertical jump heights without stretching and after a sprinting warm-up. This was the only study found to show an increase in jump height after a ballistic stretching bout. It is impossible to determine whether the ballistic stretching was the cause of the jump height increase. More research is needed in this area.

No studies were found that investigate the effects of ballistic stretching on speed and agility therefore more research is needed to determine how acute ballistic stretching affects overall athletic performance.

Chronic Effects on Performance

Only two studies were found that examine the long-term effects of ballistic stretching on performance. They have shown no significant improvement or reduction in exercise performance due to chronic ballistic stretching. Woolstenhulme's study of 43 subjects that combine basketball with ballistic stretching over 6 weeks found no significant difference in vertical jump height. Subjects stretched 2 times a week for 6 weeks. Though no difference in vertical jump was found, flexibility improved significantly (Woolstenhulme et al., 2006). These findings are confirmed in a study of another 6-week ballistic stretching protocol in 2007 (Mahieu, et. al.). Flexibility has been shown to increase due to ballistic stretching in many cases (Mahieu et. al., 2007; Taylor et al., 1990).

Optimal Utilization

Optimal utilization of ballistic stretching is unclear because very little research has been done to determine how it affects exercise. Because it is believed to contribute to an increased risk of injury, it may be unwise for beginners. In athletic settings however, ballistic stretching may be beneficial as Woolstenhulme's basketball study found. For the most part, exercise professionals have gravitated away from ballistic stretching to an improved stretching form: dynamic stretching.

Dynamic Stretching

Dynamic stretching refers to the movement of limbs in an "organized pattern to increase range of motion." Unlike static stretching movements do not exceed the individual's limits of range of motion within the joints being warmed up. The activities are sport/activity-specific (Carrand, Gallagher, &Vardiman, 2010). Some do not consider dynamic stretching a form of "stretching" but rather types of warm-up activities. Dynamic stretching would still be considered a category of stretching techniques because it purposefully elongates muscles being activated in exercise and it often replaces standard acute static stretching. It "utilizes movements that mimic the specific sport or exercise in an exaggerated yet controlled manner" (Troumbley, 2010, p. 11). This technique is most widely used prior to exercise and has become more and more prevalent in competitive athletic settings.

Dynamic Movements

Dynamic stretching includes movements that are specific to the activity that the individual is preparing for. This means that routines differ from sport to sport; a runner would stretch differently than a tennis player. Essentially, the sport or activity should be broken down into basic movements. These movements are then mimicked in an exaggerated and repetitive way to fully prepare the body. It often involves movements such as striding and lunging, and usually whole-body movements that "maintain a stable lower back and pelvis" are favored. Tai chi, yoga, and Pilates very often use dynamic types of movement. According to *The Encyclopedia of Sports Medicine*, "It is the essence of 'core' training that is critical to all musculoskeletal health" (Oakragley, 2011, p. 1397).

Some common examples of dynamic stretches for the lower body include high knees, butt kicks, and straight leg kicks. In order to warm up the hips and reduce stiffness, the person will run bringing the knees high up toward the chest. Kicking the feet back, hitting the heels to the buttocks, stretches the quadriceps muscles. Lastly, the hamstrings and hip flexors are activated by walking and swinging the legs straight forward while keeping the knee extended. These dynamic motions are often applied to running activities. To stretch and warm up the arms, arm circles can be performed by rolling the shoulders forward and backward in a circular motion. Several other motions have been developed to increase the individual's readiness to exercise.

Effects on Injury Occurrence

The effects of dynamic stretching on injury prevention remains elusive as several different theories and opinions exist. It is suggested that injury potential may increase for beginners and inexperienced exercisers attempting a dynamic stretch routine and static stretching is referred to as the "safest method"(Richard St. Pierre, 2002). This has not been proven however, and many actually find dynamic movements easier and more natural than standard static stretching. Regardless, proper technique is key for effective dynamic stretching that enhances performance without causing injury. Since the individual is actively moving into a stretch, it is important to maintain correct form so that the right muscles are being appropriately prepared for activity.

Cameron McGarr, exercise and fitness specialist encourages dynamic stretching because of its ability to prepare the muscles better for exercise therefore, reducing the occurrence of injury. He says that it should be done often because it “teaches the muscles to elongate while in motion” improving moving flexibility (McGarr, 2007, para. 2). The concept of active flexibility is thought to be a factor in decreasing the likelihood of injury. When an individual uses static stretching to prepare the muscles for activity, the active flexibility has not been increased; only passive flexibility has been improved. Dynamic stretching increases active flexibility and a person’s range of motion during exercise.

It is believed that static stretching alleviates muscle soreness but is it possible that muscle soreness could be reduced through dynamic stretching? No direct research has been published to show that dynamic stretching can be used to ease muscle soreness (Weerapong, Hume, & Kolt, 2004). However, it is observed that dynamic stretching is more effective at stretching the muscle without damaging the ligaments while static stretching often over-stretches the ligaments (Oakley, 2011). More research should be conducted on chronic dynamic stretching and its impact on preventing musculoskeletal injuries and relieving muscle soreness.

Effects on Performance

Several studies suggest that performance is positively affected by acute dynamic stretching. 3 performance tests-the T-shuttle run, the underhand medicine ball throw, and the 5 step jump) were administered to 30 Army cadets to determine if there was a difference in performance for static stretching versus dynamic stretching. In all three tests, the 10 minutes dynamic stretching had the greatest improvement. Performance was not enhanced after static stretching. This is an indication that static stretching prior to exercise should be replaced with dynamic stretching. Possible explanations for why acute dynamic stretching appears to be more effective than static stretching include mechanisms resulting from an increase in temperature within the muscles such as a reduction in joint and muscle stiffness, greater nerve impulse conduction rate, force-velocity relationship alterations; and increased glycogenolysis, glycolysis, and high-energy phosphate breakdown (McMillian, Moore, Hatler, & Taylor, 2006).

Sprint times have been shown to improve after subjects dynamically stretched compared to passive static stretching (Fletcher & Anness, 2007). The study investigated specific combinations of static and dynamic stretching to conclude what routine most positively influences speed. Even when passive static stretching was combined with active dynamic movements, sprint times significantly increased. Active dynamic notably proved to greatly improve sprint times: “The phenomenon of active dynamic stretches enhancing performance has been linked to the rehearsal of specific movement patterns, helping proprioception and pre-activation, allowing an optimum switch from the eccentric to the concentric muscle contraction required to generate high running speeds,” while static stretching seems to have the opposite effect (Fletcher & Anness, 2007, para. 20).

In a study investigating, the club head speed and ball speed during a golf swing were found to have shown an increase after dynamic stretching. In addition, the golfer's swings were straighter than without stretching in this manner. This reveals that dynamic stretching appears to improve all aspects of the sport by preparing the individual more completely for their activity (Weider, 2009).

Another study investigating the effects of dynamic stretching activity reviewed the influence of a dynamic warm-up on the power output during a leg extension exercise. Subjects performed leg extensions on two separate occasions, once without preceding stretching and once after performing a dynamic stretching treatment. Power output was found to be significantly greater after the dynamic stretching compared to no stretching. The author concluded that the results suggested that the reason dynamic stretching routines in warm-up protocols appear to enhance power performance is because common power activities are performed by dynamic constant external resistance muscle actions under different loads (Yamaguchi et al., 2007). Power outcomes were also increased in a study of 24 untrained female after a dynamic warm-up. Data were recorded at 5 minutes into exercise after the stretching protocol and again at 30 minutes to determine the prolonged effects of acute dynamic movement. Power output increased (Curry et al., 2009).

Not all studies on dynamic stretching reveal improved strength however. For example, a study that compared static stretching to dynamic stretching revealed no significant difference in strength. The 51 subjects performed static stretches of upper and lower body for 3 sets of 15 seconds. One maximum repetition was recorded for bench press and leg press. For the dynamic stretching routine, “the upper-body stretch was swinging each arm, one at a time, as far forward and then as far backward as possible in a diagonal plane. For the legs, the same movement was done for each leg, except performed in a sagittal plane. Each forward and backward movement took about 2 seconds. Three 30-second sets were administered, and a 10-second rest was allowed between sets” (Beedle et al., 2008, para. 9). These results may reflect that short bouts of repeated static stretching may not be as harmful as some studies claim. In addition, these results are consistent with other research indicating that dynamic stretching prior to exercise does not inhibit performance. An additional comparison of static (SS) and dynamic stretching (DS) signified that vertical jump was significantly improved after a dynamic stretching bout and the jump was significantly decreased after static stretching. Furthermore, electromyography of the vastus medialis revealed greater amplitude during the post DS vertical jump than after the SS bout. These results may be attributed to “post-activation potentiation,” and the decline in vertical jump performance after SS may be credited to “neurological impairment and a possible alteration in the viscoelastic properties of the muscular tendon unit” (Hough, Ross, & Howatson, 2009, p. 1). This positive impact on vertical jump height is confirmed in a 2011 Slavakian study (Vanderka, 2011).

Likewise, a study of dynamic stretching versus ballistic stretching showed a greater force output for dynamic stretching than ballistic. Significant gains were discovered in the power for dynamic stretching while ballistic stretching revealed no significant gains (Jaggers, Swank, Frost, & Lee, 2008). The acute effects of three types of stretching, static, proprioceptive neuromuscular facilitation (PNF), and dynamic, were investigated for 12 healthy and active women in 2008 (PNF stretching will be discussed in detail in the following section.) Findings revealed that knee extension power was appreciably greater after the dynamic protocol than for the static and PNF protocols (Manoel et al., 2008). A group of soccer players were evaluated to determine whether dynamic movement patterns positively affected in-step kicking. Once again, significant improvement was observed (Amiri-Khorasani et al., 2011).

Chronic dynamic stretching does not really have a place in research because it has been specifically designed as a technique for the warm-up session. Therefore, it remains unclear what long-term effect these movement patterns have on flexibility, speed, or power. Additional research is needed to determine chronic effects.

Optimal Utilization

Overall research is more supportive of dynamic stretching having a positive influence on exercise including the improvement of power output and speed (Amiri-Khorasani et al., 2011; Manoel et al., 2008; Jaggers, Swank, Frost, & Lee, 2008; Vanderka, 2011). Dynamic stretching also has shown superiority over static stretching when performed prior to activity and therefore may be more advantageous. Acute dynamic stretching appears to prepare the muscles for exercise better and should reduce injury potential because the individual is adequately warmed up for the specific activity. Static stretching has been shown to improve flexibility and reduce muscle soreness when performed after exercise bouts. Dynamic stretching has not shown benefits when performed post-exercise. The chronic benefits of dynamic warm-ups are yet to be determined by research. Appropriate steps should be taken to ensure that proper technique and form is maintained during dynamic movements in order to prevent injury.

Proprioceptive Neuromuscular Facilitation Stretching

Developed by Herman Kabat, proprioceptive neuromuscular facilitation (PNF) is a group of stretching techniques developed in 1965 (Surburg & Schrader, 1997). The purpose of this technique is to increase flexibility and range of motion through the stimulation of the neuromuscular system and the proprioceptors. PNF is an approach that attempts to increase efficiency in movement and provide the necessary range of motion to complete activities of daily living. It was also designed to improve reflexes and postural impairments in order to restore balance and coordination. It is a widely used practice in rehabilitation settings by physical therapists and other health professionals. As with other forms of stretching it is important to employ proper technique during the movements to avoid injuries to the tendons, muscles or ligaments.

PNF technique to improve flexibility can be divided into 3 basic phases. First, the muscle is lengthened in a stretch either passively or actively. The individual then preforms an isometric contraction with the muscle that was just lengthened. Lastly, the individual actively or passively stretches the muscle into further ROM. PNF movement patterns are based on two neuromuscular mechanisms: reciprocal inhibition and the inverse stretch reflex. As stated in a previous section, reciprocal inhibition refers to the contracting of agonist and relaxing of antagonist muscles that facilitates muscle contraction. The inverse stretch reflex or the Golgi tendon reflex is the protective mechanism that causes a relaxation in the muscle if too much tension is produced. Active motion is used to arouse the reciprocal inhibition response, increasing the lengthening of the muscle (Holcomb, 2000).

A few similar techniques of PNF exist that have subtle important differences. One technique is called the hold-relax and it requires a stretching partner. The muscle is stretched passively to a point of mild discomfort and the stretch is held for 6-10 seconds. Then the individual isometrically contracts the muscle against the force applied by the partner. The stretch is completed with another passive stretch. Another technique called the “Hold-relax with agonist contraction” begins with a passive stretch of the muscle by the partner and is followed by an isometric contraction. In the third phase the individual concentrically contracts the agonist muscle while the partner passively stretches. This technique results in greater flexibility due to the actions of autogenic and reciprocal inhibition. Lastly, the contract-relax method begins with a passive stretch of the muscle. The individual pushes against the resistance applied by the partner in the “antagonist pattern so that the result is a concentric contraction through the full range of motion” (Holcomb, 2000, p. 61). Then the muscle is passively stretched again (Holcomb, 2000).

Few studies were found that investigate the differences between each PNF technique. However, in 2012 a study was done to compare assisted and unassisted PNF stretching. Originally PNF stretching required the assistance of a partner, but in recent years straps have been implemented so that stretching may be completed alone. All three methods of PNF were completed with a partner and with a strap; flexibility, reaction time, and movement time were measured pre-stretching and post stretching. No significant difference was found between any of the assisted or unassisted PNF techniques and ROM significantly increased for all methods. Reaction time was not impacted and movement time decreased by 3.4% (Maddigan, Peach, & Behm, 2012). Further research would facilitate a greater understanding of how each PNF technique can be used for maximum benefit.

Effects on Injury Occurrence

PNF is a technique often used to rehabilitate injuries and provide greater mobility for daily activities. Great success has been observed in patients using PNF to return to their daily activities. However, the effect of this type of stretching on averting injury remains unclear. Few studies have been done to research the acute and chronic effects of PNF on the prevention of injury. Does PNF stretching prepare the muscles appropriately for activity as dynamic stretching was found to? In addition, are flexibility gains observed from PNF maintained chronically to contribute to the evasion of injury? The answers to these questions require extensive further research.

Acute Effects on Performance

Very few studies have been done to assess acute PNF stretching. PNF was found to have similar results on power output as static stretching does. Peak torque was found to decrease and electromyography amplitude decreased due to PNF. However, the researchers concluded that a risk-to-benefit ratio should be employed when considering the usage of acute PNF because the power reduction was minimal (Marek, Cramer, Fincher, et al., 2005). Another study found that jump performance was impaired for 15 minutes after PNF stretching took place, but after 15 minutes, maximum jumping ability was fully recovered. This indicates that PNF stretching may not be appropriate to prepare for explosive exercise movements (Bradley, Olsen, & Portas, 2007).

In contrast, another study that examined the acute effects of PNF on explosive force, maximal contraction, and jumping performance found no significant difference in performance due to the stretching (Elliot & Young, 2001). No significant change was detected in 14 soccer players from a PNF stretching routine on agility. The rationale behind the study was the notion that PNF stretching has been shown to produce an increase in musculotendinos unit stiffness which is believed to be linked to an increased ability to store and release elastic energy. Since different studies offer various results, "training status may mediate the relationship between stretching and performance." (Jordan, Korgaokar, Farley, & Caputo, 2012) A group of tennis players were studied to establish the effects of PNF on jump performance. No statistically significant change occurred to suggest that PNF has a positive influence on power production (de Paiva Carvalho, Prati, de Alencar Carvalho, & Dantas, 2009).

Range of motion in the joints has been proven to occur by countless studies due to static stretching as well as PNF. But it remains largely unknown whether these gains in flexibility are great enough to endure for an extended period of time. One study of the hip joint found significant gains in range of motion immediately following PNF. However, after 7 minutes the range of motion had diminished. The research concluded that if there is no other acute benefit to PNF besides increased range of motion, it does not need to be used because the increased ROM from stretching diminishes fairly rapidly (Knappstein, Stanley, & Whatman, 2004).

Chronic Effects on Performance

The chronic effects of PNF on exercise performance remain relatively un-researched. However, one study compared active, passive, and PNF stretching to determine the extent of improvement of glenohumeral internal rotation. The researchers observed improvements in shoulder rotation after 1-week of implementation of hold-relax PNF stretching (Hall, Oliver, & Stone, 2012). Increased range of motion results in greater mobility and performance in exercise. If this stretching routine were continued for a longer time period, perhaps even greater improvements would occur.

There is some debate over whether PNF stretching is more effective than static stretching. Many studies have compared the two techniques and observed no substantial difference in chronic ROM gains. Williford and Smith reported advances in flexibility of the hip and trunk for high school physical fitness students over a 9-week period, however very similar advances occurred for both static and PNF stretching revealing no statistical difference between them (Williford, & Smith, 1985).

When combined with resistance training, an 8-week PNF protocol elicited no statistically significant outcomes on muscle volume or strength. However, a slight overall increase did occur at the end of 8 weeks. Because the results were not statistically significant, PNF stretching was not found to be effective in improving strength. In addition, the PNF was combined with resistive training making the attribution of the slight gains in strength indistinguishable between the resistance and the PNF (Arazi et al., 2012).

In another study, a group of active women were tested to determine whether PNF produced positive gains in ankle range of motion, maximal strength, rate of force development and musculotendinos unit stiffness. After 4 weeks of training, "the experimental group significantly increased ankle range of motion (7.8%), maximal isometric strength (26%), rate of force development (25%), and MTU stiffness (8.4%) ($p < 0.001$)." The researchers concluded that joint ROM and MTU stiffness appear to be separate entities. Results suggested that PNF may be useful in increasing joint strength (Rees et al., 2007).

Several additional studies have been done that uncover the effect of PNF on range of motion. Range of motion has been found to considerably increase due to proprioceptive neuromuscular facilitation. A 4-day a week 6-week PNF protocol elicited significant gains in range of motion, but no statistically significant gains were observed in jump performance (Yuktasir, & Kaya, 2009). Another study examined the plantar flexor range of motion (ROM) and the stiffness in the Achilles tendon. The findings supported the notion that PNF stretching results in increased ankle dorsiflexion. But the increase in ROM could not be proven as a result of decreased passive resistive torque or altered Achilles tendon stiffness. The author concluded that the increased ROM is explained by an increase in stretch tolerance (Mahieu et al.,2009).

Optimal Utilization

There is still much to learn about the appropriate use of PNF stretching to enhance performance and reduce injury. In general, research does not suggest a significant gain in muscle strength or power both acutely and long-term. In a few cases, peak power was reduced after acute PNF. For this reason, unless pre-existing injuries are present, PNF is not recommended as the best approach to warm-up prior to physical activity. However, if an individual wishes to increase flexibility, PNF is a reliable option for long-term benefits. Rehabilitation settings acquire the greatest benefit from PNF by increasing mobility of an injury as well as increasing the strength of the joint. Too little research has been done to establish how PNF stretching influences the occurrence of injury. Acutely, PNF seems to present similar outcomes as static stretching so it could be assumed that injury occurrence would be similar. No research exists to suggest that injury prevalence increases or decreases due to PNF stretching.

Active Isolated Stretching

Active isolated stretching (AIS) was developed by Aaron L. Mattes. His method of stretching was created with the intent of controlling the tendon stretch reflexes. It is a “method of myofascial release, which provides effective dynamic juxtapositioning of isolated muscles, promoting functional and physiological restoration of fascial planes” (Kocho, 2002, p. 226). Reciprocal inhibition is utilized to reduce the excess tension created when passively stretching the muscle. It is believed that AIS increases range of motion through neural or mechanical changes or an increased stretch tolerance (Longo, 2009). According to Aaron Mattes (2000) himself, "The Mattes Method incorporates a key concept, which states that only relaxed myofascial structures will allow themselves to be optimally stretched. Adhering to Wolff's and Sherrington's Laws, the Mattes Method facilitates optimal myofascial stretching of isolated muscles without activating a protective myotatic reflex contraction” (para. 4). It uses a gradual stretch of no greater than 2.0 seconds promoting full range of motion and flexibility without antagonistic muscle group activation (Mattes, 2000). The process of holding the stretch for 1-2 seconds is repeated 8-10 times for optimal “melting of the fascia” (Hammer, 2007, para. 1). Active isolated stretching seeks to fix the limitations of static stretching by not holding the stretch to a duration that would trigger the myotatic reflex. Significant gains in mobility and flexibility were observed in older adults (mean age 70 $\pm$ 6.8 years) who took on an AIS routine 3 times a week for 5 weeks (Guroian et al., 2008).

As mentioned previously, ballistic stretching occurs when an individual bounces into a stretch. It is an uncontrolled motion is believed to increase the chance of injury so it is no longer utilized in most settings. AIS is significantly different from ballistic stretching because it does not activate the stretch reflex. For ballistic stretching, the muscle protects itself from being severed, and “reacts to a vigorous stretch by getting tighter rather than looser” (Matheny, 1995, p. 102). AIS involves short, slow and controlled movements that do not allow enough time for the stretch reflex to occur. The muscle being stretched is isolated and the antagonist muscles are contracted to stretch the muscle. AIS utilizes the natural neuromuscular responses to facilitate the stretch while ballistic triggers a muscle’s safety mechanism.

Effects on Injury Occurrence and Rehabilitation

There are several claims indicating that AIS is the most effective method to reduce the occurrence of injury yet, very little research was found to suggest this notion. One article advocated that the stretching prevents injury when “the weak, opposing muscle are strengthened” also (Matheny, 1995, p. 102). Another article claims that AI stretching reduces injury but does not indicate how (Condor, 1996). More research is necessary to make concrete conclusions about the mechanisms involved in the AIS method and the way it prepares muscles for activity to decrease the likelihood of damage.

Effects on Performance

No studies were found that investigate the role AIS could play in athletic performance abilities such as speed and power. Studies that do exist indicate the effectiveness of this technique on injury recovery and increasing passive ROM. Many studies review the influence of AIS and show that ROM is significantly increased. One example revealed increases in hamstring range of motion after a 6-week stretching bout and also found gains after the first session indicating acute benefits. No significant change occurred in stiffness values (Longo, 2009).

AIS was recommended as an appropriate method of stretching for cyclers as well as tennis players (Matheny, 1995). However, no formal studies have been done to confirm that this is effective in improving sport performance in these areas. One study researched the effect of 3 different stretching techniques including AIS on running economy. No effect was found linking AIS to running performance variables (Henry, 2010). Additional research is required to investigate the acute effects of AIS on other variables of performance such as muscular strength, power, agility, and speed.

Optimal Utilization

Because such little research has been performed investigating this stretching technique and its effects on exercise, it is unclear when this method would be optimally used. However, studies do indicate significant improvements in mobility and ROM for those with injuries. Therefore, presently, the optimal utilization of AIS would be after a musculoskeletal injury. An individual should consult an exercise professional prior to performing any stretching program on an injury. AIS can be used to increase range of motion and flexibility if that is an individual's exercise goal.

Conclusion

Although a wide range of research has been performed on the effects and techniques of stretching, debate still remains over the specific effects and therefore clear answers remain unknown. This may be due to the fact that based on genetics, level of training, or other factors some individuals may be high responders while others may be low responders. Therefore, most likely there is no cookie-cutter answer to the stretching technique dilemma. In addition, the effects of stretching are often difficult to quantify because of the multiple factors that may be involved. Based on the research discussed in this paper, static, ballistic, and PNF stretching techniques tend to increase acute and chronic flexibility and ROM for most individuals. Dynamic stretching appears to provide the greatest acute benefit for exercise performance in speed, strength, and power for the general population. AIS does not appear to elicit exercise performance gains, but has shown success in rehabilitation settings. More research should be done to determine how each of these techniques might be used for the maximum benefit. All of the techniques discussed in this paper have strengths and weaknesses and may benefit or inhibit performance in individuals in different ways.

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