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The History and Evolution of Stretching

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THE HISTORY AND EVOLUTION OF STRETCHING

By

Jennifer Roberts
Bachelor of Science in Physical Therapy
University of North Dakota, 1994

An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

Grand Forks, North Dakota
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1995
This Independent Study, submitted by Jennifer Roberts in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Faculty Preceptor)

(Graduate School Advisor)

(Chairperson, Physical Therapy)
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Progressive Velocity Flexibility Program 1
ABSTRACT

Virtually every athlete engages in some form of stretching before beginning a training routine or competitive event. Stretching is an integral component of endless physical therapy treatment programs for muscle strains, ligament sprains, fibromyalgia protocols, and joint replacements to name a few. However, the physiological effect of stretching and the best method for producing the desired outcome is often questioned by coaches, athletes, and therapists.

The purpose of this paper is to examine the effects of static stretching and ballistic stretching individually and in conjunction with modalities. Muscle physiology, the benefits of flexibility, and the psychological and physiological effects of warm-ups and cool-downs are also discussed.

After reading this paper, a therapist should be better prepared to choose the most appropriate muscle flexibility program for his/her patient.
CHAPTER I
INTRODUCTION

Enhanced flexibility achieved through stretching promotes greater compliance of the muscle tendon unit. However, therapists must determine which is the best method of stretching to gain the desired compliance. Two common methods of stretching are generally used in the attempt to gain an increase in flexibility. These methods are static stretching and ballistic stretching.

Static stretching is a method of stretching in which a stationary position is held for a period of time during which specified joints are locked into a position that places the muscles and connective tissue at their greatest possible length. Ballistic stretching involves quick motions characterized by bobbing or jerky movements imposed upon muscles and connective tissue structures to be stretched. These movements are initiated by active contraction of the muscle groups that are antagonistic to those which are being stretched.

Static stretching offers three advantages: (1) there is less danger of exceeding the extensibility limits of the tissues involved, (2) energy requirements are lower, and (3) muscle soreness is less likely and may in fact be relieved. These advantages are quite reasonable since connective tissue
has a very high tensile resistance to a suddenly applied tension of short duration, while demonstrating viscoelastic and plastic elongation when placed under prolonged mild tension.\(^2\) Static stretching also has the advantages of minimizing any impact of the Ia and II muscle spindle afferent fiber stimulation and maximizing the impact of the GTO.

Ballistic stretching exercises are usually not appropriate for a sedentary individual or geriatric patient but may play a vital role in the conditioning and training of the athlete. Athletic activities are predominantly ballistic in nature, and although the use of ballistic stretching has not been widely supported in literature, ballistic stretching is an effective modality.\(^1\)

The purpose of this paper is to examine the effects of static stretching and ballistic stretching individually and in conjunction with modalities. Muscle physiology, flexibility, and the effect of warm-ups and cool-downs will also be reviewed. It is a therapist’s responsibility to determine which stretching regime is most appropriate. They can make this judgement only after having an understanding of the normal physiology and pathophysiology of the structures involved, the particular patient, and the associated activities. The program prescribed for an athlete will vary considerably from that prescribed for the sedentary individual or the geriatric patient. This literature review will better prepare a therapist to implement an effective and appropriate stretching program into a comprehensive treatment regimen.
CHAPTER II

OVERVIEW OF MUSCLE PHYSIOLOGY

To better understand the effects of stretching on skeletal muscle, it is beneficial to briefly review the basics of muscle physiology. The structural unit of contraction is the muscle cell or muscle fiber, best described as a very fine thread; this muscle fiber has a length ranging from a few millimeters to 30 centimeters and a diameter of 10 to 100 micrometers. When contracting, it will shorten to about 57% of its resting length.

One might imagine a muscle contracting as a smooth shortening motion. In actuality, there is virtually continuous asynchronous activity in which the fibers are undergoing very rapid contractions and relaxations.

The myofibril is the contractile portion of the muscle cell. Each myofibril is made up of actin and myosin filaments. Actin filaments are made up of two strands of spherical or globular monomers arranged in a double helix formation. Myosin filaments are much thicker than actin filaments. Myosin molecules are made up of two protein fragments called light and heavy meromyosin. A myosin molecule consists of a long tail portion and a globular head portion. Light meromyosin has an affinity for other strands of light meromyosin and so the tail portions are attached to each other, leaving the head (globular) portion
of the heavy meromyosin dangling from the myosin filaments. These myosin heads have an affinity for actin. In addition, the head portion of the myosin contains an ATPase which is capable of splitting ATP in the presence of calcium. The splitting of the ATP provides the energy needed to produce a muscle contraction.

In addition to actin and myosin, there are two other proteins essential to muscle contraction. Tropomyosin consists of two long thin poly peptide chains arranged in a double helix formation. The tropomyosin molecule wraps around the actin chain and is thought to "cover up" the active binding sites on actin during the relaxed state. In the active state, tropomyosin moves to "uncover" the active binding sites on actin. Troponin is a protein with three subunits: (1) TnT which binds troponin the tropomyosin, (2) TnI which inhibits actin-myosin binding in the relaxed state, and (3) InC which binds calcium ions.

The sarcomere structure consists of actin and myosin filaments arranged hexagonally with each myosin strand surrounded by six actin filaments. Each myofibril has cross striations when viewed through a light microscope. The following names are given to the elements which compose the striations: The Z-Line is made up of connective tissue which holds the actin filaments in their proper alignment. A sarcomere is defined as the distance between two Z-Lines. The I-Band is made up of actin filaments. The A-Band contains both actin and myosin filaments. The M-Line is made up of connective tissue which holds the myosin molecules in their proper alignment. The H-Band is the light
area in the center of the sarcomere where there is no actin-myosin overlap. The H-Band contains only myosin filaments.\textsuperscript{4,5}

![Diagram of Sarcomere](image)

**Fig. 1--Sarcomere**


In normal skeletal muscle, the fibers contract in small groups. Each of these small groups of muscle fibers are supplied by terminal branches of one nerve fiber or axon whose cell body lies in the anterior horn of the spinal gray matter. The nerve cell body, plus the axon, its terminal branches, and all the muscle fibers supplied by these branches, together constitute a motor unit. The motor unit is the functional unit of striated muscle and an impulse descending
the motor neuron causes all of the muscle fibers in one motor unit to contract almost simultaneously.

The number of muscle fibers that are served by one axon (i.e., the number of motor units) vary widely. Generally, muscles controlling fine movements and adjustments (such as those attached to the ossicles of the ear and the eyeball) have the smallest number of muscle fibers per motor unit. On the other hand, large muscles (i.e., those in the limbs) have large motor units.

Human muscles consist of muscle fibers which vary widely in their physiological, morphological, and biochemical properties. Within one animal, different muscles contain varying amounts of the different fiber types. However, the muscle fibers belonging to one motor unit show remarkable homogeneity in their properties.

Muscle fibers are categorized according to their appearance. Some fibers have a pinkish or reddish visual appearance due to the relatively large amount of blood that is supplied to them by their extensive vascularization; other fibers appear much paler in coloring, reflecting a less prolific vascularization. These two categories have been referred to as red and white fibers. Numerous investigators have shown that when the motor neuron of a motor unit consisting of red fibers is stimulated, the resulting force twitch is slower rising and longer lasting than the force twitch that results when a motor unit consisting of white fibers is stimulated.
Engel\textsuperscript{6} proposed that the fibers be identified as Type I and Type II. The Type I fibers are acid stable and alkaline labile, whereas the converse is true for Type II fibers. Through the intensity of staining for specific enzymes, a muscle's capacity to perform work, either in the absence or presence of oxygen, can be determined. A high aerobic capacity indicates that a muscle fiber is resistant to fatigue as long as oxygen can be supplied via its vascularization. It follows that a muscle fiber with a high aerobic capacity would have a reddish appearance.

An alternative approach for subdividing the categories of muscle fibers has been proposed by Burke et al.\textsuperscript{6} They suggested the following classification based on the mechanical response of all the muscle fibers of a motor unit when their motor neurons are stimulated by a single electrical pulse (contractile response) and to a sustained train of stimuli (contractile fatigue response). They expanded the classification of the slow and fast twitch by introducing the evaluation of contractile fatigue, which may be measured by observing the time at which the amplitude of the twitch response declines and/or the rate at which it declines. They denoted FF for fast contracting, quickly fatigable units; F(\text{Int}) for fast contracting, intermediate fatigable units; FR for fast contracting, fatigue-resistant units; and S for slow contracting, fatigue-resistant units.

Control properties are those properties of motor units which describe their recruitment and firing behavior during the process of force generation. Through these modes, the central and peripheral nervous systems affect the
performance of a muscle or a group of muscles. There are a variety of specialized receptors located in the muscles, tendons, fascia, and skin which provide information to appropriate parts of the central nervous system concerning the state of the force and length characteristics of muscles.

The muscle spindle is the most studied muscle sensor organ. It is located within the muscle. The spindle consists of a capsule having a fusiform shape, attached at both ends to muscle fibers. It is arranged in parallel with the adjacent muscle fibers. The architectural arrangement is designed to favor the monitoring of muscle length and changes in length. Within the spindle (capsule), there are "intrafusal" muscle fibers. These may number from 2 to 25. These fibers have contractile characteristics similar to those of the normal or "extrafusal" muscle fibers and are separated into three categories on the basis of the arrangement of the nuclei in the middle portion of the intrafusal fiber. These fibers are referred to as bag 1, bag 2, and chain fibers.

Bag and chain fibers are distinguishable on the basis of their mechanical properties, with the bag fibers being more dynamic. Wrapped around each of the intrafusal fibers are the endings of two groups of afferent nerve fibers, the larger group Ia and the smaller group II.

The primary afferents are sensitive to both dynamic and static stretching of the intrafusal fibers, but in particular to the dynamic component of a stretch. The primary afferents are relatively large diameter, myelinated fibers and are classified as Type Ia fibers. The secondary endings are afferent fibers which
primarily innervate the nuclear chain fibers. These afferents are sensitive only to static stretch of the spindle. These afferents are smaller in diameter, myelinated fibers, and are classified as Type II fibers.

The muscle spindle is the primary receptor for length changes in muscle. As the muscle spindle is stretched, the afferents increase their firing rate. As the Ia afferents facilitate the agonist muscle there is also reflex inhibition of the antagonist muscle. This action of facilitation of the agonist and inhibition of the antagonist is known as reciprocal innervation or reciprocal inhibition. The Type II afferents can either facilitate or inhibit the extrafusal muscle in which they are located.

The Golgi Tendon Organs (GTOs) are proprioceptors that are located in the musculotendinous junction. Thus, these receptors provide almost no information concerning muscle length. Instead, they are sensitive to muscle tension. They are fusiform in shape, approximately 650 micrometers long, and 50 micrometers in diameter. They are innervated by the group Ib afferent fibers. The GTO is in series with the extrafusal fibers, unlike the muscle spindle, which is in parallel with the extrafusal fibers. Thus, when the extrafusal fibers shorten (contract), the GTO is put on stretch and the GTO afferents increase their firing rate.

The GTO is sensitive to changes in muscle tension. The GTO is the primary sensor for load or tension changes in the muscle. The GTOs are much more sensitive to an active muscle contraction than to passive stretch.
Because of this, they are more important as a load sensor than as a protective mechanism to prevent overstretching of the muscle, as was once thought.

The Golgi Tendon Organ is essentially a force sensor; therefore, it will respond in a fashion similar to an externally applied tension (during stretch) or an internally applied tension (during voluntary contraction). The spindle, on the other hand, is sensitive to length and velocity; thus, it will respond differently depending on whether it is being elongated during a stretch or shortened during a voluntary contraction.

When an external load applied to a muscle stretches the muscle, all of the spindles in a muscle are stretched and respond by providing an excitatory influence on the stretched (agonist) muscle and an inhibitory influence on the antagonist muscle. Under this condition, the muscle spindle and the Golgi Tendon Organ responses conflict.

![Diagram of Nuclear Bag, Chain Type Ia, Ib, Type II](image)

Fig. 2--Nuclear Bag, Chain Type Ia, Ib, Type II

CHAPTER III
STATIC STRETCHING

Between 30% and 50% of all sports injuries are of musculotendinous origin; the majority being acute muscle strains.\(^1\) Muscle strain follows excessive intrinsic force production, excessive extrinsic stretch, or both. The muscle undergoes an eccentric lengthening type of contraction (intrinsic force) to counteract the excessive extrinsic stretching force applied to the point of injury.\(^1\)

Several factors that contribute to muscle strain include: inadequate flexibility, inadequate strength or endurance, dyssynergenic muscle contraction, insufficient warm-up, and inadequate rehabilitation from previous injury.\(^7\)

Good flexibility enhances the tissue's ability to accommodate stress, dissipate impact shock, and improve performance.\(^1\) A muscle that can contract strongly and effectively is well-equipped to absorb force and deformation and has a reduced risk of injury.\(^1\)

The dual innervation of some muscles, such as the semitendinosus and biceps femoris, may contribute to asynchrony of firing and muscle fatigue and increase the probability of injury.\(^1\) Pre-game warm-up will increase intramuscular temperature and tissue compliance and improve the
synchronization of muscular action.¹ This will prepare the musculotendinous unit for repeated deformation in its fully lengthened position.

Inadequate rehabilitation often leads to insufficient tissue maturation and excessive scarring.¹ This can result in a suboptimal load tolerance and can initiate a chronic cycle of injury, inflammation, suboptimal repair, and re-injury.

Static stretching alone and in combination with heat has proven to be an effective method of improving flexibility and athletic performance, as well as reducing the incidence of injury.⁷

Static stretching involves placing the muscles at their greatest possible length and holding them in that position for a minimum of 15 to 30 seconds. Golgi Tendon Organs act as tension sensors and can be responsible for initiating sensor impulses, resulting in reduced resistance to stretched soft tissue. These proprioceptors simply serve to inhibit muscle contracting in the stretched tissue.¹ This relaxation phenomenon does not result when a stretch is performed quickly.

Rationale for Prolonged Stretching

In subcutaneous tissue, around joint capsules, in muscular fascia, and in other moving parts of the body, collagen and reticulum are initially laid down as a loose meshwork of randomly oriented fibers which are attached to each other at intervals.² The greater the free length of these flexible fibers between the points of attachment, the greater the amount of motion that can occur. Connective tissue is continuously removed, replaced, and reorganized. Where
there is considerable and frequent motion, loose areolar connective tissue is
developed with relatively long distances between points of attachment. In areas
where little or no motion occurs, collagen is laid down as a dense meshwork of
sheets and bands with short distances between points of attachment.

Higton and James\textsuperscript{2} performed an experiment using a strain gauge to
measure the tension exerted due to shortening of connective tissue. The
experiment is significant because it demonstrates that connective tissue exhibits
a slow progressive shortening over a period of days if it is not resisted by
considerable force. Normal motion in joints and soft tissue is maintained by the
normal movement of the parts of the body which elongate and stretch joint
capsules, muscles, subcutaneous tissue, and ligaments through their full range
of motion. The tension exerted by such movements overcomes the force which
would slowly produce contracture of the connective tissue and, consequently,
normal range of motion is maintained.

Clinical observation has shown that collagenous connective tissue, in
addition to having the property of shortening in the absence of tension, also
shows plasticity in that it slowly elongates under moderate constant tension.\textsuperscript{2}
Connective tissue has a very high tensile resistance to a suddenly applied
tension of short duration.\textsuperscript{2} As a consequence, it can withstand successfully the
high tensions exerted during intensive muscular activity (ballistic movements).
However, if it is placed under prolonged mild tension, it shows plastic
elongation.
Scientific Studies Advocating Static Stretch

Bandy and Irion\(^8\) examined the length of time the hamstring muscles should be placed in a sustained stretched position to maximally increase joint range of motion. The data analysis revealed that the change in flexibility was dependent upon the duration of stretching. Further analysis revealed that 30 and 60 seconds of stretching were more effective at increasing flexibility of the hamstring muscles than stretching for 15 seconds or not stretching. In addition, no significant difference existed between stretching for 30 and 60 seconds.

Nuzik et al\(^9\) compared low load prolonged stretch with high load brief stretch. The purpose of this study was to objectify treatment approaches by comparing the traditional method of stretching knee contracture, high load brief stretch, with an experimental method of prolonged knee extension via skin traction or low load prolonged stretch.

The results of this study demonstrated that low load, long duration tension (50 minutes, two times per day, for one month) produced twice as much residual elongation of tissue than did the high load, short duration tension (forced passive stretch to end range-hold 60 seconds, rest 15 seconds, repeat 3 times, twice per day for one month). Additional findings of interest were related to the heating of connective tissue structures. Elongation was greatest with the following sequence: 1) the tissue was heated to as high a temperature as possible; 2) while maintaining high tissue temperature, the load was applied; 3) both the load and heat were maintained for a relatively lengthy period of time.
(50 minutes); 4) before the load was removed, the tissue was cooled to well below normal body temperature; 5) the load was removed.

Sapega et al\textsuperscript{10} published a treatment protocol designed to increase range of motion in the post reconstructed and immobilized knee. Their protocol utilizes heat in addition to low load, long duration tension.

Lentell et al\textsuperscript{11} conducted a study discussing the influence thermal agents have on the effectiveness of low load prolonged stretch. Their article is entitled, "The Use of Thermal Agents to Influence the Effectiveness of a Low-Load Prolonged Stretch."

The purpose of this study was to document the effectiveness of applying superficial heat and cold in conjunction with a low-load prolonged stretch for increasing shoulder flexibility. Results demonstrated that low load prolonged stretch associated with the use of heat, ice, or a combination of both facilitated greater long-term improvements in flexibility compared with controls. However, only subjects receiving heat in the initial phase of low load prolonged stretch showed significant gains when compared to those who received stretching alone. The authors concluded that heat in conjunction with a low load prolonged stretch in a nonpathologic shoulder is a clinically superior method of improving flexibility compared with a low load prolonged stretch alone.
The Use of Static Stretching Exercises in the Athlete and Geriatric or Sedentary Populations

Static stretching should predominantly be used early in the athlete's season. The proportion of ballistic stretching to static stretching should be increased as the athlete's level of fitness and conditioning increases. If ballistic stretching exercises are used, they should be proceeded by static stretching and confined to a small range of motion, perhaps no more that 10% beyond the static range of motion. Ballistic stretching may be used to assist in the development of dynamic flexibility at the end of the athlete's available range, due to the fact that athletic activities are predominantly ballistic in nature.

The sedentary individual and the geriatric patient do not engage in high-velocity activities in their daily living lifestyles and, therefore, do not need the high degree of dynamic flexibility required by the athlete. In most instances, static stretching exercises are more appropriate for this patient population.
CHAPTER IV
BALLISTIC STRETCHING

Ballistic, or dynamic stretching is done using rapid bouncing movements to target muscles and produce elongation. This type of stretching may evoke a strong stretch reflex and leave the muscle shorter than its pre-stretching length.\textsuperscript{13}

Beaulieu\textsuperscript{14} feels that ballistic stretching creates more than twice the tension in the target muscle, compared to static stretch. This increases the likelihood of tearing the muscle, because the rapid bouncing does not allow enough time for the inverse stretch reflex to be engaged and relax the muscle. As the individual bounces, the muscle responds by contracting to protect itself from overstretching.\textsuperscript{15} Thus, the internal tension develops in the muscle and prevents it from being fully stretched.

A Study Involving Ballistic Stretching

Smith et al\textsuperscript{16} conducted a study to determine if static and ballistic stretching would include significant amounts of delayed onset muscle soreness and increases in creatine kinase. A repeated measures ANOVA revealed a significant main effect due to time, with peak soreness occurring at 24 hours after stretching. The group effect demonstrated that delayed onset muscle
soreness was significantly greater for the static stretching group than the ballistic stretching group as reported subjectively by the participants. At twenty-four hours, there was a 62% increase in creatine kinase for combined groups. These findings indicate that similar bouts of static and ballistic stretching induce significant increases in delayed onset muscle soreness and creatine kinase in subjects unaccustomed to such exercise. Furthermore, static stretching induced significantly more delayed onset muscle soreness than did ballistic stretching.

The Use of Ballistic Stretching Exercises in the Athletic and Geriatric or Sedentary Populations

Ballistic stretching exercises are usually not appropriate for the sedentary individual or geriatric patient. But, since athletic activities are predominantly ballistic in nature, ballistic stretching may play a vital role in the conditioning and training of the athlete.¹

Whenever ballistic stretching is considered, the program prescribed should be of a progressive nature; that is, a progressive velocity flexibility program should be used.¹ The progressive velocity flexibility program requires that the muscle group being stretched undergoes a transition from antagonist to agonist. It is this transition and potential dyssynergic contraction that have been implicated in muscle strain.¹ The athlete must work on his or her neuromuscular coordination in a dynamic nature in order to prevent such injuries. A motor learning response may be set up as the athlete stretches at a
higher and higher velocity over time, stimulating and integrating functional activity necessary for sport.¹

See Table 1 for outline of progressive velocity flexibility program.

Table 1.—Progressive Velocity Flexibility Program 1

Static Stretching

↓

Slow short end range stretching

↓

Slow full range stretching

↓

Fast short end range stretching

↓

Fast full range stretching
CHAPTER V
FLEXIBILITY

To be successful in a given sport, an athlete requires coordination, endurance, speed, strength, and flexibility. Depending upon the specific physical requirements of each particular sport, the importance of each of these characteristics will differ.

Many physical therapists, athletic trainers, and physicians consider flexibility to be one of the most important objectives in the conditioning programs of athletes. Flexibility can be defined as the range of motion of a joint or a series of joints that are influenced by muscles, tendons, ligaments, bones, and bony structures.\textsuperscript{15}

It is well known that cardiovascular (aerobic) exercise and strength training are essential to fitness, and while many studies document the benefits of aerobic exercise and strength training, researchers have been slow to demonstrate why flexibility is important. Russell Fleischmann\textsuperscript{19} states, "Flexibility is the forgotten fitness factor."

Most experts believe that flexibility helps prevent injury, both during exercise and in everyday life.\textsuperscript{19} The greater the range of motion of your joints, the more comfortably you will perform your normal activities. Another reason
everyday exercisers and competitive athletes alike should strive for flexibility is to improve performance. For example, according to Bob Prichard, the more flexible a runner's hips, the longer his/her strides and the faster he/she can run. Similarly, the greater the range of motion in a swimmer's shoulders, the more efficient the stroke and the greater the thrust through the water.

Inactivity negatively affects muscles, but so does a condition called tracking, which arises from repetitive movement and limits range of motion. A movement becomes "tracked" when a muscle group performs the same motion exclusively, without being put through any other motion. Tracking can also occur when you remain in one position for too long, such as sitting at a desk all day.

While stretches that target specific muscles are considered best for enhancing flexibility, any activity that takes your joints through an extended range of motion will stretch the surrounding muscles. Surprisingly, weight training - done correctly - also improves flexibility at any age. One study on the effects of strength training on nursing home residents found that flexibility increased along with strength, possibly because weight training puts muscles through a full range of motion. One activity that does not enhance flexibility is running. "Runners never really go through an extended range of motion, so the muscles actually adapt to a shorter range, and flexibility decreases," Rooks explains.
Indirect muscle injuries caused by excessive force or stress on a muscle include strains, muscle pulls, and muscle tears. These injuries occur frequently in sports and result in lost training time or withdrawal from competition. Overstretching the muscle-tendon unit causes injury. Yet the nature, location, and healing of such injuries is still unclear. The general clinical thought is that torn muscle fibers are replaced by scar (connective) tissue that must not be allowed to heal in a shortened position or muscle extensibility will be lost. However, new evidence suggests that muscle regeneration may be possible.

Factors Affecting Flexibility

Joint range of motion and muscle flexibility decreases with age. The shoulder joint's range of motion decreases approximately 15% to 20% between the ages of twenty and sixty years of age, and ankle motion declines by as much as 50%. Similar changes occur in these tissues during immobilization, suggesting an accelerated aging effect.

Muscle flexibility also decreases with age, although the biochemical and structural changes that occur are unknown. Research has demonstrated that this flexibility can be regained with exercise programs twelve weeks to twenty-five weeks in duration.

Females are generally more flexible than males, at least in younger age groups. Whether these differences are maintained throughout aging is not known.
Thermal Effects

Increased temperature has a considerable effect on collagen. Temperatures above 40° C relax collagen fibers, so that less force is required to produce deformation or, alternatively, so that the same force produces more elongation.\textsuperscript{12} The most effective way to combine heat and deformation to achieve elongation is to apply them both simultaneously and to maintain the lengthened position after the heat is removed.\textsuperscript{11} These findings may be important in assessing the value of warm-up before stretching. Intramuscular temperatures may increase to 39° C with active exercise, which may influence collagen behavior.\textsuperscript{12}

Cold appears to have no effect on collagen, and thus, does not influence the mechanical components of muscle flexibility.\textsuperscript{12} Cold applications decrease muscle spasticity and may decrease muscle spindle afferent activity which may promote muscle relaxation.\textsuperscript{12} Combining cold and static stretching is more effective than combining heat and stretching in reducing muscle pain and electromyographic activity in an injured muscle within twenty-four hours of injury.\textsuperscript{22} Cold may be applied via ice packs, cold-water immersion, or vasocoolant sprays. The effectiveness of vasocoolant sprays on flexibility is unclear; they may or may not have an effect.\textsuperscript{23}

Studies on Flexibility and Injuries

Subjects with either too much or too little flexibility in the hip and low back region may be at higher risk of injury. Cowan et al\textsuperscript{24} divided subjects into
quintiles based on their sit and reach flexibility scores. Subjects in the least flexible and the most flexible quintiles were respectively 2.5 and 2.2 times more likely to get injured than subjects in the middle quintiles. On the other hand, Meeuwisse and Fowler\(^\text{24}\) found very little relationship between the incidence of hamstring strains and sit and reach values equal to or less than 5 cm.

Bauman et al\(^\text{24}\) performed a study on collegiate female athletes. Flexibility of seven lower-body joints was measured and related to subsequent occurrences of lower extremity injuries. For hip extension and flexion, statistical analysis suggested that subjects at both extremes of flexibility were more likely to suffer lower extremity injuries. This agrees with the results of Cowan et al\(^\text{24}\) regarding flexibility in the hip-low back region. However, it was found that at most other joints there was a tendency for more lower body injuries in the least flexible group.

Ekstrand and Gilquist\(^\text{24}\) measured the range of motion of four lower body joints and classified athletes as "tight" if they were two standard deviations from average on one or more measurements. Lower body strains and tendinitis were suffered by tight athletes two times more often than athletes who were not tight.

Several studies suggest right/left imbalances in hip flexibility may increase the risk of muscle strains and sprains. Data from Merrifield and Cowan\(^\text{24}\) indicate that subjects were 5.16 times more likely to suffer hip adductor strains if they had a hip adduction flexibility imbalance of 4% or more.
Knapik et al took seven lower body flexibility measures. They found that athletes were 2.6 times more likely to suffer injuries if they had a hip extension flexibility imbalance of 15% or more. Sprains and muscle strains were the most common injuries but the incidence was about equal on both sides of the body.

Benefits Derived From Increased Flexibility

1. Injury prevention: muscles possessing greater extensibility are less likely to be overstretched during vigorous activity, lessening the likelihood of injury.25

2. Reduced muscle soreness: stretching, especially after exercise, can help reduce the next-day muscle soreness that often results from a strenuous work-out.25

3. Skill enhancement: optimal flexibility aids athletic performance. Sufficient shoulder flexibility is necessary before the serve in tennis can be properly mastered. Proficient golf skills require flexibility throughout the hips, trunk, and shoulder regions.15

4. Muscle relaxation: stiff tight muscles are relaxed by easy gentle stretching.15
A warm-up and stretching are not the same thing. A warm-up is an activity that raises the total body temperature as well as the temperature of the muscles to prepare the body for vigorous exercise.

Theoretically, the following physiological changes take place during warm-up and should enhance performance:15

1. Increased muscle temperature and reduced injury: The temperature increases within the muscles that are used during the warmup. A warmed muscle both contracts and relaxes more quickly. Therefore, both speed and strength should be enhanced during exercise.

2. Increased blood temperature: The temperature of the blood as it travels through the muscles increases. As blood temperature rises, the amount of oxygen it can hold becomes reduced. This makes available more oxygen to the working muscles.

3. Improved range of motion: The range of motion around joints is increased especially if flexibility exercises are a part of the program.
(4) Reduced risk from sudden strenuous exercise: Proper warm-up will limit the amount of subendocardial ischemia when people participate in sports or sudden vigorous activity.

The major aims of a warm-up are to achieve better results in the subsequent athletic performance and to minimize the chances of incurring an injury. Methods of warming-up can be either active, with one performing muscular exercise during which metabolism increases, or passive, using massage, hot showers, warm baths, or diathermy.

Active warm-up usually consists of various physical exercises, such as stretching, jumping, and/or running. Through these exercises, an effort is made to improve the performance capacity of the locomotion and metabolic systems (general warm-up). Before participating in athletic performances demanding general concentration, steadiness, coordination, fine muscle movements, and/or skills, it is also useful to repeat important movements (specific warm-up).

In order to maximize the benefits of warm-up, one should design warm-up procedures as closely as possible to the kind of activity to be performed as well as to the individual athlete. Factors such as the exercise intensity and duration and whether the warm-up consists of intermittent or continuous exercises are important.

Physiological Effect of Warm-ups

The muscle functions as a "chemodynamic engine" that transforms chemical energy into mechanical work and at the same time produces large
quantities of heat. The increase of body temperature with exercise is due to heat production by the active muscles, and therefore, depends upon both exercise intensity and duration.

This body temperature increase improves one's performance capacity in many ways. Zunta et al mentioned the disappearance of the subjective feelings of stiffness following warm-up. When the body temperature increases, transmission of nerve impulses, nerve and muscle irritability, contractility, and power output of a muscle also increase. Many investigators have found that the mechanical efficiency (work completed/energy utilized) of a muscle improves when body temperature increases.

During warm-up, the glucose needed for starting muscular function is liberated from liver glycogen by sympathetic stimulation. If disturbances in glycolysis occur, physical performance capacity suffers. One of the factors limiting performance capacity is the final product from anaerobic glycolysis, lactic acid. Results of several studies have been published showing that subsequent to warm-up, less oxygen is needed to perform a certain amount of physical work. In addition, following warm-up VO2 max is slightly higher than during strenuous physical exercise performed without warm-up. And, during athletic performances lasting only a few minutes, VO2 max remains 5% lower if warm-up is inadequate. It can be concluded that a warm-up increases the cardiorespiratory response to exercise and decreases the exercise-induced blood lactate accumulation.
Very little scientific attention has been directed toward the effect of warm-up on ventilation. Investigators have found that oxygen is more completely dissociated from hemoglobin due to the increase of temperature in the tissues caused by physical exercise.\textsuperscript{17} This means that as a result of warm-up, the blood releases oxygen to tissues more easily.

At the starting point of a competition, the increase in heart rate is elevated by increased sympathetic stimulation caused by excitement. In experiments performed with endurance athletes, it has been observed that a warm-up causes increased heart rate, which did not return to resting values before the start of competition.\textsuperscript{17} Also, with heavy physical exercise, heart rate reached a steady rate more quickly following warm-up than without it.\textsuperscript{17}

Despite the positive effects of a pre-competition warm-up reported by numerous researchers, others have found a lack of positive effects. Chwalbinska and associates\textsuperscript{18} failed to find any change in the circulatory, ventilatory, or metabolic response to exercise regardless of whether or not warm-up occurred. Another researcher\textsuperscript{17} was unable to find any significant difference between heart rate, lactic acid, and oxygen uptake due to warm-up.

Psychological effects of warm-up receive considerably less attention than physiological ones. The reason for this is that psychological experiments are more difficult to standardize. In preparing for competition, athletes spend their time not only in achieving physical readiness, but also in concentration,
attempting to either discharge or increase their aggression. Arousal has the following effects on performance:\(^{17}\)

1. A high level of arousal is useful in sports requiring strength, speed, and endurance.
2. A high level of arousal impairs performance in sports requiring skill, coordination, and concentration, or a complex series of movements.
3. A moderate level of arousal is useful in all sports.

Cool-Downs

The purpose of a cool-down is to facilitate recovery following a maximal competitive performance. Just as a warm-up is a step between rest and maximal performance which improves the performance capacity, cool down is a step from maximal performance to rest which facilitates recovery.\(^{17}\)

A cool-down makes it possible to attain a physiological balance more quickly after competition. Maximal performances can result in the formation of lactic acid, which should be eliminated as soon as possible or subsequent performance will be adversely affected.\(^{17}\) An active cool-down has been found to eliminate lactic acid much more quickly than rest. The oxygen debt is also compensated for more quickly. Breathing oxygen, however, has not been shown to accelerate the elimination of lactic acid. A cool-down helps to relieve muscular tension after maximal strain. The muscles attain their resting length sooner, and the prolonged pains due to muscular tension may be prevented.
A cool-down may be carried out either actively or passively. Relaxed stretching and shaking of the muscles are an essential part of active cool-down. The goal is to make the muscles return to their resting length to improve their circulation and to prevent the formation of muscular hardening. After strenuous training, muscle stretching should be performed 2-3 hours later. After participation or training, the tissues are at their highest temperature. Stretching at this time has two effects. First, it will assist in further improving flexibility. Secondly, post-participation stretching will assist in decreasing or preventing muscular soreness commonly present after strenuous activity. When stretching after participation, the muscle or muscle groups to be affected should be maintained in an elongated position as the athlete "cools down." This static stretch will assist in maintaining the flexibility gained.

It can be useful to use the cool-down period to analyze the past performance part by part and to consider the possible ways of improving it. This retrospective analysis frequently helps the athlete to relax and view the performance more objectively.

Traditionally, passive procedures have been of more marked significance in cool-downs than in warm-ups. Massage, sauna, hot showers, warm baths, and diathermy do not compensate for the physiological effects of an active cool-down.

Warm-ups and cool-downs have documented physiological and psychological effects which can improve physical performance capacity and/or
facilitate muscular recovery. However, investigators of the physiological effects of warm-ups have obtained contradictory results concerning the benefits of warm-ups on performance.\textsuperscript{17,18}

There is some agreement concerning the physiological effects of warm-ups. For example, during general warm-up, the body temperature rises which significantly improves the physical performance capacity.\textsuperscript{17} Activation of the respiration and the circulation improves muscular blood flow and oxygen uptake. Oxygen is better released from hemoglobin which further improves oxygen uptake in the tissues. Muscle viscosity decreases, which results in an improvement of muscular mechanical efficiency.\textsuperscript{2} The velocity of nerve impulses and the sensitivity of nervous receptors also increases.\textsuperscript{17} The risk of injuries and cardiovascular complications decreases. All of these factors significantly improve the performance capacity.

In general, active warm-ups and cool-downs are more beneficial than passive approaches. In practice, athletes should warm-up for 1-2 hours, varying the intensity from 40\% to 100\% of the maximum.\textsuperscript{17} The average intensity of warm-ups is about 60\% of the maximum.\textsuperscript{17}

Cool-down can help relieve the physical and psychological tensions created by the competition. Active cool-down helps to facilitate physiological recovery, eliminate lactic acid, and return the muscles to their resting length.\textsuperscript{17} A cool-down also provides an opportunity to evaluate and analyze the performance.
Warm-ups are most beneficial in sports which require strength, speed, endurance, and skill.\textsuperscript{17} A warm-up is more effective the more fully the athlete believes in its effects.\textsuperscript{17}
CHAPTER VII
CONCLUSION

Static and ballistic stretching techniques have been demonstrated to increase muscle flexibility. Based on my literature review, I have concluded the following: Ballistic stretching may pose the greatest potential for microtraumatic injury. Although this method of stretching is warranted in the athletic population for gaining and maintaining dynamic flexibility, static stretching may be the most desirable stretching for most individuals. Static stretching is a part of virtually every stretching routine used either alone or in combination with ballistic techniques.

Benefits derived from increased flexibility include injury prevention, reduced muscle soreness, skill enhancement, and muscle relaxation. To improve flexibility, a stretching program should be pursued at least three times per week. In order to maintain flexibility gained, the patient should engage in his program at least one time per week, and once a stretching program is discontinued, the muscle flexibility gained will gradually be lost.

The ultimate goal of any muscle flexibility program is to increase the ability of the muscle to lengthen through the necessary range of motion. Regardless of the type of individual for whom the therapist is developing a
muscle flexibility program, the basic components of the sequence are the same: (1) a general warm-up, (2) participation in an exercise or stretching program, (3) a cool-down or post-participation period. A warm-up provides numerous positive physiological and psychological benefits. Warm-ups seem to be most beneficial in sports which require strength, speed, endurance, and skill. The effectiveness of a warm-up or pre-competition routine relies most heavily on the athlete's belief in its effects. A cool-down is necessary for a more efficient return to physiological balance following competition. The psychological process of "reliving" or objectively evaluating the performance helps the athlete deal with disappointment and loss as well as look at the positive aspects of the performance.
REFERENCES


