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Effects of stretching on jump performance: A systematic review of literature

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EFFECTS OF STRETCHING ON JUMP PERFORMANCE: A SYSTEMATIC REVIEW OF THE LITERATURE

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ABSTRACT

EFFECTS OF STRETCHING ON JUMP PERFORMANCE:

A SYSTEMATIC REVIEW OF THE LITERATURE

by Vrashank B. Dave

The purpose of this systematic review of literature was to agglomerate, summarize, and analyze the trial studies that investigate the effects of different types of stretching on the performance of different types of jumps. Only results of the studies examining the effects of stretching on jump performance were reported. The inclusion criteria were developed based on the systematic review guidelines and previous literature reviews. The search for the studies were conducted during late 2011 to early 2012 on databases such as SPORTDiscus, Web of Science, Academic Search Premier, and Medline. The studies testing the effects of the stretching on jump performance were gathered. Fifty-two studies were included in the review. The studies reviewed were determined to be of evidence level 1b as categorized by Center of Evidence-Based Practice. The static stretching, proprioceptive neuromuscular facilitation type of stretching and other stretching techniques that required the participants to hold the stretch over 20 s at a point of discomfort had a significant physiological effect – reduced H-reflex, that was counteractive to improved jump performance. The effect of dynamic stretching was similar to an active full range of motion.

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Chapter 1 Introduction

Stretching is a form of physical activity in which a muscle or a group of muscles are placed in a lengthened state by positioning the joints in the opposite direction to the action of that target muscle or group of muscle action(Weerapong, Hume, & Kolt, 2004, p. 190). Stretching is common as a part of warm up, or as a warm up itself, before a sports activity (Fradkin, Zazryn, & Smoliga, 2010; Marek, Cramer, Fincher, Massey, & Dangelmaier, 2005; Stamford, 1995; Tsolakis, Douvis, Tsigganos, Zacharogiannis, & Smirniotou, 2010; Witrouw, Mahieu, Daneels & McNair, 2004). According to Shrier (2005), the belief is that stretching will improve performance. According to Fradkin et al. (2010), the idea of performance improvement can be explained as "a concept of measuring the output of a particular process or procedure, then modifying this to increase the effectiveness of the initial process or procedure" (p.140). Stretching has been investigated for its contributions in several areas of study: (1) to reduce the chance of muscle injury (Herbert & Gabriel, 2002; McHugh & Cosgrave, 2010; Shehab, Mirabelli, & Gorenflo, 2006; Small & Mc Naughton, 2008; Thacker, Gilchrist, Stroup, & Kimsey, Jr., 2004), (2) to improve athletic performance (Papadopoulos, Siatras, & Kellis, 2005), (3) to prevent delayed onset of muscle soreness (DOMS) (Johansson, Lindstrom, Sundelin, & Lindsrom, 1999), and (4) to increase the pain-free range of motion (ROM) of the joint (Ryan et al., 2008). Before discussing the previous reviews and studies performed on stretching, understanding the fundamental physiology of stretching would augment the understanding the stretching is important.

Underlying Physiology

The sarcomere is the structural and functional unit of the muscle. The sarcomere consists of actin and myosin protein filaments. The actin and myosin filaments lie side by side and overlap in a normal resting state muscle. The overlap between the actin and myosin increases as the agonist muscle contracts. Similarly, lengthening of the sarcomere, and in turn the muscle fiber, takes place when an antagonist force is applied to the muscle. In this situation, the overlap between the actin and myosin decreases relative to the resting position. The muscle is considered to be in a stretched position (Hall & Guyton, 2011a).

The muscle is comprised of intrafusal and extrafusal muscle fibers (Hall & Guyton, 2011c). The intrafusal muscle fibers and the extrafusal muscle fibers are arranged parallel to each other. The intrafusal muscle fiber is a group of eight to ten muscle spindles innervated by γ motor neurons and they provide the proprioceptive information of muscle such as the amount and rate of change of length of muscle fiber. The function of γ motor neuron is to maintain muscle sensitivity regardless of muscle length. The extrafusal muscle fibers make up the bulk of the muscle, and are innervated by the α motor neuron. The function of α motor neuron is to generate tension by stimulating contraction of extrafusal muscle fiber. The α motor neuron and γ motor neuron are co-activated to keep the muscle spindles sensitive to the change of muscle length. The golgi tendon organ (GTO) is situated in series to muscle fibers at the junction where muscle and tendon attach the bone. The changes in muscle tension provide different degrees of pull to the tendon stimulating the GTO afferent that is supplied by β fibers.

The stretch stimulus and the stretch reflex. A stimulus is an event that produces a response in an individual. Stretching increases intramuscular tension. This stimulates the proprioceptors located in a muscle spindle. Stimulation of muscle spindles can elicit a reflex contraction of the muscle if the stimulus exceeds the reflex excitation threshold value and the reflex arc is intact. Bombardment of dormant anterior horn cells (A.H.C.s) by impulses initiated from the spindles increases central excitation and facilitates stimulation of these cells. As long as the reflex arc is intact, a response (muscle contraction) will be elicited. When a stretch is applied to weak muscles, the reflexive muscular response increases (Gardiner, 1975). Thus, stretching has been presumed to be a valuable means of initiating contraction and accelerating the muscle strengthening process.

As a function of the stretch reflex, when intrafusal or extrafusal muscle fibers are stretched, the GTO senses the degree of stretch and controls the dynamic length of a muscle (Hall & Guyton, 2011c; Smith, 1994). The spinal stretch reflex sends efferent impulses to recruit motor units to initiate muscle contraction, to prevent muscle injury from overstretching. When the stretch is held for more than 20 s, the central nervous system ceases the efferent impulse for muscle contraction. This is called desensitization. At this stage, if the stretch is released the muscle will be at this lengthened position temporarily (Gardiner, 1975; Hall & Guyton, 2011b). The muscle or the muscle group reaches the resting state after some time depending upon muscle qualities like viscosity, stiffness and succeeding activity (Viale, Nana-Ibrahim & Martin, 2007).

The sensory and motor nerves are basically classified in to three types; A fibers (which are further classified into A alpha, A beta and A delta), B fibers, and C fibers. The α and β fibers are myelineted and thicker nerve fibers and have the fastest conduction speed among other nerve fibers. The (sensory or motor) impulse travels faster in the Aα and Aβ fibers than in Aδ fibers. Fast pain signals travel through Aδ, and slow pain signals travel though C fibers, whereas the stretch reflex operates through Aα fibers. The sensation of pain at the spinal cord level transmits by balance between activities on the thick and myelineted fibers (Aα and Aβ) and less thick fibers (Aδ and C) (Hall & Guyton, 2011d). Any activity in the thicker fiber will block the sensation transmitted through the thinner fibers. Thus, the pain transmission (by Aδ and C fibers) will be blocked by the desensitized sensation of muscle at its stretched length (by Aα and Aβ fibers). This is known as stretch-induced analgesia. This process is also hypothesized to be the cause of temporary stretch-induced strength deficit (Hall & Guyton, 2011d; Viale, Nana-Ibrahim & Martin, 2007). Besides analgesia, this mechanism also affects the nerves that send afferent signals of proprioception. This causes an altered sense of proprioception until it returns to the resting state.

Neurophysiological response of muscle to stretch. The thickest nerve fibers within a muscle are Iα-afferents that originate from muscle spindles. As the stretch of a muscle increases, the strength of the stimulation also increases. The first fibers to response will be Iα-afferents. These fibers travel from muscle spindles into the spinal cord and make monosynaptic connections with α-motor neurons innervating the muscles that contain the spindles. A burst of activity in an Iα-afferent fiber may be expected to induce a monosynaptic reflex contraction of the muscle. When this reflex is induced by electrical stimulation of the muscle nerve, it is called an H-reflex (Latash, 1998).

When a stretch reflex is activated in an agonist muscle, reciprocal inhibition may occur. Reciprocal inhibition is the decreased muscular electrical activity (inhibition) in the antagonist muscle group of the joint. The GTO monitors tension in muscle fibers being stretched and has an inhibitory impact on muscle tension in the muscle-tendon unit in which it lies, particularly if the stretch is prolonged. This effect is called autogenic inhibition. Although facilitating reciprocal inhibition may be a mechanism to improving muscle extensibility, it is more likely that tensile stresses applied to noncontractile connective tissue in and around muscle is the major factor for improving muscle extensibility (Kisner & Colby, 2007).

The current state of knowledge concerning stretching. The purpose of this section is to summarize the current state of knowledge concerning stretching as presented in previous reviews of literature. Smith (1994) reviewed the research related to stretching to understand the role of stretching in warm up. From this review, Smith (1994) concluded that stretching increases flexibility by increasing the length of the muscle for a short period of time. Smith (1994) also concluded that stretching in warm up could increase joint range of motion (ROM), decrease chance of injury, relieve delayed onset of muscle soreness and reduce the chances of recurrence of the injury. The purpose of the review by Shrier and Gossal (2000) was to compare the effect of different methods, frequency and duration of stretching. The researchers concluded that stretch-induced analgesia reduces musculotendinous stiffness and temporarily increases the ROM of the joint after holding the stretch for 30 s. Shrier and Gossal (2000) also concluded that long-term benefits of stretching could be achieved by regularly following a 10-s stretch-hold protocol. The purpose of the review of literature by Deyne (2001) was to discuss changes caused by passive stretching at a cellular level and to propose a mechanism of action for the same. The researcher concluded that stretching triggers interlinked processes at the biomechanical, molecular, and neurological levels. Yet another review conducted by Harvey, Herbert, and Crosbie (2002) sought to determine whether stretching has a lasting effect on ROM. They determined that ROM of the joint increases at least for a day after stretching. However, the study did not conclude how long the effect of stretching lasts. The purpose of the review by Thacker, Gilchrist, Stroup, and Kimsey, Jr. (2004) was to determine if stretching reduces the chances of injury. The results of the review by Thacker et al. (2004) suggested there was no direct evidence that stretching helps reduce the incidence of injury. However, these researchers purported that regular bouts of stretching can indirectly help in reducing the incidence of injury. Witrouw et al. (2004) conducted a review of literature to determine the effect(s) of stretching in injury prevention. The researchers explained several mechanisms that would help in preventing injury; however, they concluded there are not enough studies that support the idea that stretching reduces the chances of injury. They also concluded that stretching makes the muscle more compliant, however, the effects of compliant muscles in the sport performance are inconclusive since explosive activities require higher intensity of stretch shortening cycle of the muscle than low intensity activities such as jogging, swimming. A flexible muscle can achieve more stretch shortening cycle as compared to less flexible muscle. Likewise, low amplitude activities require a low amplitude stretch shortening cycle. Considering that concept, Witrouw et al. (2004) proposed that athletes participating in sports that require explosive activities should perform stretching of relevant muscles directly prior to the sporting event. The purpose of the review of the literature by Decoster, Cleland, Altieri, and Russell (2005) was to determine the most effective stretch positioning, optimal duration of stretch hold, and optimal technique to improve the flexibility of hamstrings. The researchers found that static stretching and slow-reversal-hold, which is a type of proprioceptive neuromuscular facilitation (PNF) stretching, have similar effects on ROM when held for 30 or more s. The researchers also concluded that regular daily stretching is more beneficial than stretching immediately before the activity. Woods, Bishop and Jones (2007) performed a review of literature to understand (a) the effects of regular stretching and warm up on chances of injury to the muscle during physical activity and (b) its effects of stretching on the musculotendinous unit. The researchers concluded that stretching applied for longer periods would help flexibility. Kovacs (2006) argued that stretching before physical activity reduces the power production and speed of muscle contraction, and that stretching does not help in reducing the risk of muscle or ligament injury. The purpose of the review by Small, McNaughton, and Mathews (2008) was to understand whether the inclusion of stretching in the warm up helps reduces incidence of injury. The researchers confirmed that stretching helps in preventing muscle strains, and ligament sprains. The results were inconclusive for various other types of injuries. Herbert and Gabriel (2002) sought to understand whether stretching before or after exercise affects the delayed onset of muscle soreness and to document the role of stretching in decreasing the chances of injury and improving the performance. The researchers concluded from a review of five studies that stretching does not prevent injury, does not prevent delayed onset of muscle soreness, nor does it improve performance. A systematic review (Shrier, 2004) examining the effect of stretching on performance concluded that stretching immediately prior to performance of a sports activity has a detrimental effect on the performance. The review included the studies that utilized tests of performance such as isometric force, isokinetic torque, and jump height. McHugh and Cosgrave (2010) reviewed literature to understand the effects of stretching to prevent injury and its effect on performance. The researchers concluded that acute stretching before sports activity will reduce force production. The stretch-induced strength reduction is less if the stretching is combined with some pre-participation activity or warm up. Rubini, Costa, and Gomes (2007) reviewed literature to understand the acute and long-term effects of stretching-induced strength deficit and explored the mechanism behind it. The researchers found that that the protocols for stretching used in the studies they reviewed were not consistent and therefore suggested further studies in this area.

Problem Statement

In previous reviews of literature, the following problems were identified:

1. The parameters of different types of stretches are not well defined. For example Tsolakis et al. (2010) performed an experiment on ballistic stretching but the commands or directions for the ballistic stretching were exactly the same as dynamic stretching used by Hough et al. (2009), Yamaguchi et al. (2007) and Fletcher (2010).
2. The time of stretching and the limit to which the muscles were stretched were not clearly specified. For example, Behm and Kibele (2007)

mentioned the muscles were held in stretched position for 30 s each to a point of discomfort (25%, 50%, 75%, or 100%). Whereas Yamaguchi et al. (2007) used a different way of describing the stretches and never mentioned the time period for holding the stretch.

3. The studies have varying protocols, which may influence the effect of stretching on performance. Hence, the effects of an “isolated act of stretching” (Shrier, 2005) have not been examined. What have been studied are the effects of stretching with warm up or protocols containing stretching with different physical activities related to the sport. For example, McMillian, Moore, Hatler, and Taylor (2006) and Christensen and Nordstrom (2008) have stretching as a part of warm up as they were exploring the effects of different warm ups on performance, whereas Papadopoulos et al. (2005), Marek et al. (2005), Hough et al. (2009), Cronin, Nash, and Whatman, (2008) incorporated pre-stretching warm up of some sort, to learn the effects of stretching. The results of these studies were without true baseline readings as the researchers made their baseline measurement after a warm up, which is a form of stretching. Ross (2005) performed a study to learn the effects of stretching but never compared it to a control condition to explain the difference between the stretching group and a non-stretching group.

4. In a review of effects of stretching on ROM by Decoster et al. (2005), it was concluded that it is not possible to specifically determine the effect of

stretching since all the previous reviews of literatures have utilized different variables of stretching. The different stretching variables included the position assumed to stretch the same group of muscles, stretch duration times for the same stretching maneuver, and stretching techniques.

While many aspects of stretching have been researched and reviewed in the literature, no previous review of research on stretching has examined the specific effect of stretching on vertical or horizontal jump performance. The previous reviews on stretching studied the effect of stretching on risk of injury (Woods, Bishop, & Jones, 2007; Herbert & Gabriel, 2002; Shehab, Mirabelli, & Gorenflo, 2006; Thacker et al., 2004), delayed onset of muscle soreness (Herbert & Gabriel, 2002), isokinetic torque (Magnusson, 1998; Shrier, 2004), 10m sprint (McHugh & Cosgrave, 2010), running speed (Shrier, 2004; McHugh & Cosgrave, 2010), generalized performance (Herbert & Gabriel, 2002), ROM (Harvey, Herbert, & Crosbie, 2002), strength performance (Rubini, Costa, & Gomes, 2007) and isometric force (Shrier, 2004).

Statement of Purpose

The purpose of this research was to review the effects of different types of stretching on vertical and horizontal jump performance. The issues of defining stretching techniques, when to stretch (i.e., before or after sport activity), the limit to which muscles should be stretched, the stretch duration, and the effect of different stretching protocols on jump performance were addressed.

The effects of stretching were studied in terms of performance in jumping because the jump represents the work done as a synchronized activity of the neuromuscular system. Most recreational or professional sport activities require power and agility as two of the major components amongst all other components related to performance (Shrier, 2004). According to Gonzalez-Rave, Machhado, Navarro-Valdivielso, and Vilas-Boas (2009), the vertical jump is a reliable test in professional players as well as the recreationally active population. The vertical jump assessment can also provide information on the force production capacity of the extensor muscles of the lower limbs. To jump higher, or a longer distance, a combination of neurological stimulus and strong muscular action components is required (Alpkaya & Koceja, 2007; Behm & Kibele, 2007; Elliott & Worthington, 2001).

Hypotheses

It was hypothesized that the review of the literature would reveal the following, that:

1) Acute bouts of stretching held for 30 s or more per stretch are detrimental to the jump height/distance.
2) Regular participation in a stretching protocol may produce some changes in physiological characteristics (increase in blood supply, increase in motor units recruitment, increase in length of muscle, hypertrophy of the muscle, etc.) of the muscles that undergo are stretched.

3) These physiological changes may lead to improvement in jump performance following at least six weeks of regular stretching protocol (vertical height, horizontal distance, motor unit recruitment, muscle activity as recorded by EMG, etc.).

Limitations

The inclusion and exclusion of the articles in this systematic review of literature were selected without blinding for author names or institutions or journal published. This has been considered as a source of bias in selection of literature for the review (Decoster et al. 2005). The inclusion of the articles was limited to those that analyzed the effects of stretching on human participants. The scholarly papers published in academic or professional journals were limited to the trial or experimental studies, and not the papers proposed only mechanisms of stretching. It was assumed that the studies that were identified for this systematic review of literature appropriately analyzed their data. Studies investigating the effect of stretching on patients with contracture or other pathology were not included. The final limitation of this review was that only the effect of stretching on jump performance was investigated and not all the other dependent variables that could measure force production such as sprinting, isokinetic torque, or isometric force production.

Delimitations

The studies included in this systematic review included stretching only of several groups of muscles (e.g., hamstrings, gluteals, quadriceps or plantar flexors). These studies investigated the stretching of muscle groups of individual muscles of the lower limbs and determined the effect of stretching on that muscle or muscle group during jump performance. Only studies published in English will be included. Studies investigating the effect of stretching on dependent variables other than jump performance were included, but only the result(s) related to jump performance were included in this systematic review of the literature.

Operational Definitions

1. Ballistic stretching: "Ballistic stretching involves repetitive bouncing movements in the muscle's lengthened position" Smith (1994, p. 14). Ballistic stretching is high in amplitude and low in duration.
2. Compliance: "To fully understand the effect of compliance we need to appreciate the difference between the active contractile (muscle) component and the passive (tendon tissue) component of the muscle-tendon unit. According to Witvrouw et al. (2004, p. 445), the ability of a muscle to absorb energy is dependent on both components. In a compliant system when the contractile elements are active to a high level, more energy can be absorbed by the tendon tissue, thereby reducing trauma to muscle fibers. However, in case of a low compliance of the tendon, forces will be transferred to the contractile apparatus with little

energy absorption in the tendon". Compliance is the quality of the tissue to yield pressure without disruption of structure or function (Elizabeth, 2010). Compliance is inversely related to stiffness.

3. Counter-movement jump (CMJ): CMJ is defined as a jump that "started with fully extended knee then flexed it eccentrically after which the vertical jump took place" Dvir (1985, p. 15).
4. Delayed onset of muscle soreness (DOMS): DOMS is defined as "exercise-induced muscle tenderness or stiffness that occurs 24 to 48 hours after vigorous exercise" Kisner and Colby (2007, p. 890).
5. Drop jump (DJ): Drop jumps is a jump that "initiated the eccentric flexion in knee by first jumping down from a bench 20cm to 100cm high (flexion was assisted by the ground reaction force)" Dvir (1985, p. 15).
6. Elasticity: "Elasticity implies that the change in the muscle length is directly proportional to applied load" Smith (1994, p.14). This ability of the muscle to lengthen in response to a load or stimulus and contract back to the resting position is called elasticity.
7. Myofibrillogenesis: "To explain whether the stretched muscle fiber ultimately leads to longer muscle fiber with more sarcomeres in series (myofibrillogenesis), signal sensing, signal transduction, and subsequent gene transcription must take place, resulting in sarcomere assembly" Deyne (2001, p. 822). Myofibrillogenesis is a developmental process at the end result of which adult muscular system is developed. The process

included the events in the following order: differentiation of difference muscle cell precursors, migration of myoblasts, activation of myogenesis, and development of muscle anchorage ("Medical conditions: Online," 2011).

8. Nociceptors: Nociceptors are a type of sensory receptors neurons that sense the painful stimulus Hall and Guyton (2011d, p.559). The process of transmitting the painful, potentially damaging stimulus to the brain via fast transmitting neuronal network is called nociception Fein (2012, p.5).
9. Passive stretching: Passive stretching is a "type of mobility exercise in which manual, mechanical, or positional stretch is applied to soft tissues and in which the force is applied opposite to the direction of shortening" Kisner and Colby (2007, p. 895).
10. Passive torque: "Resistance to stretch was defined as the passive torque offered by hamstring muscle group during passive knee extension using an isokinetic dynamometer." Magnusson (1998, p. 67).
11. Post activation potential (PAP): PAP "is defined as an excited or sensitive neuromuscular condition, following intense loading" (as cited by Fletcher, 2013, p. 6).
12. Proprioceptive neuromuscular muscular facilitation (PNF) stretching: "Proprioceptive neuromuscular muscular facilitation is an approach to the therapeutic exercise that combines functionally based diagonal patterns of movement with techniques of neuromuscular facilitation to evoke motor

responses and improve neuromuscular control and function." Kisner and Colby (2007, p. 195).

13. Static stretching: "Static stretching implies a slow stretch to the muscle held for 6-60 s. With the slow build-up in tension, the inverse stretch reflex is involved, which induces relaxation in the muscle ad enables further stretching and increases flexibility." Smith (1994, p. 14). "Static stretching usually involves moving the limb to the end of its range of motion (ROM) and holding the stretched position for 15-60 s" Behm and Chaouachi (2011, p. 2633) and Norris (2013, p. 20).

14. Static jump: A static jump is the one "for which the starting position was that of an isometric knee flexion of about 90°" Dvir (1985, p. 15).

15. Stress: Stress is " load or force applied to a tissues per unit area" Kisner and Colby (2007, p.895).

16. Stress-relaxation: "Muscle offers less resistance to the passive stretching increases its capacity of distending when muscular compliance increases. This phenomenon is called stress-relaxation" Rubini, Costa and Gomes (2007, p. 219). This process causes a decrease in muscle tension.

17. Stretch reflex: "The musculoskeletal system has an inherent built-in protective device made up of the muscle spindle and GTO, which are highly sensitive receptors acting to prevent overstretch of the passive joint structures and muscle tendon unit respectively. The muscle spindle

is attached to the intrafusal and extrafusal muscle fibers and is sensitive to active or passive stretch of the muscle. The receptors detect the degree of stretch applied to the muscle and control its dynamic length via the stretch reflex." Smith (1994, p. 14). The reflex contraction of the muscle when the tendon of that muscle is stretched is called a stretch reflex.

18. Stretching: A muscle can be considered in a stretched position when the overlap between actin and myosin is minimal. "Stretching is an intervention, which puts tension on the soft tissues" Harvey et al. (2002, p. 2). Stretching is "any therapeutic maneuver designed to lengthen (elongate) pathologically shortened soft tissue structures, thereby increasing the range of motion" Kisner and Colby (2007, p. 895).
19. Stiffness: "Stiffness is defined by force required to produce a given change in length" Shrier and Gossal (2000, p.1). In a stiffer system, more force is required to cause a change in muscle length as compared to less stiff system.
20. Viscosity: Viscosity is a measure of the resistance of fluid when deformed by tensile stress or shear stress. The term viscosity is used to describe the thickness or internal friction of a substance. For example, water is thin and has lower viscosity, whereas honey is thick and has high viscosity (Symon, 1971).

21. Warm up: Warm up can be defined as, “a defined period of preparatory exercise to enhance subsequent competition or training performance” Fradkin et al. (2010, p. 140). A warm up is a bout of exercise performed preceding an exercise protocol in order to increase blood circulation, release muscle tension and increase awareness (Jonas, 2005).

Chapter 2 Literature Review

The purpose of this review of literature was to summarize the previous reviews of literature on the effects of stretching. The abstract of the reviews in this chapter includes information pertinent to the purpose of this study. Stretching is purported to reduce the risk of injury (Herbert & Gabriel, 2002; Small et al. 2008; Thacker et al., 2004; Witvrouw et al. 2004; Woods et al. 2007), reduce soreness (Herbert, & Gabriel, 2002) and increase joint ROM (Decoster et al. 2005).

Smith (1994) reviewed previous research to understand if stretching should be included as a part of warm up. The researcher did not mention the source and the criteria of the studies included in the review. Smith assembled the review using the following groupings: the benefits of stretching, applied physiology to explain the stretching, different stretching techniques used in the literature, duration and frequency of stretching, and finally, proposed suggestions on how to stretch. Smith found that stretching improves flexibility by temporarily increasing the length of the muscle, increasing ROM of the joint, decreasing chances of injury, relieving delayed onset of muscle soreness, and also reducing the chances of recurrence of injury, if stretching was included as part of rehabilitation. Smith's results were inconclusive regarding the effects of stretching and flexibility on energy expenditure during sport or exercise. Smith suggested that the load applied during the stretch is proportional to how much the musculotendinous unit stretches. Maximal results are achieved when small loads are applied for longer periods of time. Higher loads applied for shorter periods may lead to injury. This theory is also supported by the theory that suggests the muscle has elastic properties. Questions regarding the stretching frequency and daily repetitions were inconclusive in the review. Smith suggested that a stretching protocol should be created and performed a minimum of 15 to 20 mins before the sporting activity. Slow static stretches are preferred over the ballistic “bouncy” stretching. Smith suggested holding the stretch for 15 to 20 s and repeating it three to five times for maximum benefits. Stretching should be performed at least 15 to 20 mins before exercise and after the exercise. The activity of stretching should be performed year round to improve and maintain flexibility, as flexibility is one of the key factors in preventing injury. To avoid imbalance between the agonist and antagonist muscle groups, Smith suggested stretching both muscle groups. Stretching should be enjoyed, so that it becomes something that one wants to do regularly and not something one has to do (Smith, 1994).

Shrier and Gossal (2000) reviewed articles that compared the effectiveness of different methods and frequencies of stretching that were cited in MEDLINE and SPORTDiscus. The purpose of this review of literature was to determine three things: (1) how many times does one have to perform stretching and the duration of each stretch to achieve the maximum benefits in the sport activities; (2) does temperature affect stretching; and (3) what is the most effective method of stretching (static stretching, ballistic stretching or PNF stretching). These researchers did not include studies that investigated the effects of stretching on pathology or disordered muscles. To answer the duration and frequency of the stretching protocol question, the researchers found that the immediate effects of stretching a muscle or muscle group for a duration of 30 s temporarily reduces musculotendinous stiffness and increases ROM by inducing stretch-induced analgesia. The stretch-induced analgesia may also be the reason for increased stretch tolerance. The long-term effects of stretching would be similar after a regular stretching routine performed for 10 weeks. This would be applicable for most people ranging from athletes to the recreationally active. Shrier and Gossal (2000) suggested that applying ice or heat decreases pain and increases in ROM. The increase in ROM is because of the analgesic effect of ice or heat application. The ice or heat increases the stiffness of the muscle. Application of the heat or ice to the muscle, along with stretching in the initial stages, would help when the muscle is tight. After the muscle reaches a state of flexibility, applying heat or ice will help in decreasing pain, which would help in stretching the muscle further, but also increase the stiffness. The researchers also found that, out of the PNF stretching (agonist-contract-relax and contract-relax), the ballistic stretching, and the static stretching; the PNF stretching technique is more effective in achieving ROM. According to Shrier and Gossal, PNF stretching is the most effective way to stretch, if the goal is to increase the ROM. Between the two types of PNF stretching, contract-relax helps in achieving more ROM as compared to isometric hold-relax. The continuous static stretching is the second most effective way to increase the ROM, followed by ballistic stretch bounces. The added benefit of static stretching is ease in stretching when alone.

Deyne (2001) discussed the effects of passive stretching on muscles at a cellular level. The purpose of this literature review was to explain the physiological mechanisms of stretching. Deyne suggested that stretching a muscle stimulates biomechanical, neurological and molecular processes. The stretching force is transmitted through the protein-protein chain, which stimulates myofibrillogenesis. Deyne proposed three theories as to what may happen following myofibrillogenesis (increase in the sarcomeres leading to increase in the length of muscle fiber): (1) the cytoskeletal molecules and the muscle protein may undergo phosphorylation (addition of a phosphate group to the organic molecule or a protein structure (Guyton & Hall, 2000), (2) selective growth hormone controlled by paracrine or exocrine regulation may be secreted, or (3) the channels activated by the stretch may lead to influx of ions. Deyne did not explain the ion influx. However, Viale, Nana-Ibrahim & Martin (2007) suggested that during stretching when the length-tension property of the muscle is altered, the sodium-potassium pump is activated. This pump leads to change in the polarity of the muscle until it returns back to resting state. These researchers suggested that the increase in the ROM is related to changes at the cellular and molecular levels of the muscle fiber.

Herbert and Gabriel (2002) reviewed the effects of stretching before and after exercise on delayed onset of muscle soreness. They also studied the effect of stretching on decreased risk of injury and improving performance. The researchers decided the strategy for reviewing the literature prior to initiation of the review. The researchers used the following databases: Medline from 1966 to February 2000, CINAHL from 1982 to January 2000, SPORTDiscus from 1949 to December 1999 and PEDro to February 2000. Only randomized or quasi-randomized studies from these searches were reviewed. There were five studies that examined the effects of stretching on DOMS in the pool of the studies reviewed. These studies suggested that there was no or minimal effect of stretching on DOMS. They also showed that stretching, prior to exercise, does not prevent or reduce the incidence of injury. The researchers did not mention any results regarding the effects of stretching on improving movement performance.

Harvey et al. (2002) performed a systematic review of literature to determine whether stretching has lasting effects on ROM. The researchers examined studies that researched the effect of at least one day stretching. The researchers searched the following electronic databases: MEDLINE from June 1966 to 2000, EMBASE from 1988 to 2000, OVID search and Cochrane. They included studies, which involved stretching by application of splints and casts, and they also included studies examining duration, frequency and manual stretching of any intensity. The studies were delimited to randomize the distribution of the participants to be included in the review. Lastly, the studies were also refined to report the effect of stretching in terms of ROM, flexibility, or compliance one day after the last stretch protocol. Researches published in languages other than English, and unpublished studies, were not included. Thirteen studies were included and classified based on the quality of their methods and analysis. The PEDro scale was used to assess trial quality. PEDro scale is a 10-point scale that is developed to rate the trial studies. The researchers found that one-day after the completion of stretching there was increased ROM by 8°. The conclusion was derived from medium and poor quality studies. There were no high quality studies as per the PEDro scale measures. The researchers failed to discuss the effect of stretching after duration longer than one-day post last stretching bout.

Shrier (2004) performed a review of literature to determine whether stretching helped improve performance. Shrier included all studies investigating stretching and performance identified from searches in MEDLINE and SPORTDiscus. The review consisted of 23 studies. The review of literature included studies that tested running speed, jump height, isometric force or isokinetic torque. Shrier found that performing regular stretching routines improves the speed of the muscle contraction and generation of isometric contraction force. This research also suggested that visco-elasticity of the muscle and tendon put under a stretch was inhibited which lead to reduced stiffness of the musculotendinous unit. The reduced stiffness resulted in decreased energy consumption to move the muscle. In light of this knowledge, the researcher proposed that it might be the cause for reduced economy for running after stretching. Reduced economy of running results in less energy to do the same amount of work. The researcher concluded that stretching damages muscle fibers. Shrier explained that muscle stretches of as low as 20% of the resting length of the muscle fiber cause damage to the sarcomere. Hence the acute detrimental effect can be understood. Neverthless, engaging in regular stretching is claimed to improve athletic performance (Shrier, 2004).

Thacker et al. (2004) performed a systematic review of literature to determine the efficacy of stretching on reducing chances of injury. The researchers searched the following electronic databases: MEDLINE from 1966 to August 2002, Current Contents from 1997 to August 2002, Biomedical Collection from 1993 to 1999, and Dissertation Abstracts in all the languages from MDConsult, Cochrane Library, and SPORTDiscus. They then performed a meta-analysis on studies that conducted randomized control trials. Thacker et al., (2004) found 361 studies comparing the effects of passive stretching, static stretching, ballistic stretching, isometric contractions, and PNF stretching. Six studies out of 361 studies, which examined the effects of stretching on reducing the risk of injury with the control of randomization and blinding in their method were included for the review. The researchers decided a set of variables to measure the quality of the study to be included. The set of variables checked the experimental design, data presentation and statistical analysis. The maximum score for a good study was 100. The qualified studies were analyzed based on the high versus low quality score for the meta analysis. Two part results were drawn: effect of stretching on injury reduction and effect of stretching on flexibility. A static stretch for 30 s is the most effective for improving flexibility. The improved flexibility after the stretch remains for 6 to 90 mins. A regular stretching protocol may be more effective in improving the effects than an acute bout of stretching. According to the research, detrimental effects from stretching included, (1) a temporary strength deficit (2) decreased jump performance, (3) increased running economy and (4) increased arterial blood pressure and decline in performance. The researchers did not find evidence that would suggest that stretching helps in preventing injury. Initially they concluded that more quality evidence is required to help determine if stretching pre or post activity is beneficial to enhance the performance.

Witvrouw et al. (2004) reviewed experimental research regarding stretching to understand its effect on preventing injury. The process of data collection and analysis of the data was not shared in the paper. The researchers explained the relation between stretching and movement and proposed an underlying mechanism for the same. The proposed mechanisms were supported by the studies they reviewed. The researchers discussed the mechanisms that take place in the functional unit of the muscle during the stretching movement. The researchers explained that, during stretch-shortening movements such as hopping and jumping, the energy for the movements, which involve stretch-shortening movement like jumping, comes from the elastic recoil property of the muscle. When a muscle is elongated before it is activated, the muscle contraction will be stronger. During the eccentric phase of the stretch-shortening cycle, energy is stored. This energy is used during the concentric phase to increase muscle output. The researchers suggest compliant muscles perform strong eccentric movements. Therefore, activities that require high intensity stretch shortening contractions require more compliant muscle units. The researchers concluded that their literature review is inconclusive in determining if stretching prior to activity can prevent injury or not. However, based on the compliance property of the muscle and review of the studies, they suggested that it would be prophylactic to stretch prior to activity that involves a high rate of stretch shortening of the muscle. Stretching would make the tendon more prepared to absorb energy for the high stretch shortening movement like jumping and hopping. Activities such as jogging and cycling were considered movements with low or no stretch shortening cycles.

Decoster et al. (2005) reviewed studies to determine the best positioning, duration, and techniques to stretch and improve the flexibility of the hamstrings. To identify the literature pertinent to their review the researchers searched MEDLine from 1966 to November 2004, the Cumulative of Nursing and Allied Health database from1982 to November 2004, SPORTDiscus from 1949 to November 2004, and Embase from 1988 to November 2004. The studies with randomized controlled trials and quasi-experimental studies, which included hamstring stretching, were eligible to be included in the review. The studies reviewed were rated using the PEDro scale, a 10-point scale. Studies reporting ROM at knee or hip with healthy subjects ranging in age from 14 years old to 60 years old were included. The studies used various positions to stretch hamstrings but all the positions helped to significantly improve the ROM when compared to the control group. Hence, all the positions to stretch the hamstrings mentioned by the reviewers are acceptable. The reviewers noted that static stretching resulted in more than twice the range gained when compared to dynamic stretching. The reviewers did not find any difference in gains of ROM when static stretching and PNF (slow-reversal-hold) stretching technique were compared. The researchers noted that a stretch held for 30 or more s once per day was more effective than holding stretches for 15 s once per day. The warm-up without stretching did not improve hamstring flexibility as much as warm up combined with stretching. The researchers provided a systematic method of collecting and summarizing results, but they did not discuss the effects of stretching on improvement in performance.

Kovacs (2006) presented an argument with evidence as to why static stretching should be avoided with warm up or before participating in sports or physical activity. The researcher claimed that stretching within an hour before the physical activity reduces joint ROM, decreases muscle strength, and over all impairs performance. Stretching before the physical activity does not decrease the chances of injury. However, Kovacs suggests that trainers and coaches should teach athletes to stretch their muscles regularly at a time unrelated to sport participation. This will have more benefits compared to stretching right before sport activity. The researcher suggested that, after a sport specific warm up, no stretching should be performed before the performance.

Rubini et al. (2007) reviewed literature to determine the effects of stretching on strength performance and reviewed the underlying mechanisms of stretching. The research articles were collected from the following article databases: MEDLINE from 1966 to 2006, EMBASE from 1974 to 2006, Cochrane Database of Systemic Reviews from 1993 to 2006, Lilacs 1982 to 2006, and SciELO from 1997 to 2006. The researchers briefly mentioned the criteria for the inclusion of the studies. The inclusion criteria were: the study had to be in English, Portuguese or Spanish language and it should mention the acute effects of stretching of stretching on any strength determinant. Rubini et al. found that with stretch duration of 120 s up to 3600 s led to decrease in 4.8% to 28% strength (isometric, isotonic, or isokinetic strength). The findings relevant to jump performance were derived based on information from the review of studies. They found that a stretching bout reduces the strength production of the muscle. Hence, stretching reduces jump performance. There are conflicting results in different studies, but it might be the result of studies using different stretching techniques. There are few studies that have tested the chronic effects of stretching on jump performance. Chronic stretching studies in animals have shown to increase muscle size. The researchers discussed neurological adaptation, structural adaptations, cellular adaptations, and hormonal adaptations, which may be caused by stretching. The neurological adaptation of muscle observed by the researchers was the stress-relaxation effect and activation of nociceptors with activation of the GTO to inhibit α motor neuron. The alteration of neurological properties of muscle may lead to change in viscoelastic properties of muscle. These changes in viscoelastic properties of muscle lead to the structural adaptation of the muscle. The stretch exercise makes the muscle less viscous. A less viscous muscular state facilitates actin and myosin filament sliding. To confirm this concept, the researchers suggested future studies with chronic stretching. The researchers reported the cellular adaptation following stretching. The researchers also reported that after stretching muscles for 24 hours per day for up to 30 days increases in hypertrophy for muscles in animal studies were found. In human studies the results suggested that there was evidence of myofibrillogenesis. The researchers assumed that stretching for longer periods stimulates protein synthesis. Gold-spink et al. (1995), found that hormonal adaptation of stretching for various durations in various positions causes increase in insulin-like growth factor and messenger ribonucleic acid (mRNA). These findings resulted in a study using mice as subjects. Nevertheless, the findings infer that stretching can cause hypertrophy of muscles. The researchers concluded that at the time of recommending a stretching protocol, one should consider the type of sport, duration of each stretch, and number of sets that should be performed.

Woods et al. (2007) reviewed the effects of warm up and stretching on muscular injury when engaging in any type of physical activity. The researchers also studied the effects of regular warm up and stretching on the musculotendinous unit. The researchers did not specify their sources or the criteria for their search and selection of the literature. However, these researchers mentioned that the warm up helps create a quick and smooth muscle contraction by raising the temperature of the muscle and reducing the viscosity of the muscle's functional units. The increase in internal temperature is because of the vasodilation of arteries in active muscles and organs. The researchers classified stretching into three types: static, dynamic, and PNF stretching. The researchers found that three repetitions of static stretches, held for 30 s, increasing intensity based upon participants' perception, increases muscle length. The researchers also found that the increase in the muscle length lasted for 24 hours post static stretching intervention. The researchers also found that regular stretching helps improve flexibility and the benefits are observed by applying low loads of stretch for longer periods of time. In general, warm up has shown to decrease the chances of injury during a sports activity.

Small et al. (2008) performed a systematic review of research to understand the effectiveness of stretching during warm up to prevent injury during sport. The researchers used MEDLINE, SPORTDiscus, PubMed and ScienceDirect databases to locate studies pertinent to the review. They included research examining the effect of stretching on reducing the risk of injury. Out of

364 studies located, only 4 studies passed the researchers' rigorous inclusion criteria. All four studies showed that stretching reduced sprain and strain injuries. The evidence was inconclusive for other types injuries.

McHugh and Cosgrave (2010) performed a literature review to analyze the effect of stretching on injury prevention and improving performance in sports. The researchers did not mention the source or criteria for selecting the studies for the review. Most of the studies were conducted to determine the effect of static stretching, dynamic stretching, or PNF stretching. The researchers explained that after stretching, EMG signals become weak indicating that the neural connection with the muscle contraction weakened after a single bout of stretching. The researchers also indicated that, because of the stretch induced strength loss, there is no benefit of stretching before physical activity. However, because of insufficient evidence, and the medium quality of the available evidence, it is difficult to provide a definitive conclusion regarding the effect of stretching on performance. The authors concluded that stretching increases the joint ROM, though they did not indicate how it helps in prevention of injury.

Kay and Blazevich (2012) performed a systematic review to determine the acute effects of static stretching on maximal performance. The researchers followed the PRISMA guidelines to perform their review. Kay and Blazevich used centralized search software, MetaLib. MetaLib searched MEDLINE from 1966 to 2011, ScienceDirect from 1823 to 2011, SPORTDiscus from 1985 to 2012 and Zetoc from 1993 to 2011. The researchers identified the articles from the abstracts of the studies in the search results. The full articles that were eligible for the systematic review were retrieved from the search results. Original studies were selected, if the study was determining acute effects of static stretching on maximal muscle performance. Any study measuring strength, power, and speed dependent activity was considered measuring maximum muscle performance. Studies conducting randomized or quasi-randomized trials that matched the PEDro inclusion criteria were included in the review. The PEDro inclusion criteria were, 1) the study compared at least two interventions, 2) the compared interventions were used as a maneuver in physical therapy practice, 3) the study was performed on human subjects, 4) the intervention was used randomly on the participants in the study, and 5) the article was available as full article in an peer reviewed journal. Two reviewers read all the articles for inclusion or exclusion with conflicts resulting in discussion. Stretch duration, muscle groups stretched, maximum muscular muscle performance results, whether the changes were significant or not within less than 20 min of stretching, mean reduction in performance, and measure taken towards control and reliability data were summarized by one reviewer. The second reviewer reviewed the abstracts. The total count of studies initially located totaled 4559. Only106 studies were met criteria for inclusion and reviewed. The mean quality of study methodology was calculated to 5.4±0.9 points in PEDro 10 point scale. Kay and Blazevich reported that many studies did not have a control group. This raised a serious concern regarding the quality and validity of the results. The authors concluded that, according to 55% of studies, acute stretching caused significant reductions in strength, power, or speed related performances. According to 69% of the studies, acute stretching did not create significant reductions in strength, speed or power related performances. The difference in the percentages reported was because of many studies reported more than one parameter in the same study. Out of 106 studies reviewed, only 10 studies mentioned the duration of stretch hold. According to nine out of the ten studies, where participants were instructed to hold the stretch for less than 30 s for each muscle, no significant reduction in performances resulted. Only one study concluded significant reductions in 20-meter sprint velocity. Kay and Blazevich concluded that static stretching held for less than 45 s could be safely used before the strength, power or speed related performances without any detrimental effects on performance. Stretches held for more than 60 s may be moderately detrimental to performance.

Summary

Smith (1994) reviewed the literature to determine if stretching should be included as a part of warm up. The results from the review by Smith suggested that stretching improves flexibility by temporarily increasing the length of the muscle, increases ROM of the joint, decreases chances of injury, relieves delayed onset of muscle soreness, and also reduces the chances of recurrence of injury, if stretching was included as part of rehabilitation. The results were inconclusive regarding the effects of stretching and flexibility on energy expenditure during the sport or exercise. Shrier and Gossal (2000) reviewed articles that compared the effectiveness of different methods and frequencies of stretching. They found that the immediate effects of stretching a muscle for duration of 30 s temporarily reduced musculotendinous stiffness and increases ROM by inducing stretch-induced analgesia. Deyne (2001) suggested that stretching a muscle stimulates biomechanical, neurological and molecular processes. A systematic review (Shrier, 2004) examining the effect of stretching on performance concluded that stretching immediately prior to the sports activity had a detrimental effect on the performance. In this same review, performance was measured based on force or power. This led to the recommendation that if an athlete stretches, it should be after their particular sport activity or at a time unrelated to their sport activity (Shrier, 2004). Herbert and Gabriel (2002) reviewed literature to understand the effects of stretching before and after the exercise on post exercise muscle soreness, risk of injury and performance of an athlete. The findings of this study were inconclusive with regards to reduction in injury and athletic performance. Harvey et al. (2002) found that one-day after the completion of stretching there was increased ROM by 8 degrees. Thacker et al. (2004) found that regular stretching may be more beneficial than acute bouts of stretching at a time related to the activity in light of medium to low quality studies included in the review. Their quality measure indicated a need for better quality studies on stretching. Kovacs (2006) suggested that stretching before physical activity reduced the power production and speed of muscle contraction, and that stretching did not help reduce the risk of muscle or ligament injury. Rubini et al.

(2007) reviewed literature to understand the acute and long-term effects of stretching-induced strength deficit while exploring the mechanism of action for this detrimental effect on muscles. The researchers found that the protocol for stretching used may have been the cause of their results. Thus, the researchers concluded that more research is needed in this area. McHugh and Cosgrave (2010) reviewed literature to understand the effects of stretching to prevent injury and its effect on performance concluding that acute stretching before sports activity will reduce force production. The stretch-induced strength reduction is less if the stretching is combined with some pre-participation activity or warm up. Kay and Blazevich (2012) reviewed literature to determine the acute effects of static stretching on maximal muscle performance. The researchers concluded that a static stretch held for less than 30 s can be performed prior to the main activity without any detrimental effects on activities measured in strength, power or speed output.

Chapter 3 Methods

This systematic review of literature examined the effect of stretching on jump performance. The term systematic review was an exhaustive review of literature that focused on a well formulated and highly focused question that attempts to identify, appraise and assemble all the extant research relevant to that question (Centre for Reviews and Dissemination, 2009; Hemington & Brereton, 2009). This chapter will describe in detail the procedures for identification of articles relevant to the purpose of this paper, the inclusion and exclusion criteria of experimental studies, the method for assessing the quality of each included study, the approach to synthesizing the research study findings, and the guidelines for interpretation of these findings in relation to the purpose of this systematic review.

Identification of Relevant Research Studies

This section of the chapter will explain the process of identifying relevant research articles for potential inclusion within this systematic review.

Database. The articles relevant to the topic of this review were identified from search engines available through the San José State University Library system. The search engines used for identifying the research articles were SPORTDiscus, Web of Science, OregonPDF in Health and Performance, Academic Search Premier and Medline. The ProQuest search engine in the San José State University Library system was used as a homologous search engine for searching theses and dissertations submitted by prior master or doctorate students. The searches in the different databases covered the years of the search time period provided by the database. Articles that were unavailable online but were available as paper copies were collected by photocopying the article from the journal stored at the San José State University Library. The articles that were unavailable online or available at the San José State University Library were sought for on the webpage of the journal. If full text of any article was not available through the methods described above, it was requested and obtained through the interlibrary loan internet access database (ILLIAD) system offered at San José State University Library. Any conference papers or expert statement reports that were found in the search results pertinent to the topic of the study were also included in the review. Additional efforts were made to obtain copies of special communications (Shrier, 2004). The authors of these unpublished studies were contacted by email.

List of terms for searching research databases. The terms used in each search engine to identify articles were stretching, stretch, jumping, jump, effects of stretching on jump performance, vertical jump, PNF, ballistic, static, static stretching, warm up, elasticity, flexibility, and Sargent jump. A new search was conducted if a new term for stretching or jumping was found in any study. The search was performed first on PubMed and then on different research databases for the new terms found for stretch or jump.

Articles were selected after reading the title and the abstract available on the search results page. Full text articles of all abstracts that mentioned that stretching was tested were acquired. If it was unclear from the abstract then the full text of the study was collected, and the methods section of the study were read. The search of research articles did not just rely on the searching of key words in research databases. The reference list of all articles for the review was reviewed to identify additional relevant research studies. These articles were then reviewed to find any additional cited research that might contribute to this review of literature. This process of article collection, reference list review, and identification of additional relevant research was continued until no new research articles were found. Once all the search engines had been queried in a similar manner, all the articles were read to determine if they met the inclusion criteria. The articles were then sub-divided into applicable and non-applicable categories based on the content of the research study.

Study selection. A set of inclusion and exclusion criteria that fulfilled the purpose of this review were identified after discussions with the thesis advisor. The inclusion/exclusion criteria were edited if new criteria were learned during the process. Once the research articles identified through the computer database searches had been collected, the electronic and/or paper copies of each article were sorted based on the criteria of inclusion (see below). To assure the reliability of the decision to include or exclude a study, the abstract of the included, as well as the excluded, studies of the entire pool of collected studies were reviewed at least once with the thesis advisor.

Criteria for inclusion and exclusion of studies. The criteria for inclusion or exclusion of the studies was based on the requirement that studies included in this systematic review helped form a better understanding of the effects of different stretching techniques to improve jumping performance. The stretching technique were bracketed to the ones which involved taking the limb to the end ROM and holding it actively or passively when stretch is felt for a specific duration. The jump performance was bracketed to the ones in which the researchers measured either height of the jump or distance covered by the jump. The following were the specific inclusion and exclusion criteria:

1. The age or date of the studies was only delimited by the inclusionary time frame of the various databases used herein.
2. Studies were delimited to research conducted on human subjects.
3. Studies were delimited to those testing the effects of stretching on jumping. Any other force or power determinant, for example, sprint performance, repetition maximum, fast isokinetic movement etc., was not included in this review.
4. The age of the participants was not delimited.
5. Studies that tested the effects of stretching on participants with soft tissue contracture due to any neurological impairment or musculoskeletal injury were not included in this review.
6. The review was delimited to the studies published in English.

7. Studies that used positional stretching such as the use of splints, casting, or any other sort of instrumental stretching techniques were not included in this review.
8. Studies that used stretching as an independent variable that was named other than stretching, but the commands to perform it matched active stretching, passive stretching, PNF stretching, ballistic stretching or dynamic stretching were included in the review.
9. Studies using jump as a measure to score performance were included. Studies that measured the jump as a test for diagnosing pathology of soft tissue were not included in this review.
10. Studies that used jumps such as counter movement jump, squat jump, drop jump, hop for distance test, triple jump, or three step jump as the dependent variable were included in this review.
11. Studies that stretched body parts other than lower limbs were not able to test the effect of stretching on jump. Hence those studies were not included in this review.

The included articles were reviewed for the type of stretching and its effects on the type of the jump the study investigated. All information regarding the type of stretching and the type of jump are presented. Other parameters investigated in these studies were discussed.

Synthesis of the Research Study Findings

The articles were reviewed in chronological order by the year they were published. The studies eligible to be included in the review were presented by summarizing the studies. All information regarding the participants, procedures, directions for stretching, directions for jumping, results, researcher's conclusions and proposed mechanisms are summarized for each study. The level of evidence explained by Phillips et al. (2012) was referred to determine the quality of the study. The method to conduct a systematic review of literature was adopted as described by Hemingway and Brereton (2009).

Chapter 4 Results

Introduction

This chapter contains the following subsections: search results, included and excluded studies, abstracts of included studies, and the collection of the conclusions of all the included studies. The search results section includes the details of the search procedure and the steps followed to identify the studies discussed in this review. The details regarding excluded studies are described in the section following the search details. The abstracts section includes the abstract of each study that fit the inclusion criteria for this research paper. The conclusion summarizes the contents of the above sections.

Search Results

As mentioned in the delimitations, the searches were performed within a delimited time span. The date setting was not delimited. The following databases were searched for relevant studies: Academic Search Premier (1875 to June 2012), Web of Science (1950 to June 2012) with lemmatization, SPORTDiscuss (1914 to 2012) with full text, Oregon PDF in Health & Performance (since 1948 to July 2012), and ProQuest Dissertations and Theses (1861 to those accepted up to Aug 2012). The searches conducted at the Web of Science included the Web of Science databases (1975 to June 2012), MEDLINE (1950 to June 2012), Biological Abstracts (1969 to June 2012), and the Journal of Citation reports (the dates were not mentioned in the search database). After the first search, searches were conducted on a monthly basis until no new search results appeared. All of the collected full texts were summarized contemporaneously after the first search attempt. The additional studies from the search results were summarized after each additional search.

The studies that were unavailable online search databases or located via ILLiad were manually searched in the library. There, the journals were located according to their call numbers. These particular studies were obtained in full text by scanning the studies.

The indexes for the journal issues that were unavailable online were scanned for any titles suggesting that the studies evaluated the effects of stretching on jump performance. Any study mentioning stretch or jump (passive stretching, active stretching, dynamic stretching, ballistic stretching, PNF stretching, countermovement jump, drop jump, single hop for distance, vertical jump, Sargent jump) was collected after the abstract was read, and it was deemed to determine the effects of stretching on jump performance.

When all of the studies had been collected, the reference lists of all the studies were scanned for titles suggesting that the cited studies evaluated the effects of stretching on jump performance. If any such title was found, the title was searched at www.pubmed.gov, and the abstract was read. If the abstract indicated that the study determined the effects of stretching on jump performance, the full text was acquired using one of the search databases provided by San José State University library services. If the full text was not available in the search databases, electronic journal access was attempted. If the full text of the study was not accessible, the study was requested from the ILLiad service provided by San José State University library services. Information regarding the study was inputted and submitted on the student account's request page. ILLiad provided an electronic copy or a hard copy within 3–7 days.

Once all the studies were collected by repeating the process described above, the researchers whose names most frequently occurred in the search results and the researchers who had performed reviews of the literature related to stretching were contacted by email. Five researchers were contacted by email, using the email address provided on the first page of the study. Dr. D. G. Behm had changed institutions since the time of the study's publication. His prior institution provided his new email address, and he was contacted. The email to the authors and the list of authors contacted is presented in the appendix at the end of this review. The email to the researchers included two documents: the summary of the thesis proposal and the reference list of the studies. The summary of the thesis consisted of the key points supporting the need for this review and the planning of the review's result section. Two authors replied that they had previously researched the area of stretching and that they were not up to date on the current research on the topic. Communication with the other three authors was continued through further emails, and these exchanges provided valuable insights for the purpose of this review. In addition to providing their reference lists in the areas of stretching and warm up, the researchers also mentioned their views on the current trend of studies related to stretching and warm-up. One researcher provided a list of studies related to warm-up and stretching. The reference list was checked against the list of studies that had already been collected and the list of studies that had been requested through ILLiad but not yet received. These reviews and studies were obtained in full text online or by a manual search.

The processes of collecting and summarizing the full texts and contacting the authors were performed contemporaneously during late 2011 and early 2012. All the trial studies were found to be of 1b evidence level as described by the levels of studies by Phillips et al. (2012). The following section consists of the abstracts of the studies that fit the inclusion criteria of this literature review.

Review of Studies

This section of the chapter includes the paraphrased summaries of all the studies that fit the inclusion criteria discussed for the purpose of this review. The studies were summarized as per the guidelines mentioned in the Centre for Reviews and Dissemination's systematic reviews (2009). In addition to the general guidelines, the thesis advisor provided suggestions for preparing the abstracts. The summaries include details and information about the stretching performed by study participants and the jumps performed. According to the Centre for Reviews and Dissemination, the following information was extracted from each study:

1. Study characteristics, such as the purpose of the study, hypothesis, recruitment of the participants, inclusion and exclusion of the participants, and the study method (randomizing and blinding)
2. Participants' characteristics, such as age, gender, comorbidities, and fitness status
3. The study's interventions and setting, including independent and dependent variables, such as position assumed to stretch, duration of the stretch hold, stretch intensity, directions to stretch/jump, and the experiment protocol
4. Outcome analysis, such as definition, measurement units and tools, and the units of measurement as used in the study; the number of participants enrolled and the number of participants whose data were analyzed are included in the summary of the study.
5. Any theories proposed for the effects and comparisons of the effects between the different stretching.

The abstracts of the studies were prepared by extracting the information consistently, as described above. The summaries were prepared with the idea of answering the question of this review, compiling ideas for subsequent studies, and putting together information related to stretching and jumping. One researcher extracted data to prepare the summary, and at least two other experts reviewed the completeness of the information. The paper was proofread by three other people to check the quality of the content and writing.

Carvalho et al. (2012) determined the immediate effects of warm-up with active stretching, passive stretching, and dynamic stretching on squat jump performance and countermovement jump performance. The participants (n=16) were tennis players. They practiced tennis drills at least 8 hr per week. The participants performed a 5-min warm-up, five submaximal squat jumps, and five countermovement jumps before the experimental conditions. Immediately after the experimental conditions, the participants performed three squat jumps and three countermovement jumps.

The participants were randomly divided into four groups. The first group was the control group; they performed pretest conditions, rested for five min, and then performed posttest jumps. The participants in the second group, the active static stretch group, stretched themselves without any assistance from researchers or fellow participants. The participants in the third group, the static passive stretching group, assumed the position, and the researchers stretched them. The active static stretches and passive static stretches were held for 15 s, to a point of mild discomfort. Three sets of active, static, or passive static stretching were performed. The dynamic stretching participants performed rebound movements in the position assumed for static stretching; they were instructed to achieve greater stretch in each repetition.

To stretch the hamstrings, the participants assumed a long sitting position. In this position, the participants flexed at the hip to touch their toes. To stretch the quadriceps muscle, the participants lay on one side and completely flexed the target, contralateral leg at the knee joint. Next, to stretch the triceps surae muscle, the participants assumed a position to push the wall with the elbows extended. In this position, the participants were instructed to slide the target leg back with the heel in contact with the floor until a stretch was felt in the calf region.

To perform the squat jump, the participants assumed the starting position with the knees at 90° and the hands on the hips. At the command, the participants jumped as high as possible. The participants performed the countermovement jump from a standing position with self-selected countermovement depth and hands on the hips. The data were analyzed with one-way repeated analysis of variance.

The researchers concluded that the active static stretch condition participants had the highest vertical height, followed by the dynamic stretching group participants, and finally, the passive static stretching group. The difference in the vertical jump height was significant; however, the effect was not statistically significant. The effect of stretching on the squat jump was also statistically insignificant. However, within groups, the vertical jump height for the squat jump was lower for the active static stretching and passive static stretching groups, compared to that of the dynamic stretching and control groups. The researchers explained, based on previous studies in this area that the cause for the results of this study may be because of decreased muscle stiffness.

Place, Blum, Armand, Maffiuletti, and Behm (2012) sought to determine the acute effect of self-performed PNF quadriceps stretching with 5 s of stretching and contraction on vertical jump performance, neuromuscular function, and range of motion. The participants were 12 healthy men involved in at least 2 hours of physical activity per week. The participants visited the lab three times for data collection. During the first visit, participants were familiarized with the study's data collection procedure and different activities. The experimental data collection session consisted of quadriceps PNF stretching or a control activity with the dependent variables. The experimental sessions were conducted on separate days with a break of 2–7 days. The participants had a submaximal warm-up session for 5 min on the cycle ergometer. During the experimental data collection sessions, participants performed active range of motion of hip extension and knee flexion, three electrically evoked quadriceps contractions, two sets of maximum voluntary contractions of hamstrings and quadriceps, and two sets of countermovement jumps and drop jumps. A 10-second rest was provided between recording the two jumps. The jumps were performed with the hands on the hips. The participants were instructed to perform the PNF stretches by 5 s of hamstring contraction followed by 5 s of passive stretching of the quadriceps, followed by 5 s of isometric contraction hold for quadriceps. The participants performed standing quadriceps passive stretches. The pretest activities were also performed post–stretching intervention. The jumps were performed immediately after and 15 min after the intervention. The control group walked at a self-selected pace. The drop jumps were performed from a 30 cm height. The jump performances were recorded on a force plate, as recommended by Kistler, Winterthur, Switzerland (Place et al., 2012). The vertical height of the jump was calculated by $h = g \times \text{flight time}^2/8$, where, h is height, and g is gravity. The highest jump was considered for the data analysis. Place et al. concluded that PNF stretching does not influence the countermovement jump or the drop jump performance. The researchers described the effect of the PNF stretching as comparable to that of the control group in this study. The active ROM remained the same at the end of the study; that suggests the PNF stretching might not have been well executed by the participants.

Sandberg, Wagner, Willardson, and Smith (2012) determined the effects of static stretching on vertical jump height. The researchers also sought to understand the neural activity in the agonist and antagonist muscle groups. Sixteen participants engaged in resistance training at least twice a week for 6 months volunteered. The participants were prepared for the trial by EMG electrode placement, testing maximum voluntary contraction, and a 10-min rest. The EMG data were collected for the vastus lateralis and the long head of biceps femoris for the knee extension tests only. The EMG data were not collected during the vertical jump measurement. The experimental group performed the static stretching, followed by a 90 s rest, and followed by the vertical jump test. The hip flexors and the dorsiflexors were stretched prior to the vertical jump test.

To stretch the iliopsoas muscle group, the participants assumed a half-kneeling position. In this position, the participants were instructed to extend their hip and externally rotate the thigh (by bringing the foot in medially). During the hip flexor stretching, participants were instructed to keep the spine in an erect position. The researcher stretched the participants' dorsiflexors. The participants assumed a supine position with the feet positioned outside the testing couch. The researchers pulled the toes and pushed the heel to bring the foot into plantar flexion. The stretching was performed from distal muscle group to proximal muscle group (dorsiflexors first, followed by the hip flexors). The stretching was held for 30 s, to a point of mild discomfort. The vertical jump trial measurements were recorded with a Vertec device (Sports Imports, Columbus, OH, USA as cited by Sandberg et al., 2012). The participants were allowed to perform the countermovement jump trials until they failed to reach a greater height in two consecutive jumps. Participants self-selected the depth of the countermovement phase. The researchers provided no details regarding the arm swing; however, the countermovement jump described required the arm swing to reach the highest point. The differences in the descriptive statistics between the stretch and the non-stretch conditions were analyzed using paired t-tests. The researchers concluded that the vertical jump height and power increased significantly after the static stretching protocol.

Pearce, Latella, and Kidgell (2012) revised the protocol from Pearce, Kidgell, Zois, and Carlson's (2009) study by adding five repetitions of vertical jumps, a test of changing direction (a 505 agility test), and a 20 m sprint. The participants were 15 healthy male university students. The participants visited the lab five times. The first two weeks were used to familiarize participants with all the test protocols. During the third, fourth, and fifth weeks, the participants visited the lab to perform a randomly assigned intervention from among the three potential interventions. The experimental protocols from the Pearce et al. (2009) study were modified to match the aim of this study. The participants completed general warm-up for 5 min prior to performing the pre-stretch vertical jump for baseline data. The jumps were recorded on a contact mat, Smartjump (Fusion Sport, Australia). The instructions to perform the vertical jump were similar to the countermovement jump performance. The participants were instructed to perform the vertical jump with the hands on the hips and bringing the knee angle to 60° to 80° during the countermovement phase of the jump. After 5 min, the participants performed five repetitions of the vertical jump. After the jump performance, the participants performed one of the three interventions: static stretching, dynamic stretching, or the control intervention, consisting only of general warm-up. These were the same intervention activities as in the 2009 study. The participants then performed a maximum vertical jump test, a five vertical jump test, a 505-agility test, and a 20-m sprint. The angle of the knee during the jump tests was measured by an electric goniometer. Pearce et al. concluded that no intervention condition resulted in a significant difference in maximum vertical jump height. The different warm-up conditions did not increase or decrease the jump height in the five vertical jumps test.

Mikolajec et al. (2012) determined the effect of one week of stretching and strengthening exercise on running speed and power performance in National Collegiate Athletic Association (NCAA) Division I male basketball players. The participants were 14 males with training experience of 6.8 ± 2.9 years. The data were collected over a period of 3 weeks; the study consisted of three, one-week phases. The 5 m sprint, 20 m sprint, and countermovement jump for power were recorded in the beginning and at the end of three weeks. During each data collection phase, the participants first warmed up for 15 min prior to running and performing agility drills and, followed by stretching. The participants performed four different stretching exercises; they repeated each ten-second stretch three times. They were instructed to stretch at an intensity of 80% to 90% of the full ROM. The researchers did not describe positioning details for the stretching exercises or the countermovement jumps.

Participants practiced twice a day. During the first practice of the day, participants performed the regular warm-up, followed by static stretching of the muscles involved in the flexion and extension of the hip, knee, and ankle. They held the stretch for 10 s at 80–90% of full ROM. On the last day of each week, the participants performed a 5 m sprint, a 20 m sprint, and countermovement jumps. The jumps were recorded on a force platform. The second week, practices were similar to those of the first week, except the participants did not stretch. The third week's practice consisted of regular warm-up protocols, followed by isometric strength training for hip and knee flexors and extensors as well as dynamic strengthening exercises. The dynamic strengthening exercises were comprised of 80–85% of one repetition maximum of half squats and toe raises. Participants performed two sets of three repetitions of dynamic exercises, with a 2 min break between sets. The sprint times were measured by laser diode system LDM 300-sport (Jenopatic, Jena, Germany as cited by Mikolajec et al., 2012). Post hoc tests were performed to understand the effect of different workout protocols on the speed and strength determinants. The researchers concluded that vertical countermovement jump performance could be improved by using exercises to strengthen lower-limb flexors and extensors and excluding the pre-performance stretching component.

Fletcher (2013) studied the effects of different exercises commonly used in the warm-up session preceding a sporting event on jump height performance. Fletcher hypothesized that higher-intensity warm-up activities would result in higher jump heights. The experiment consisted of randomized, counterbalanced, repeated measures. Sixteen healthy collegiate males volunteered for the study. The participants' mean age was 21.38 ± 0.52 years; their mean body mass was 75.1 ± 5.26 kg. The participants were well-trained athletes participating in team sports or track and field at a collegiate level. Participants began with either 5 min of seated rest, standardized active warm-up, a set of dynamic stretches, or a standardized parallel squat. Following the activities, the participants performed squat jumps, countermovement jumps, or drop jumps. The participants performed the four different activities or the control condition followed by one of the three jumps. The participants performed three different types of jumps in the control condition. Three days elapsed between each set of activities and jumps. All data were collected at the same time of the day. Participants were asked to refrain from alcohol use for 24 hr prior to data collection. Familiarization sessions were conducted to practice the warm-up and the jump data collection with EMG set up and to record one repetition maximum for parallel squat. All the jumps were performed with the hands on the hips. The start position for the squat jump was with the knee at 90°, as set by the universal goniometer. The participants performed the countermovement jump with self-selected squat depth and without any pauses during upward or downward movement. The drop jump was performed from a height of 0.2 m. The participants were encouraged to jump as high as possible. The jump mat (Just Jump, Probiotics Inc., Huntsville, USA as cited by Fletcher, 2013) was used to measure the jump height.

The EMG electrode placement sites were shaved and cleaned with alcohol swabs to minimize electrode impedance below 5 kΩ. The ground electrode was attached at the lateral malleolus at the right ankle. The electrodes were attached on the skin at the muscle belly with the muscle in a contracted state. The preamplified electrodes were arranged parallel to the muscle fibers with an interelectrode distance of 2 cm. The EMG data were collected for the gastrocnemius muscle, the tibialis anterior muscle, the biceps femoris muscle, and the rectus femoris muscle. The Datalink and Datalink software (Biometrics Ltd, Gwent, Wales, UK as cited by Fletcher, 2013) was used to rectify and average the highest of jump out of the trial of three jumps. The experiment activities performed for the data collection are indicated below:

1. Seated rest for 5 min
2. Jump test for jump height (countermovement jump, drop jump, or squat jump)
3. Active warm-up, consisting of 10 min on a cycle ergometer at a power output of 100 W
4. Seated rest for 5 min
5. Jump test for jump height (countermovement jump, drop jump, or squat jump)
6. Two sets of 10 repetitions of dynamic stretches, performed as deep squats at a rate of 100 beats per min
7. Seated rest for 4 min
8. Jump test for jump height (countermovement jump, drop jump, or squat jump)
9. Three repetitions of parallel squats at 30% of one repetition maximum, followed by 2 min of rest, followed by three repetitions at 70% of one repetition maximum, followed by 2 min of rest, followed by two repetitions at 90% of one repetition maximum
10. Seated rest for 4 min

11. Last jump test for jump height (countermovement jump, drop jump, or squat jump)

The control condition was analyzed with a 1 × 3 way repeated measures analysis of variance (ANOVA). To measure the experimental conditions to determine which of the three increased the jump height, a 3 × 4 way repeated measures ANOVA was used. To determine differences between the mean jump height and average EMG output after different preparation strategies, a 3 × 4 × 4 way repeated measures ANOVA was used. Pairwise comparison was done after ANOVA analysis, using post hoc tests with SPSS for Windows. The researcher concluded that under control conditions for all three jumps, the second, third, and fourth jump trials were significantly higher than the first jump in all jump trials. The post hoc analysis revealed that countermovement jump and drop jump height improved significantly as compared to the squat jumps. Statistical analysis of the effects of individual components of the performed activities revealed that there was significant change in jump height after each intervention including for post-stretch observations. The EMG activity increased after dynamic stretch intervention in the squat jump for the rectus femoris and gastrocnemius muscles. The author noted that there was a considerable increase in jump height after the dynamic stretch component.

Considering the description of the dynamic stretch given in this study, the stretch does not meet the definition of stretching a muscle. The stretch component performed in this study is similar to the stretch component in stretch shortening or plyometric activities (Yessis, 2009). The dynamic stretch described in the study does not match a static stretch, which is held for 20 or 30 s, or a ballistic stretch, which is a quick bounce movement.

Turki et al. (2011) performed a study to determine the effect of dynamic stretching combined with four types of post-activation exercises of different muscles on vertical jump performance. The researchers also wanted to determine the time required for recovering from the four experimental interventions in terms of the vertical jump performance. The participants were 20 males, all highly trained handball, soccer, or basketball athletes. The participants performed physical training for their sports five to six sessions of approximately 90 min in a week. All participants performed six different interventions in 3 weeks. The six treatment protocols were:

1. Three sets of three-repetition maximum of dead lift exercise (concentric protocol)
2. Three sets of three-repetition maximum voluntary-contraction back squats (isometric protocol)
3. Three sets of three tuck jumps (plyometric protocol)
4. Three modified drop jumps, only without the dynamic stretching (eccentric protocol)
5. Dynamic stretching only (dynamic stretching protocol)
6. Control protocol

Since the subjects were highly trained athletes, they had prior knowledge of how to correctly perform the intervention exercises. However, the participants were taught the correct form for performing dead lifts and back squats. The participants performed each treatment protocol in counterbalanced and randomized order. They were asked to continue with their regular routine workouts, but not to increase resistance or add strenuous activities during the course of data collection for this study. Apart from performing the six interventions, the participants visited the lab once for determining their three-repetition maximum for back squats and deadlift exercises.

The participants performed the countermovement jumps immediately after the dynamic stretching sets. They also performed countermovement jumps after five min of a light jogging warm-up. During the 10 min of dynamic stretching, the participants performed five active dynamic exercises targeted for the gastrocnemius muscle, the hamstrings group of muscles, the quadriceps group of muscles, the hip extensor muscles, and the gluteal muscles. They performed each exercise 14 times while walking 20 m. The participants were given 10 s of rest between each set. To target the gluteal muscle, they walked with high knees. The participants walked with knee extension and ankle plantar flexion. The participants swung the hip until they felt a stretch in the hamstrings. Participants stretched the hip adductors by assuming a hurdler's position while walking. The participants performed heel kicks to the buttocks to stretch the quadriceps and walked on tiptoe, performing plantar flexion while moving forward, to stretch the gastrocnemius muscle. The data collection protocols included a standard generalized warm-up and countermovement jump before the intervention. The participants rested for 10 min, followed by 10 min of dynamic stretching of their lower limbs. Then participants performed one of the six warm-up protocols. After each protocol, the participants performed one to two maximal countermovement jumps after 15 s, 4 min, 8 min, 12 min, 16 min, and 20 min. The jumps were recorded on Quattro Jump portable force plates (Kistler Instruments AG, Winterthur, Switzerland as cited by Turki et al., 2011). The participants were asked to jump with the hands on the hips. The jump height was measured by the displacement of the center of gravity with respect to the body mass, calculated by the force plate. The authors concluded that 10 min of dynamic stretching increases the strength of nerve impulses along the muscle pathways that performed the movements. The peak power outcome was different for each individual in the study. The inclusion of deadlift may have slightly increased the participants' strength.

Frantz and Ruiz (2011) performed a study to compare the effects of dynamic warm-up and static warm-up on lower body explosiveness in collegiate baseball players. Twenty-five Midwestern University baseball players participated in the study. The data were collected over seven weeks. During the first week, each participant performed one of three warm-ups, followed by jump measurements. The third warm-up was the control group. Static warm-up was tested during the second and sixth weeks. The dynamic warm-up was tested during the first and fifth weeks. During the third and seventh weeks, no warm-up condition was tested. The fourth week was used as a rest week. Following the warm-up protocols, the participants were tested for vertical jump and long jump. The entire session of warm-up and jump testing took 10–20 min.

The dynamic warm-up included forward lunges with the forearm on the opposite instep, backward lunges with rotation, jackknife movements, knee-to-chest movements, bending to touch the toe, marching with straight legs, straight-leg marching with skipping, lateral shuffles with countermovement, lateral leg swings, straight leg swings, hip rockers, reverse hip rockers, inverted hamstrings, fast lunge, short carioca, long carioca, falling starts, back pedals with turns, and back pedals with two lateral turns. The researchers did not describe the details regarding positions for the dynamic movements.

The static warm-up consisted of standing hamstrings stretches to the middle, left, and right; calf stretches to the right and left legs; deep side lunges to the right and left; squatting butterfly stretches; straddle stretches to the left, right, and middle; sitting butterfly stretches; sitting figures of four stretches to the right and left; right and left torso twists; left and right piriformis stretches; and lying quadriceps stretches to both legs. Again, the researchers did not provide details regarding stretch hold duration or intensity.

Countermovement jumps on the Just Jump System were used to measure the explosiveness of the lower body. Repeated measures ANOVA revealed that there was considerable difference in the effects of three different warm-up conditions on the jump performances. The post hoc analysis revealed that dynamic warm-up produced better results compared to static warm-up or no warm-up. Frantz and Ruiz also mentioned that the static warm-up did not lower the jump height, even though it was not as high or long as that performed after dynamic warm-up. The author did not discuss the detail if the stretches were distinctly static hold or dynamic stretch.

Hobara et al. (2011) determined the effects of static stretching on leg stiffness for two-leg hopping. All 14 participants were healthy and recreationally active. Before data collection, the participants performed hops on a force plate for 5 min as part of warm-up. The participants stretched the triceps surae muscle by standing straight on an inclined board with 30° dorsiflexion at the ankles. The hips and knees were kept straight. The participants assumed this position for 3 min. A few s after stretching, the participants moved onto the force plate (9287A, Kistler Japan Co., Ltd, Tokyo, Japan as cited by Hobara et al., 2011). The participants performed jumps on the force plate 15 times with a digital metronome. The single trial for jumping took 7 s. The participants were instructed to hop with a short contact time on the force plate. The sixth through tenth hops were used for data analysis. The Kistler force plate was used to measure vertical ground reaction force. The leg stiffness was determined by taking the ratio of peak vertical ground reaction force to the middle of ground contact phase as directed by Farley and Morgenroth (1999) (Hobara et al., 2011). The data were analyzed using a one-way repeated ANOVA method for each parameter. The researchers concluded that passive stretching for 3 min did not alter leg stiffness or vertical displacement. Hobara et al. suggested that the unaltered stiffness might be because humans maintain leg stiffness for certain loading of legs by various intralimb compensation strategies. The second reason proposed by the researchers was that the musculotendinous junction might absorb the effect of passive stretching, which could lead to no negative effects from stretching.

Bubanj et al. (2011) determined the effect of a warm-up only protocol and a warm-up with static stretching protocol on explosive strength. Seventeen university students, who were actively participating in sports, participated in the study. Countermovement jumps were used as a determinant of explosive strength. The countermovement jumps were performed on a Myotest (Myotest, n.d. as cited by Bubanj et al., 2011) that calculates vertical jump height by measuring flight time. The participants were instructed to avoid certain activities during the 2-week intervention period. The participants completed five repetitions of countermovement jumps as pretest and posttest measures. After the pretest, the participants performed static stretching of lower limb muscles (which muscles were not specified by the researchers) until the point of discomfort and held the stretch for 30 s. Control group participants performed only countermovement jumps and no stretches. Descriptive statistics was used to understand the difference between the countermovement jump pretest and posttest. The control group scored better mean value scores. However, the improvement in the jump height was the same in pretest and posttest for the experimental group and the control group. Bubanj et al. concluded that static stretching prior to the countermovement jumps did not have positive or negative effects on jump performance.

The researchers explained the results of the study by describing the physiology of the GTO and its inhibition as mentioned by Guyton and Hall (2000). The GTO, located in the skeletal fibers, transmits information regarding the muscle's tension to prevent damage. The GTO would inhibit maximal contraction in order to prevent increase in muscle tension that could cause injury to the muscle.

Perrier, Pavol, and Hoffman (2011) compared the effect of warm-up with static stretching and dynamic stretching on countermovement height. The participants were 21 recreationally active male university students. On data collection days, the participants performed general warm-up, followed by the intervention and then a sit-and-reach test. After the sit-and-reach test, participants performed 10 maximal effort countermovement jumps. Data collection days were separate three to seven days. The warm-up jogging was self-paced for 5 min. The static stretching protocol consisted of seven lower-limb stretches. Participants were instructed to hold the stretch for 30 s and repeat each stretch twice. The static stretches were targeted to stretch major lower limb muscle groups. The dynamic stretch protocol consisted of 11 exercises with gradually increasing intensity.

The seven static stretches were standing quadriceps stretches, supine hamstrings stretches, hip flexor stretches in lunge position, hip adductor stretches in butterfly position, figure-of-four positions for piriformis stretches, supine lower back stretches (with one knee brought toward the chest), and gastrocnemius stretches in lunge position with the heel pressed to the ground.

The dynamic stretching protocol included easy skipping with arm swings, skipping for distance with arm swings, skipping for height with arm swings, running backward with heel extension during the stride phase, low lateral shuffles with 20-second breaks between repetitions, Romanian dead lifts with a single step, diagonal walking lunges, knee-to-chest walking, straight leg strides, and cariocas.

The participants were instructed to increase the intensity of the dynamic stretching activities to 50% in the second repetition, 75% in the third repetition, and 90% in the fourth repetition. The countermovement jumps were measured on the force plate (Kistler USA, Amherst, NY, USA as cited by Perrier, Pavol, & Hoffman, 2011). Perrier et al. used repeated measures ANOVA to measure the three different interventions on the countermovement height. First and last jump data were not used for the analysis; thus eight jumps were considered. Perrier et al. concluded that the jump height increased after dynamic stretching protocols, compared to static stretches and the control group. The second and third jumps were higher than the eighth and ninth jumps.

Pacheco et al.(2011) determined the acute effects of different stretches with different hold times and muscle activations during warm-up on the squat jump, the countermovement jump, and the drop jump. The participants were 49 healthy university students; they were selected if they were actively participating in sports or physical activity for 15–20 hrs. per week. Four different types of stretches were used as interventions for the study. The static passive stretches were held for 30 s. The contract-relax stretches were performed in three phases: isometric contraction for 4 s, relaxation for 4 s, and then static passive stretches held for 15 s. Static active stretching in passive tension was performed by antagonist contraction and held in the stretched position for 6 s. Contracting and stretching the agonist muscle simultaneously performed static active stretching in active tension (the muscle was put under tension by eccentric contraction of the target muscles); the stretched position was held for 4 s. Participants were given orientation and familiarization sessions. The experiment consisted of pretest jumps, followed by warm-up, followed by stretching, followed by posttest jump performance recording. The pretest and posttest consisted of three jumps on the Bosco platform, which was used along with the ERGO-JUMP Bosco System (Byomedic 2008, Barcelona, Spain as cited by Pacheco et al., 2011). The drop jump was performed from a 40-cm height. All the jumps were repeated two times with 20-second breaks between each trial. Rest periods of 1 min were provided between the different jump trials. The warm-up consisted of continuous running for 10 min at a low intensity. Participants executed each condition with minimum of a 72 hr break. The effects of different interventions on the pre- and post jump were determined by descriptive statistics. The increase in the vertical jump height was statistically significant after static passive stretching with active tension for all the jumps. However, countermovement jumps had maximum effect on the different interventions. Jump performances after static passive stretching with passive tension in the agonist, held for 6 s, saw an increase in jump height. The jump height was reduced for the simple static passive stretch held for 30 s.

Venderka (2011) studied the different effects of static stretching and dynamic stretching on explosive power in healthy individuals. Explosive power was measured with countermovement jump and the squat jumps. The participants were 24 male students at the Faculty of Physical Education and Sports at Comenius University. The participants were involved in scheduled physical training for a sport of their interest for two to three times a week. The participants performed the jumps on a contact platform (FitroJumper as cited by Venderka, 2011). First, participants performed jumps before any warm-up. Following the jumps, the participants stretched in six positions, stretching the plantar flexors, the hamstrings, the knee extensors, the hip adductors, the gluteus, and the spine erectors, in that order. They held each stretched position for 30 s. Their jumps were tested after 3 min of rest. The participants performed one jump every 3 min, for a total of four jumps. After the jump tests after static stretching, the participants performed dynamic stretching, followed by a series of countermovement jumps and squat jumps to test the effects of dynamic stretching. The dynamic stretching was described as consisting of swinging movements. The same protocol was repeated after 48 hr only the dynamic stretching and jumps were performed before the static stretching and jumps.

The jump height was calculated by the time of flight with the help of the contact platform. The squat jump height decreased 2.8% after static stretching, but increased 2.67% after dynamic stretching. Similarly, the countermovement jump height decreased 4.58% after static stretching; it increased 2.46% after dynamic stretching. These values indicated that there was not a significant amount of improvement in jump height as compared to the pre-warm-up jump height. The jump height increased by 6.33% when participants performed dynamic stretching prior to the jump for vertical height tests. The jump height decreased after participants engaged in static stretching. The effect on the countermovement jump height was similar when dynamic stretching was performed before the static stretching. The jump height increased 6.92% after dynamic stretching, and decreased after static stretching. Venderka hypothesized that the effects of stretching reflected the changes in the viscoelastic nature of the muscle caused by the stretches.

Cagno et al. (2010) studied the effects of static stretching on rhythmic gymnastics, vertical jumps, and technical leaping. The researcher intended to examine empirically and subjectively the amount of variance in technical leaping. Thirty-eight gymnasts between 11 and 17 years old, who were competing at an international or national level, participated in the study. The vertical jumps included squat jumps, countermovement jumps, and hopping tests. The technical leap included split leaps with legs stretched, split leaps with rings, and split leaps with the trunk bent backward. The jumps' flight times and ground contact times were recorded with the help of OptoJump systems (Microgate, Bolzano, Italy, as cited by Cagno et al., 2010). Three different judges graded the technical leaps. The judges graded the jumps based on international point codes. The participants performed the jumps and the leaps under two different conditions: once after their typical warm-ups and again after static stretching. The typical warm-up consisted of jogging for 4 min, plyometric training for 4 min, and 10 min of ballistic stretching of the back and leg muscles and strength training for abdominal and dorsal muscles. The participants were divided into two groups of 19, and both groups performed jumps and leaps. For the second testing session, participants performed four different lower-body stretches. They stretched the hamstrings in a long-sitting bilateral stretch. Participants stretched gastrocnemius and soleus muscles in a unilateral standing position with and without bending the knees. They stretched the quadriceps in a unilateral standing position. The same parameters were tested after 4 min of static stretching. The participants were asked to jump as high as they could with their hands on their hips for the squat jumps; they were also asked to assume a starting position with the knees at 90° and hands on the hips. For the hop test, participants moved in a series of seven small jumps, as fast as they could.

Participants performed three trials of each jump with a 30-second break between each trial. The researcher found that flight time for the vertical jumps was not affected by static stretching performed beforehand. After static stretching, the ground contact time for the hop test increased. The static stretching also reduced the technical leaps' flight time, but not their ground contact time, which lowered the point scores.

Bird et al. (2010) determined the reliability of the acute effects of static stretching on vertical jump performance. The participants were 13 females and 11 males, all recreationally active university students. The participants performed the warm-up on a cycle ergometer for 5 min at 120 W, followed by two to four vertical jumps. The participants performed three jumps followed by a set stretches. After the stretching, the participants performed jumps without taking a rest period. The participants performed the same protocol for 8 days, with at least a 24-hr break between each data collection session. The participants performed jumps with their hands on their hips. The stretching protocol was adapted according to the National Strength and Conditioning Association guidelines as explained by Baechle and Earle (2008) (Bird et al., 2010). Participants held the static stretch for each muscle for 30 s, to a point of slight discomfort after the full ROM. They stretched the gluteal, quadriceps, hamstrings, and calf muscles. To stretch the gluteus muscles, participants assumed the figure-of-four position on the floor. In this position, the participants pulled their extended legs toward their chests. The participants performed quadriceps stretches in unilateral standing positions with supports. They then flexed their target knees with posterior pelvic tilts and pushed the heels into the gluteus bulk. The participants performed a sitting unilateral hamstrings stretch. The participants assumed the figure-of-four position with the target leg straight in front. The participants tilted their pelvises anteriorly and leaned forward to touch their toes with their hands. To stretch the gastrocnemius muscle, participants stood against the wall and slid their target legs back, with the foot constantly in contact with floor untill they felt the stretch. The vertical jump test was performed on a Kistler force plate. The researchers did not mention details about the hand swing or type of jump. The jump height was calculated using the time from takeoff to landing on the force plate. Interclass corelation coefficients were used to measure the reliability and repeated measures; ANOVA was used to compare the effect of stretches on the jump performance.

Bird et al. concluded that the effect of stretching on the jumps was consistant across the trials. The sit and reach increased significantly from the first trial. After stretching, the jump peformance did not decrease for any participants; it did increase, although not significantly. There was no difference between the male and female participants, in terms of the effects of stretching on jump performance. The researchers did not explain if the participants were asked to do a countermovement jump, squat jump, or a standing jump to achieve higher vertical jump height.

Fletcher (2010) conducted a study to learn the difference between the effects of slow-velocity dynamic stretch and fast-velocity dynamic stretch on jump performance. The researcher designed a randomized, counterbalanced, and repeated measures study. Twenty-four healthy male athletes competing at a collegiate level volunteered for the study. The participants were not allowed to drink alcohol or do any strenuous activity for 24 hr prior to each testing appointment. The participants were also advised not to consume any food or drink any beverages containing caffeine for 2 hr prior to the tests. The participants were given at least 2 days of rest between testing trials. The author accounted for diurnal variations by testing at the same time of the day.

Three jumps were used for the study: countermovement jumps, drop jumps, and squat jumps. All groups performed a warm-up consisting of jogging at 10 kph for 10 min. Depending upon their assigned groups, participants performed either jogging with no stretching, slow dynamic stretching (50 beats per min), or jogging and fast dynamic stretching (100 beats per min). A metronome measured the rhythm of the dynamic stretches. The participants performed 90° squats, forward lunges, sit-ups, ankle dorsiflexion, ankle plantar flexion, high knee lifts, and heel flicks and swung the leg forward and sideways for their dynamic stretching exercise. Each process was conducted in a randomized order with a 1-week gap between trials. All jumps were performed with hands on hips. The jump height was estimated using a jump mat (Just Jump, Probiotics Inc., Huntsville, USA). EMG readings for the gastrocnemius, tibialis anterior, biceps femoris, and vastus lateralis muscles were recorded for each jump. The EMG sites were shaved and wiped with alcohol swabs; the electrodes were placed on the belly of the muscle parallel in direction to the muscle fibers. The electrodes were pre-amplified with a sampling frequency of 1000 Hz. The EMG data obtained were rectified, integrated, and averaged. After the end of each test session, EMG normalization was conducted by having each participant perform a maximum isometric contraction. For the kinematic analysis, joint markers were placed on the sternum, the greater trochanter, the lateral malleolus, the lateral aspect of calcaneus, and over the head of the fifth metatarsal. Data analysis showed that all three jumps (countermovement, drop, and squat) improved significantly with the fast dynamic stretching trial when compared to the slow dynamic stretch and the non-stretch trials. For the drop jumps and squat jumps, the slow-dynamic-stretching trial resulted in improvement compared to the non-stretching trial. The kinematic analysis showed significant increases in knee flexion and takeoff velocity. The pairwise comparison showed that the improvements were similar in the slow-dynamic-stretch group and the fast-dynamic-stretch group compared to the no-stretch group. The EMG analysis showed that the output for gastrocnemius was much higher after fast dynamic stretch compared to no stretch for the countermovement jump trial. The EMG analysis for drop jump trials showed an increase for biceps femoris in fast dynamic stretching than no stretching group.

For the squat jump, the EMG readings for vastus lateralis were significantly higher for the fast-dynamic-stretching group than the no-stretching group.

Fletcher posited several mechanisms to explain the results of the study. The first is that a dynamic stretching regime increases the heart rate and core temperature. However, there was significant difference between jump performances after slow dynamic stretching and fast dynamic stretching, whereas there was not much difference in heart rate and core temperature. Thus, the first proposed mechanism did not explain all the results.

The second mechanism posited by Fletcher was that stiffness of the musculotendinous unit is increased more by fast dynamic stretching than by slow dynamic stretching. According to the suggested mechanism, an impulse is transmitted faster to produce elastic energy of skeletal muscle in a stiffer musculotendinous unit. If this mechanism is to be considered, the EMG should have shown the evidence of a difference between fast dynamic stretching and slow dynamic stretching, but they did not. Thus the EMG results of the study do not support the explained mechanism.

The third possible explanation for the results is post-activation potential, meaning muscle activity prior to a movement has a considerable impact on the movement performance (Sale, 2002). This suggests that, for a skilled sport-specific activity, a warm-up would result in more forceful and faster muscle contraction. The fast dynamic stretch could have evoked the potential for muscle activation. This potential for muscle activation decreases the electromechanical delay, resulting in increased force production of the muscle tissue. The proposed post activation potential mechanism is supported by the results of the study.

Murphy et al. (2010) studied the effect on hip flexion ROM and overall performance of static stretching repetitions only, held for 6 s; 5 min of aerobic cycling followed by static stretches, held for 6 s; and 5 min of aerobic cycling before and after static stretching held for 6 s. The contermovement jump, along with other dependent variables, was used to measure the effect of the different protocols.

The participants were 11 male university students; five were recreationaly active, and six were involved in resistance training with the goal of improving performance in various competitive sports. The study tested the effects of stretching on ROM and performance.

The effect was measured by the contermovement jump height. The study consisted of four different types of warm-up. In the static-stretching-only warm-up, the participants stretched the hip extensors, the quadriceps, and the plantar flexors. They repeated the stretches six times, and held each stretch for 6 s. The second warm-up consisted of 10 min of treadmill exercise at a speed of 10 kph, followed by similar sets of static stretches. The third warm-up protocol included 5 min of treadmill execise before and after similar sets of stretches. The fourth group was the control group; they only performed 10 min of treadmill exercise. The countermovement jump and other dependent variable activities were performed before the warm-up, 1 min after, and 10 min after the warm-up.

The countermovement jumps were not constrained. As the participants were allowed to swing the arms and the depth of the countermovement was unrestricted. The countermovement jump height was measured by placing chalk on the participant's hand; in addition, an examiner was present beside the jump platform to verify the jump height within 1 cm. The performance warm-up protocol was analyzed by four warm-up protocols with two countermovement jumps at 1 min and 10 min after the warm-up. Murphy et al. concluded that there was no statistically significant difference between the effects of the different types of warm-up on the countermovement jump height.

Fletcher and Monte-Colombo (2010) determined the changes in physiology after static and dynamic stretching and the effect on performance. The researchers measured performance based on participants' countermovement jump, drop jump, peak torque, heart rate, core temperature, movement kinetics, and EMG after the stretching intervention. The participants were 21 healthy male college students, all recreational soccer players.

The experimental design included three conditions: the control, which was warm-up and no stretching, warm-up with static passive stretch, and warm-up with static dynamic stretch. The warm-up protocol consisted of jogging for 5 min at a self-selected pace. Participants stretched the hamstrings, quadriceps, adductor group of muscles, abductor group of muscles, gastrocnemius, and the solei muscle in static passive stretching and static dynamic stretching protocols. They held the static passive stretches for 15 s per muscle or muscle group, at the point of discomfort. Participants performed all stretching exercises once per muscle for both legs; they paused for 5 s between each stretch. After the static passive stretching protocol, participants jogged for 5 min. The third condition was performed as a movement, but the participants remained in situ; hence the researchers categorized it as static dynamic stretching. The static dynamic stretching warm-up protocol included heel flicks, high knees, hip rolls, calf raises, straight leg skipping, and lunging movements. Participants performed each movement 12 times, and repeating these sets twice per leg.

After the stretching protocol, the participants were randomly assigned to perform three countermovement jumps or three drop jumps. The jumps were performed on a jump mat (Just Jump, Probiotics Inc., Huntsville, Alabama as cited by Fletcher & Monte-Colombo, M., 2010). The participants performed drop jumps from a bench of height of 0.3 m; they were advised to jump as high as possible. The data were analyzed using repeated measures ANOVA.

Fletcher and Monte-Colombo concluded that there were significant difference in countermovement jump height, with ES = 0.803 where $p < 0.001$. However, countermovement jump height was highest after the static dynamic stretching protocol, followed by warm-up only (the control condition), and followed by the static passive stretching condition. The drop jump height after static dynamic stretching increased 5.9% as compared to static passive stretching. Drop jump height increased by 4.9% after the control condition as compared to static passive stretching. Fletcher and Monte-Colombo proposed that stiffness decreased after stretching—hence the reduction in jump height.

Dalrymple et al. (2010) examined the acute effect of static stretching, dynamic stretching, and no stretching on countermovement jumps in female collegiate volleyball players. Twelve females, competing in NCAA Division II volleyball, participated in the study. The participants were injury free.

Participants were advised not to eat for four hour or engage in resistance training for 48 hr before testing. The study was a randomized balance model study. The participants performed three different stretching sessions over a period of 3 weeks. On the day of data collection, they jogged on an indoor track for 5 min at low intensity. After jogging for 2 min, the participants performed stretches for 8 min. The participants took a 1 min break after stretching, and then performed five countermovement jumps with 1 min of passive rest between each jump. The static stretching protocol consisted of four stretches. For a calf wall stretch, to stretch the gastrocnemius muscles, participants put their hands on a wall and slid back the leg to be stretched. For a side quadriceps stretch, to stretch the quadriceps, they brought the heel of the leg to be stretched to the buttock, while lying on their sides. To perform a hamstring stretch, the participants sat upright on the floor, with their hips flexed and knees extended, and bent forward to reach their toes until they felt the stretch in their hamstrings. To stretch their hip extensors, they lay on their backs and brought the hip and knee to flexion-form extension, to bring the thigh to the chest until they felt the stretch in the hip extensors. They performed all the above stretches on both legs, performing three sets of 15 s stretches with a 20 s rest between sets.

The dynamic stretches targeted the same muscle groups as the static stretches; participants performed them on an 18 m course. They performed two sets of each stretch, ensuring it took the same amount of time as that taken for the static stretches. The dynamic stretch consisted of calf raises to stretch the opposite leg's gastrocnemius, slow butt kicks to stretch the quadriceps, leg swings to the opposite hands with the knee extended to stretch the hamstrings, and knee tucks to the chest to stretch the hip extensors. The no-stretching group did not perform any physical activity after the 5 min of jogging and before the jump test. The vertical jump height was calculated by vertical force trace. The vertical jump height was manually calculated and not determined using software. The results were analyzed by ANOVA method.

The researchers concluded that there was no difference between the effects of static stretching, dynamic stretching or no stretching on the countermovement jump. The researcher suggested that females have less musculotendinous stiffness than men in their medial gastrocnemius, and thus females did not show any improvement in jump performance. This warrants a future study on effect of different types of warm-up on performance in the different sexes.

The purpose of the study by Chaouachi et al. (2010) were to determine the effects of static and dynamic stretching on jump performance, to learn the effects of different sequencing of static and the dynamic stretches within the warm-up routine, and to determine the difference between the effects of stretching to point of discomfort and submaximal intensity stretching on jump performance, sprint time, and agility. Twenty-four students, NCAA Division I players from their various sports teams, volunteered for the study. The participants participated in 10 hrs per week of explosive and/or cardio workouts. The researchers tested eight different warm-up protocols with different stretching types and intensities. The warm-up protocols were, warm up with static stretching up to the point of discomfort, warm up with static stretching not reaching the point of discomfort, warm up with dynamic stretching, warm up with static stretching up to the point of discomfort followed by dynamic stretching, warm up with static stretching not reaching the point of discomfort followed by dynamic stretching, warm up with dynamic stretching followed by static stretching up to the point of discomfort, warm up with dynamic stretching followed by static stretching not reaching the point of discomfort, and the control condition, warm-up with no stretching, followed by rest.

The dependent variables were sprinting speed with 5 mins and 10 mins split times, vertical jump height, horizontal jump distance, and outcome on T-drill to measure agility. The participants visited the laboratory 10 times; they were acquainted with the testing protocols in the first two visits. The participants performed the eight different warm-up conditions on the other eight visits. Data collection days were separated by 48 hr. On the day of data collection, the participants performed general warm-up for 5 min, followed by 10 min of stretching. The participants performing the control protocol did general warm-up for 5 min followed by 10 min of rest. For the participants following the experimental procedures, the data collection protocol was counterbalanced. The experimental warm-up was followed by specific explosive warm-up for 5 min followed by a 2 min rest period. Finally, the participants tested for agility, countermovement jump height, sprint performance, and a five-jump test. The initial 5 min of warm-up included mild to moderately paced activities on the treadmill. The 5 min of specific explosive warm-up consisted of sprints and agility drills with increasing intensity.

Participants performed static and dynamic stretches to stretch the plantar flexors, hip flexors, hamstrings, gluteal muscles, and adductors. To stretch the gastrocnemius muscle, participants stood on a step with only half of the feet on the step. In this position, they lowered the heels while maintaining the knees in extension. To stretch the quadriceps group of muscles, the participants assumed a unilateral standing position against a wall and brought the heel to the buttocks. To stretch the adductors of the leg, the participants stood with their feet as wide apart as comfortable, and then shifted their weight from one side to other. Participants performed the dynamic stretches as continuous movements. They lifted the target leg off the floor and dorsiflexed the ankle so that the toe pointed upwards. To stretch the hip extensors, the participants performed a knee-to-chest movement. The participants performed an anterior kick type of motion with extended knee and flexing at the hip to perform a dynamic stretch of the hamstrings. The dynamic stretching of the adductors was achieved by side swings of the leg, and the dynamic stretching of the quadriceps consisted of heel kicks to the buttock. They performed each static stretch two times for each leg with a 10 s rest between each stretch; they held each stretch for 30 s. The two intensities of stretching were up to the point of discomfort, and slightly less than the point of discomfort, or approximately 90% of the point of discomfort.

Vertical jump performance was measured on the portable force plates (Quattro Jump; Kisler, Winterthur, Switzerland). All the jumps were performed with the hands on the hips. The countermovement jumps were performed from a standing position. The participants were instructed to bend their hips and knees to a comfortable level before jumping as high as possible. The aim of the five-jump test was to cover as much distance as possible in five jumps. The participants were asked to jump with both feet together; they were not allowed to take any steps backward to take off for the jump. The total distance was determined with a measuring tape.

There was no effect on either jump performance from performing the warm-up components in a particular sequence or from performing stretches at different intensities. While there was no improvement in the results, there were also no detrimental effects on the trained participants. The researchers proposed that the stretch-induced deficits in strength production might not be evident in trained athletes. Chaouachi et al. suggested that the decrease or lack of changes in the jump performances could be because of stiff musculotendinous units. The researchers suggested that a more pliant muscle has better energy storage and utilization capability. Changes in the stiffness of the muscle affect the force transmission.

Tsolakis et al. (2010) determined the effects of static and ballistic stretching on the legs' flexibility and power output in males' and females' fencing performance. Ten males and 10 females experienced in fencing at an international level volunteered for the study.

All participants performed low-intensity jogging at a self-selected pace for 8 min. After jogging, the participants performed sit-and-reach tests, squat jumps, countermovement jumps, drop jumps, tests for time and power of lunges, and tests for time of shuttle in a randomized order. After these testing activities, the participants performed either static stretching or ballistic stretching. The two different stretching protocols were performed on two different days separated by at least 48 hr. After stretching, the participants performed the same testing activities.

For the static stretching, participants performed three sets of 20 s stretches for three different muscle groups. They stretched the quadriceps in single stance, standing and bringing the heel of the target leg to the gluteus fold of the same side. To stretch the hamstrings, the participants adopted a unilateral long sitting position and bent over at the hips. They stretched the calf muscles by single-leg standing. They performed ballistic stretching for the same muscle groups using kicks to the buttocks, knee raises, and calf raises. To measure the time of lunge, the photocells were arranged at a distance of two thirds of each participant's leg length; participants were asked to perform the fencing lunge at maximal speed. The photocells were arranged such that they were triggered when the participant's chest and the photocell were at equal height. The shuttle test included fencing for five m forward and five m backward. The participants had to move forth and back in fencing position from the starting line and cover a total distance of 30 m. During fencing, participants wore the fencing uniform and shoes but held no weapons.

The researchers analyzed the data for the two types of stretching conditions with pre and post ANOVA tests. The Bonferonni test was performed if significant difference were found in any of the observations. The Bonferonni test is a type of multiple comparison test that attempts to prevents data from incorrectly appearing statistically significant. They concluded that the static of ballistic stretching does not have any significant effect on flexibility or power, which would affect the countermovement jump, drop jump, and squat jump performances. The researchers found a consistent decrease in all three types of jump tests in this study; they suggested that athletes, fencers in particular, can continue performing three sets of 20 s stretches during warm-up, as it affects the fencing performance of neither males nor females.

The researchers compared the findings with other studies testing the acute effects of stretching by suggesting two possible mechanisms. First, the motor neuron excitability that is reduced during stretching of the muscle tissue may have been recovered. The researchers pointed out that Guissard, Dutchateau, and Hainaut (1998) found that H-reflex recovers quickly after static stretching (Tsolakis et al., 2010).

Galdino et al. (2010) studied the effect of different kinds of flexibility training on ballistic force production capacity of the same muscle group. Twenty-five healthy, active women of age 28 $\pm$ 3.5 years participated in the study. All participants were involved in strength training.

The researchers conducted the study on three consecutive days; each day, participants performed 10 min of warm-up followed by a baseline vertical jump. Next, they performed one type of stretching or flexibility exercise for 10 min followed by another vertical jump. On the first day, the participants did not perform any stretching or flexibility exercise to enable measurement of the control data. On the second day, the participants performed submaximal intensity stretching. Following the submaximal stretches, participants performed vertical jumps. They stretched the hamstrings by lying supine and flexing the hip while extending the knee. The gastrocnemius muscle stretch consisted of lying supine and performing dorsiflexion. On the third day, the participants performed the same routine, but applied greater pressure for a greater intensity stretch. The participants performed countermovement jumps with the hands on the waist as part of the vertical jump routine. The warm-up included 10 min on a cycle ergometer to reach 60% of their age-adjusted maximum heart rate. A paired t-test was used for an intragroup comparison. The effect of stretching on the countermovement jumps was also measured 0using descriptive statistics. To compare intergroup data, a 3 x 2 ANOVA and repeated measures ANOVA with routine and pre and post data were performed. Post hoc was also performed after ANOVA analysis. The control-day data indicated that no activity's absence influenced the jump performance. The stretching-day data analysis revealed that the jump height decreased a little after the stretches. However the post-stretching jump performance was reduced significantly on the third day, when the stretching intensity was greater. The researchers concluded that stretching at submaximal and maximal intensity reduces the explosive power of the jump. They did not provide details regarding the duration of the stretch hold or particular terms for the stretch intensity like "to the point of discomfort," "less than the point of discomfort," or "greater than the point of discomfort." However the results of this study concur with those of the previous studies.

The purpose of Hough, Ross, and Howatson's study (2009) was to learn the effects of static stretching and dynamic stretching, and to note EMG activity of the vastus medialis after stretching the plantar flexors, hip flexors, hip extensors, and quadriceps femoris. Eleven healthy males participated in the study. All of the participants were involved in collegiate-level competitive sports. During the 24 hr before testing, they were asked to refrain from any strenuous physical activity. Then, participants performed static stretching, dynamic stretching or no stretching as a part of experimental set up. Participants visited the laboratory on three separate days with 24 hr between each experiment day. On experiment days, participants were set up with electrodes on the motor points of the muscles in which the activity was to be recorded. Bipolar electrodes were used on a cleaned and abraded skin surface. Following the EMG electrode placements, participants warmed up on an ergometer for 5 min with 1 kg of resistance and maintained 70 to 75 rpm. After warm-up, the participants lay on their backs and were assisted with static stretches. The muscles were stretched to a level of mild discomfort and held for 30 s each. For dynamic stretching, the participants followed verbal commands, contracting the antagonist muscles of the area to be stretched and performing the dynamic movement. Participants performed the dynamic movement for stretching the targeted muscles five times slowly, and then 10 times fast. The participants did not make bouncing movements while performing the dynamic stretching. For the control group, participants performed three maximal vertical jumps after the warm-up phase. The participants stood on the jump mat with the feet placed shoulder-width apart. They then flexed at the hips and knees to a comfortable depth with their hands on their hips and held this position for 2 s. After 2 s, the participants jumped on command. A contact-mat system was used to measure jump height and flight time. The vertical jump height was less after static stretching than after the condition not involving stretching. The vertical jump height for the condition not involving stretching was less than that of dynamic stretching.

Hough et al. explained the elements of the mechanism responsible for the results found in the experiment. The researchers stated that the stretching had not been performed to the point of pain, so defied the mechanism suggesting a neurological block as a result of nociceptor responses. Instead, the researcher proposed that the static stretching might have stimulated the GTO. Stimulating the GTO would lead to reciprocal inhibition and hence decrease the motor neurons that supply the antagonist muscle. The result would be relaxation in the muscle that was supposed to generate tension. This would lead to a reduction in force production. The researchers also suggested that the change in the viscoelastic properties of the musculotendinous unit could have led to reduction in the muscle's force production. A stiffer musculotendinous unit improves the muscle's force production properties as it positively impacts on the musculotendinous unit's length-tension and force-velocity relationships.

The researchers pointed out that the increased EMG activity during the dynamic stretching activity could have improved mechanical and electrical muscle activity. The dynamic stretching activity may have triggered postactivation potential, which improves the quality of muscle contractions by increasing the release of calmodulin-dependent protein kinases II from the sarcoplasm and increasing the phosphorylation of the myosin postmaximal voluntary contractions of the target muscle.

Yuktasir and Kaya (2009) determined the effect of 24 sessions of static stretching and a contract-relax type of PNF stretching on ROM and drop jump height after a day of the last intervention for each of the treatments. The participants were 29 healthy students. They were randomly distributed into three different groups: a static stretching group, a contract-relax type of PNF stretching group and the control group. The data collection took place during three different sessions. Before the six weeks of stretching, the ROM and the drop jump parameters were measured. Then participants stretched 4 days a week for 6 weeks. Following the 6 weeks of intervention, participants underwent ROM and drop jump measurement again. They were instructed to drop from a 60 cm high box onto a contact mat with the hands on the hips and then jump straight up as high as possible. The ROM was measured using a goniometer. For their static stretches, the participants lay on the couch with the hip and knee at 90 °. Next, the experimenters extended the knee to stretch the hamstrings, and bend the ankle to stretch their triceps surae muscle. To perform the contract-relax PNF stretches, the participants were instructed to lie on their backs with the hip in flexion at 90 ° and the knee extended with a neutral ankle. As they lay in this position, they were assisted to flex the ankle into 10 ° dorsiflexion with hip extension for 10 s. The participants then extended the hip against the submaximal force being applied for 5 s, followed by 5 s of rest. Next, the participants were assisted to move the hip into flexion with the knee extended and the ankle in dorsiflexion for stretching. The stretch phase of the contract-relax PNF was held for 15 s. The third intervention was the control session. The control group did not participate in any exercises.

Yuktasir and Kaya performed descriptive statistics and one-way ANOVA to analyze the difference between the three groups. None of the three groups had any statistically significant changes in performance after 6 weeks of intervention. The researchers did notice an increase in ROM in the PNF group participants. There was no significant increase in ROM in static stretching group participants. Yuktasir and Kaya concluded that 30 s of PNF and static stretching has no effect on drop jump performance.

Curry et al. (2009) compared the effects of static stretching, dynamic stretching, and light aerobic activity on muscular performance in women, measured using a variety of tests. Twenty-four recreationally active participants volunteered for the study. The participants were randomly distributed into groups, and the researchers received no information regarding their distribution. All the participants performed all of the experimental tests; all participants also served as control subjects. The different experiment days were separated by at least 48 hr.

On the experiment days, the participants performed warm-up for 5 min on a cycle ergometer; the intensity of the warm-up was measure by the Borg scale of perceived exertion. Participants maintained a perceived exertion of between 10 and 11 on the scale. The dependent variables were the Thomas test to measure quadriceps flexibility, countermovement jump height, and the time required in reaching peak force. After the pretreatment test measurements, the participants performed the independent variables of the treatment: light aerobic activity, static stretching, or dynamic stretching. The posttest measurements of the dependent variables were recorded twice, after 5 min and after 30 min of warm-up. The light aerobic activity session included 5 min of cycling, and another 10 min of cycling as a part of their treatment. The participants were instructed to cycle a constant rate of 70 rpm and the resistance was adjusted until participants perceived exertion in the range of 10–11 on the Borg scale. The static stretching protocol consisted of 5 min of cycling followed by three sets of static stretches of six different muscle groups. Each stretch was held for 12 s and stretched to the point of discomfort. Both lower limbs were stretched, one after the other. To stretch the gluteal muscles, the participants assumed a unilateral long sitting position with one foot over the knee of the target leg (the figure-of-four position). In this position, the participants brought the bent knee toward the contralateral shoulder. The participants assumed modified hurdler's position to stretch the hamstrings, extending the target leg to the front, with the toes pointing to the ceiling and bending the contralateral limb so that the sole of the foot made contact with the medial aspect of the target leg's thigh. In this position, the participants bent at the hips to touch the toes of the target leg. The participants stretched the hip flexor muscles in a stride-kneeling position; then the participants bent forward while keeping the trunk in an erect position. To stretch the quadriceps muscles, the participants assumed a unilateral standing position. In this position, they flexed the target knee and brought the heel to the ipsilateral buttock. To stretch the gastrocnemius muscle, the participants assumed a stride-standing position with the hands on the wall. In this position, they kept the back leg straight and behind them, and slid it backward while maintaining constant contact between the heel and the floor. The participants stretched the soleus muscle in the same position as the gastrocnemius muscle by slightly bending the leg that they slid back. The dynamic stretching protocol consisted of 5 min of cycling for light warm-up followed by nine active movements through the active ROM for 10 min. The dynamic stretching included side leg swings, forward leg swings, a sideways jumping-jack motion, fast hopping, hopping high, knee-to-chest motions, butt kicks, a combination of knee-to-chest movements and butt kicks into a cycling motion, straight-single-leg skipping, and walking lunges. For the countermovement jumps, participants were asked to stand 15 cm away from a wall. The tip of the middle finger was marked using a marker and they were asked to mark on the wall the highest point of the jump. The participants performed three jumps; they were allowed to take one step in preparation for the jump. The researcher concluded from the post hoc test that all measurements for both posttreatment tests, after 5 min and after 30 min, were significantly lower than the pretest measurements for all the test conditions. The researchers speculated that females have less muscle stiffness and thickness as compared to their male counterparts. As this study had only female participants, the same stretching protocol may not have brought about any changes in the results. The researchers suggested that for testing any stretching protocol, females should be included among the participants to help determine if the same stretching protocols affect males and females differently. If this were the case, then it might be worthwhile to determine the difference between males' and females' musculotendinous units.

Pearce et al. (2009) determined the effect of a bout of exercise after static and dynamic stretching as part of the warm-up. The researchers also intended to relate the intensity of the participants' warm-up activities with their heart rates. The participants were 13 healthy students from a university population, 18–28 years old.

Before the intervention or the collection of baseline data, collection participants completed a VO_2 max test on a treadmill. The participants completed a general warm-up for 5 min at 65% of their maximum heart rate, followed by a preintervention jump test. The control group performed general warm-up activities and then performed a jump test immediately after the warm-up, as well as 10 min, 20 min, and 30 min after the warm-up. The static stretching group performed static stretches, followed by a countermovement jump test, followed by the same series of activities as the control group. The dynamic stretching group performed a dynamic stretching protocol, followed by a countermovement jump test, followed by the activities performed by the control group. The countermovement jump tests were conducted on a custom-built force plate at a rate of 2000 Hz. The participants were instructed to bend their hips and knees to 60–80° during the countermovement phase of the jump and keep their hands on their hips. The force plate data collected was analyzed with LabVIEW software.

The general warm-up that all groups performed consisted of two sets of running 10 m with high knees and arms swinging, two sets of stepping sideways and moving laterally for 10 m, two sets of crossover activity with sweeping movement for 10 m each, two sets of skipping with high knees and arm activity for 10 m each, and a single set of running in a zigzag pattern for 20 meters.

The static-stretching participants performed two sets of static stretches for all lower-limb muscle groups. They held each stretch for 30 s, with 15 s of relaxation between sets. To stretch the hamstrings, the participants sat on the floor with the target leg in front of them and the other leg flexed so that the sole of the foot touched the medial aspect of the target leg. In this position, the participants leaned forward to reach the foot of the target leg. To stretch the gastrocnemius muscle, they performed a double-leg stretch: they kept the feet together 1 m away from the wall and leaned toward the wall, placing the hands on it. To stretch the hip-flexor group of muscles, the participants assumed a forward-lunge position with feet placed comfortably, as far apart as possible. In this position the participants lowered the center of mass until a stretch was felt in the hip-flexor muscles. To stretch the quadriceps muscles, participants assumed a standing position and brought the heel of the target limb to the gluteal muscle bulk by bending the knee and simultaneously tilting the pelvis posteriorly while maintaining the spine in an erect position.

The dynamic stretching protocol consisted of movements with an exaggerated ROM. Participants performed two sets of 10 repetitions on each side of a knee-to-chest movement. While doing this movement, the participants were instructed to rise up on their toes. They performed one set of 10 repetitions of an anterior-posterior leg swing with the wall providing side support. They performed one set of 10 repetitions of medial-lateral leg swings, supporting themselves with the wall in the front. They performed one set of 10 m of a hurdler's knee-raise movement, going forward and backward. They performed two sets of moving 10 m while touching the heels to the buttocks for quadriceps stretches. They also performed two sets of walking 10 m with heels raised and stepping on tiptoes as they moved forward.

The heart rate data from the three groups were compared by one-way ANOVA. The tests were used to compare the effect of the various treatments on the tests. Pearce et al. (2009) concluded that there was a 10.7% difference in countermovement jump height between the static and dynamic stretching groups immediately after the stretching condition. The researchers failed to clarify, which groups' vertical jump was higher. The main aim of the experiment design was to understand the difference between the poststretch jump and the postsecondary-warm-up jump. The researchers concluded that the countermovement jump height increased 7.2% immediately after the secondary bout of warm-up activities, compared to prestretch (baseline) data. Similarly, the control group saw an increase of 8.52% in countermovement jump height after the secondary bout of warm-up activities as compared to prestretch (baseline) countermovement jump height. For the static stretching group, the countermovement jump height increased 3.7%.

Taylor et al. (2009) sought to determine whether the detrimental effects of static stretching continue after a bout of sport-specific activity performed after the stretching. Thirteen healthy netball players from the Australian Institute of Sport netball program participated for the study. The participants were familiarized with the experiment in two sessions before the actual tests. The participants performed a 300 m submaximal run followed by either nine static stretches or 16 dynamic warm-up movements.

The static stretches were held for 30 s each, to the point of mild discomfort, and were repeated two times for each limb. They targeted all the major muscle groups of lower extremity, including the calf, the Achilles tendon, the hamstrings, the gluteus maximus, the quadriceps, the lower-back muscles, the groin muscles, and the quadratus lumborum muscle.

The dynamic warm-up consisted of 16 ROM movements, which gradually increased in intensity. The following movements were included: high knees, kicks to the buttocks, cariocas, hamstring swings, groin swings, arm swings, fast high knees, swerving, side stepping, Spiderman walks, low-squatting sideways walks, upper-body rotations, vertical jumps, running at different intensities, countermovement jumps with fast 5 m sprints, and sprints for 5m followed by countermovement jumps.

After the stretching and dynamic warm-ups, participants were given a 2–3 min rest and then tested for a 20 m sprint and a vertical countermovement jump. The participants were instructed to bend their knees to a self-selected depth before performing the jump. The researchers did not provide details regarding the hand swing during the countermovement jump. Following the testing of the dependent variables, a 20 m sprint and countermovement jump, the participants performed netball-specific warm-up and then tested again for the dependent variables. The researchers used descriptive statistics and paired t-tests to analyze the effects of the two independent variables, static stretching and dynamic stretching, on vertical jump and sprint performance. The vertical jump height after the dynamic warm-up activities was greater than the height of jumps performed after static stretching in both tests. When the results of the first test, of static stretching and dynamic warm-up activities, were compared with those from the second test, which included sport-specific activities, the second test results were better for both conditions. The difference, however, was not statistically significant.

The researchers suspected the improvement after dynamic warm-up activities could have been because those activities increased the muscle temperature. Increased muscle temperature has been shown to support rapid and forceful muscle contractions. The results also showed improved results for the static stretching condition followed by sport-specific activities, which indicates that any detrimental mechanism can be minimized by the performance of sport-specific activities.

Gonzalez-Rave et al. (2009) compared the acute effects on squat and countermovement jumps of just heavy-load resistance training, just static stretching, and heavy-load resistance training combined with static stretching in an untrained population. The researchers hypothesized that at least one treatment of heavy-load resistance training and stretching would alter the squat jump and the countermovement jump performance, if not both. The participants were randomly assigned to one of three groups. Those participating in the heavy-load resistance training session attended a session in which their three repetition maximums were determined for the squat exercise. The squat exercise was performed on a Smith machine with the knees at 90°. The participants performed a series of tests that simulated actual experiment-day tests.

The participants in all the groups performed a general warm-up on a cycle ergometer at a comfortable speed. The participants rested for 3 min after the general warm-up, and then performed two pretreatment vertical jumps for baseline measurement. Following the general warm-up and the pretreatment jumps, the heavy-load resistance training group performed one set of four repetitions with 85% of one repetition maximum half-squats. The participants tested for the squat jump and the countermovement jumps without a rest after the resistance training. After the set of resisted squats and jumps, the participants rested for 3 min. This complete set of resisted squats followed by jumps was repeated three times with a 3 min rest period between each set. The group engaging in heavy resistance training plus stretching followed the same protocol of heavy resistance; in addition, they also performed three stretches, holding each stretch for 15 s. The stretches were performed three times with a 3-min break between each protocol. The rest period and the posttest remained the same for the stretch group.

The groups performing stretches, just static stretching group and the heavy resistance combined with static stretching group, stretched the hamstrings, the quadriceps, and the calf muscles. The participants assumed a bilateral long–sitting position and flexed forward at the hips to simultaneously stretch the hamstrings of both legs. The quadriceps group of muscles was stretched one leg at a time; the participants assumed a unilateral standing position and flexed the knee of the target limb to bring the heel to the ipsilateral buttock. The calf stretch was also performed on one leg at a time. Each stretch was held for 15 s.

The test consisted of three squat jumps and three countermovement jumps; out of the three jumps, one best jump was selected for data analysis. The participants were instructed to perform the squat jumps with the hands on the hips, keeping their knees in 90° and jumping at the command. The countermovement jumps started with participants in a standing upright position.

On the command, they flexed their knees and hips into a squat position and then jumped without any pause.

The researchers analyzed the data with the Bonferonni post hoc test. The researchers concluded that the squat jumps and countermovement jumps improved after the first static-stretching set and remained the same after the second and third sets of stretching. The improvements in the jump performance were not significant; hence the hypothesis put forth by the researchers did not hold true. The researchers had suspected that the participants' condition would affect the effects of stretching or loading on the vertical jump performance, that professional athletes would experience more potentiation and a less-conditioned population would feel more fatigued. In this experiment, the opposite was true. Since the researchers did not record neuromuscular activity, the decrease in postactivation potential could not be explained by the neuromuscular mechanisms associated with stretching and jumping.

Bazett-Jones, Gibson, and McBride (2008) conducted a study to determine the effect of 6 weeks of stretching on ROM, 55 m sprint time, and vertical jump height. Twenty-one athletes from NCAA Division III women's track and field participated in the study. Participants were divided randomly into stretching and control groups; 10 participants were in the stretching group and 11 in the control group. The control group participants were instructed not to stretch the hamstring muscles during the course of the participation in the study, although they were allowed to stretch any other muscle or muscle group. The participants in the stretching group stretched their hamstrings as part of their warm-up, prior to their sport-specific exercises. The participants stretched the hamstrings in a unilateral standing position; they positioned the heel of the targeted leg on an 8–12 in (20 to 30 cm) raised area with the foot dorsiflexed and the knee in extension. The participants were instructed to stretch the hamstrings to the point of mild discomfort while keeping the back straight and anteriorly tilting the pelvis. The stretch was held for 45 s and was repeated four times with a 45–60 s break between each repetition. The data for analysis were recorded the day before any stretching protocol was taught, during the 3rd week, and after the 6th week. The participants did not perform any other training or stretching on the day of testing the dependent variables.

The ROM for both the legs were tested by having participants lay supine, stabilize the hip and knee at 90˚, and then extend the knees. The vertical height of the countermovement jump was measured on a Kistler Quattro Jump Force Plate (Kistler Instrument Corp., Buffalo, NY as cited by Bazett-Jones et al. 2008). The participants performed a countermovement vertical jump with the hands on the hips to prevent additional movement from arm swing. The researchers utilized a two-way ANOVA test to analyze the data. The researchers concluded that 6 weeks of static stretching had no effect on vertical jump performance. They supported the results of this study by explaining the mechanisms suggested by Hunter and Marshall (2002); the researchers in previous studies have hypothesized that the improvement in the performance after chronic stretching stems from the increase in muscle compliance and reduction in energy requirements. According to Bazett-Jones et al., there was no increase in the jump performance in this study because there was no increase in the ROM or change in compliance of the muscle. They suggested that a regular stretch protocol, not performed during warm-up or sports-activity time, be developed, which would increase the compliance of the muscle and might help improve the jump performance. To support this hypothesis, they suggested that more studies investigating different chronic stretching (stretching for a longer period) protocols should be performed to determine the effect on different athletic activities.

Kinser et al. (2008) determined the effect of simultaneous stretching and vibration on ROM in forward-split and explosive-force performance in competitive young athletes. Explosive force was measured by vertical jump. The participants were 22 females of age mean 11.3 ± 2.6 years. All the participants were competitive gymnasts, who had been participating in competitions for the prior 2.4 years. The experimental protocol consisted of simultaneous vibration and stretching as the independent variable. The participants performed flexibility tests and vertical countermovement and static jumps as dependent variables. All participants performed the experimental protocol of simultaneous stretching and vibration. They were then divided into four control groups: stretching without vibration and flexibility testing, vibration without stretching and flexibility testing, stretching without vibration and explosive strength, and vibration without stretching and vertical jump test. The data collection was counterbalanced for the experimental group and for the four control groups (stretching without vibration and flexibility testing, vibration without stretching and flexibility testing, stretching without vibration and explosive strength, and vibration without stretching and vertical jump test). The simultaneous stretching and vibration was applied to four muscle groups. The participants were in a forward-split position with the dominant leg in extension while vibration was applied to the four muscle groups of the lower limbs. The participants performed four sets of stretches held for 10 s each with a 5-s break between each set. The participants stretched to the point of discomfort. The sites of stretching were the anterior thigh, posterior thigh, anterior lower leg, and posterior lower leg. The vibrating machine was place in a manner that the muscle in a stretched position received the vibrations. The vibrations were given at a frequency of 30 Hz. Participants performed jumps for maximum vertical height and flexibility measures before and after the treatment protocols. Flexibility was determined by measuring the height of the anterior superior iliac spine from the ground in split position. This test has a high reliability. The jump height, duration of jump, and flight time were measured by portable force plates (National Instruments, Austin, TX as cited by Kinser et al., 2008). The portable force plates were set at sampling rate of 1000 Hz. The group differences were analyzed by effect size and t-test.

There were no significant effects on the mean jump height for the simultaneous vibration and stretching group (from 20 $\pm$ 3 cm to 19 $\pm$ 3.5 cm). There were also no significant effects on mean flight time (from 402 $\pm$ 30 ms to

400.1 ± 34.2 ms). The researchers concluded after t-test analyses that the mean jump measures, jump height, and flight time for static jump and countermovement jump were not affected in young competitive gymnasts by stretching or vibration at 30 Hz.

Samuel et al. (2008) sought to determine the effects of static stretching and ballistic stretching for the amount of time considered as practical by the experimenters on vertical jump, lower-extremity power, and the quadriceps to hamstrings ratio. Twenty-four healthy university students participated for the study. The dependent variables were vertical jump, power, and torque. Vertical jump was measured by using Kistler force plates (type 9281B, Kistler Instrument Corp., Amherst, NY as cited by Samuel et al., 2008), power was measured by countermovement jump height, and torque was measured by using Biodex System 3 Dynamometer (Biodex Medical Systems, Shirley, NY as cited by Samuel et al., 2008). The independent variables were static stretching, ballistic stretching, or no stretching. All participants performed all of the independent variables on three different days with 48 hr. rest between each test. Participants attended an orientation prior to testing, in which they were acquainted with the procedures and tests. On the test day, the participants warmed up, performed the stretching technique of their respective groups, and then were tested for the jump. The participants stretched their quadriceps and hamstrings muscle groups. To stretch the quadriceps, the participants assumed a unilateral stance and brought the heel to the gluteus while posteriorly tilting the pelvis. To stretch the hamstrings, the participants assumed a long sitting position. Next, they positioned the target leg in extension and the contralateral leg so that the sole of the foot touched the medial aspect of the knee. The participants anteriorly tilted the pelvis to flex at the hips. The participants were instructed to stretch until they felt a strong stretch in the targeted muscle group and hold for 30 s for each muscle group.

To perform the ballistic quadriceps stretch, the participants flexed the knee until they felt the stretch in the quadriceps, and within 2 s of feeling the stretch, they extended their knee to the point where they did not feel stretch any longer. For ballistic stretching of the hamstring muscles, the participants flexed forward at the hip and trunk until they felt a strong stretch and then bounced forward and backward. The bouncing movement created by the ballistic stretching was performed with a metronome set at rate of one bounce per second, for a total of 30 s. The control group performed the countermovement jump testing immediately after 5 min of warm-up. The researchers concluded that neither static stretching nor ballistic stretching affected the vertical height of the countermovement jump or the torque produced by the hamstrings and quadriceps muscles. The stretching did not affect men and women differently. The researchers compared the mean power output for the three groups and found that the static stretching and ballistic stretching had a detrimental effect on power. When compared to the static-stretching and ballistic-stretching groups', the control group had a greater mean power. The researchers suggested the mechanisms that could have caused the reduced jump performance after the static stretching were reduced muscle activation and reduction in musculotendinous unit stiffness.

Wallmann, Mercer, and Landers (2008) studied the effect of the dynamic activity on the surface electromyographic activity of the gastrocnemius, and the effect of dynamic activity with static stretching on countermovement jump performance. The participants were seven men and six women who were untrained and healthy. Kistler force plates (Type 9281B; Kistler Instrument Corp., Amherst, NY as cited by Wallmann et al., 2008) were used to measure jump performance. Telemetry EMG system (Noraxon USA Inc., Scottsdale, AZ as cited by Wallmann et al., 2008) was used to record the EMG activity of the muscle. The electrode placement area of the skin was shaved and wiped with alcohol. The electrodes were placed 2 cm apart on the lateral head of the gastrocnemius, one-third of the way down from the head of fibula. A baseline reading was taken at the beginning of the data collection day by recording no muscle activity. For EMG data collection, the participants walked at a speed of 3 miles per hr. (4.82 kmph) for 5 min on a treadmill. A 15-min rest period was provided before the prejump data collection began. Two different prejump data points were collected on two separate nonconsecutive days. For the dynamic-activity-only protocol, the participants performed continuous hopping for 1.5 min; muscle activity during the first and last 10 s was recorded. For the protocol consisting of dynamic activity with static stretching, the participants performed the same hopping activity followed by stretching the gastrocnemius three times. The participants stood on an inclined board with straight knees to stretch their gastrocnemius muscle. The stretch was repeated three times and held for 30 s each time. The participants performed three countermovement jumps in 30 s with their feet together and hands on the hips. The EMG activity from the point of takeoff (value dropped below 20 N) to landing was considered for averaging and data analysis. Average EMG was calculated after full wave rectification and the zero offsets were removed.

The muscle activity after the dynamic activity was only reduced by 2.4%; the muscle activity after dynamic activity with stretching was reduced by 12.6%. Wallmann et al. (2008) concluded that the two interventions had no effect on the jump height. The muscle activity difference pre- and post intervention was not statistically significant.

The purpose of a study by Christensen and Nordstrom (2008) was to determine the effects of three different types of warm-ups on a large sample size. The researchers also wanted to know if different genders would see any difference from these warm-ups on vertical jump performance. Sixty-eight participants (36 were men and 32 were women) from North Dakota State University volunteered for the study. All participants were NCAA Division I athletes. The three warm-up protocols were a 600-m jog only, a 600-m jog followed by dynamic stretching, and a 600-m jog followed by PNF stretching. The warm-ups were followed by vertical jumps. The Just Jump mat was used to measure the jump height. The participants were divided into six different groups so they could participate in all three warm-up protocols on three consecutive days.

The contract-relax stretch method was used as the PNF stretch for the experiment. Participants contracted the target muscle group in a stretched position, held to the count of two, and then a partner passively stretched the muscle to the count of five. Participants performed PNF stretching on the hamstrings, quadriceps, hip adductors, and calf muscles.

The dynamic stretches consisted of five repetitions of sets of eight exercises: skipping for height, walking lunges, side shuffles, short-step low cariocas, cariocas with high knees, backward runs, high-knee runs, and butt-kickers. All these exercises were familiar to the participants. The testing jumps took place approximately 2 min after the warm-up and stretching protocol. The participants were allowed a self-selected countermovement depth to utilize the benefit of the stretch-reflex mechanism to increase the vertical jump height (Wilk et al., 1993).

The researchers analyzed the data with a one-way analysis of variance with repeated measures, analyzing the men and women's data separately as well as the combined data. They concluded that there were no significant differences in vertical jump height after any of the three types of warm-up. There was no significant difference between men and women's vertical jump height after any of the warm-up and stretching protocols.

Christensen and Nordstrom explained the results by stating that this study included dynamic activities, such as carioca. Other studies have used methods like immersion in water and stationary bicycling as a means of raising body temperature. According to the researchers' review of literature, most active or passive activities that raise the body temperature help improve power performance, although that might not be the case for endurance activities.

Hamada and Sasaki (2008) performed a study to determine the effects of static stretching on vertical jump performance. The study was excluded from the review because an English translation of the study was not available.

Cronin, Nash, and Whatman (2008) compared the acute effects of passive static stretching, vibration, and a combination of both on knee-joint range of motion and on jump performance. Ten healthy participants volunteered for the study; all were free from any musculoskeletal injuries. All participants performed stretching, vibration, and a combination of both on separate days as the independent variables. The participants' ROM and vertical jump height were measured before, immediately after, and 10 min after the interventions. The participants performed light jogging at their perceived 40% max before any of the interventions and after preintervention testing. To measure the ROM, the lateral epicondyle of the knee and the lateral malleolus were marked with black marker, and a marker was placed in line with the greater trochanter on the couch participants lay on. A specially constructed frame was attached to the couch, and the knee was tied to the frame with the frame at 90˚ to make sure the hip was not flexed past 90˚. In this position, the participant was asked to extend the knee as far as they could. Video data were recorded to analyze the knee angle.

The stretching protocol consisted of three sets of stretches held for 30 s each time, to the point where comfortable stretch was felt. The participants positioned the target leg on the vibrating machine, which was not yet vibrating, by flexing at the hip and keeping the knee in extension while anteriorly tilting the pelvis. The vibration was applied to the hamstrings in this partial-lunge position at a frequency of 34 Hz and acceleration of 42.2 ms^{-1}. To perform the combination of stretching and vibration, the participants assumed the position for the vibration, and after the vibration, they were given 5 s to assume the stretching position. The participants performed three sets of stretches and vibration held for 30 s. The vertical jumps were measured on a jump mat. The participants were instructed to jump with the hands on the hips from a self-selected depth. They jumped until their performance reached a plateau between one cm and 1.5 cm.

The researchers analyzed the data using one-way repeated ANOVA. They reported a slight, acute increase in the ROM. Vibration only and vibration in combination with stretching did not increase or decrease the vertical height of the countermovement jump. The researchers suggested that the acute improvement in the joint's ROM might have been due to the creep response of the muscle.

Jaggers et al. (2008) compared the immediate effects of dynamic stretching and ballistic stretching on vertical jump height. Ten males and 10 females from a local college participated in the study. All the participants were healthy without any medical problems that would affect the data of this study. The participants visited the laboratory on three nonconsecutive days. On the first day, they were acquainted with the procedures, and their heights, weights, and leg lengths were recorded. The participants performed a 5-min warm-up on a treadmill at a self-selected pace followed by a vertical jump test for baseline measurement. The subjects were instructed not to participate in any lower body exercise within 24 hr of the testing appointment. On the two testing days, the participants performed two sets of ballistic or dynamic stretches, depending on which group they were assigned to on that day. Then, the participants performed three countermovement jumps on Kistler Quattro Jump (Amherst, New York as cited by Jaggers et al., 2008) force plates. The researchers did not give details about the countermovement jump. The participants performed three sets of five ballistic stretches or dynamic stretches.

The ballistic stretching for this study targeted the hip flexors (iliopsoas and rectus femoris), hip extensors (gluteus maximus and hamstrings), hamstrings, spinal erector muscles, gastrocnemius, quadriceps, hip adductors, and the sartorius muscle. The ballistic stretching was performed for a period of 30 s at a rate of 126 beats per min. The hip flexor muscles were stretched in forward-lunge position, one leg at a time. In this position, the participants performed up and down motions with the beat. The hip extensor muscles were stretched by bringing the thigh to the chest while lying on the back. Placing the hands over the thigh, participants pulled the thigh toward the chest in bouncing motions. The hamstrings, the spinal erector muscles, and the gastrocnemius muscle were stretched in a long sitting position. The participants were asked to try to grasp the feet or ankles, and then produce the bouncing motion at the hips. In this position, the participants were instructed to produce the motion from the hips, and keep their arms stable. The participants assumed a unilateral stance position for the quadriceps stretch. The bouncing motion was produced by trying to touch the heels to the buttocks at the rate of the beats. To stretch the hip adductors and the sartorius muscle, the participants assumed an erect-sitting position with flexed and externally rotated knees so that the soles of the feet were in contact. In this position, the participants bounced their knees to produce the ballistic stretch.

The dynamic stretching action was performed five times slowly and then 10 times as powerfully as possible. The antagonist muscle group movement was performed so that the agonist muscle, which was the target muscle, felt stretched. The dynamic stretches focused on the same five muscles groups as the ballistic stretches. To stretch the hip flexors, the participants stood on one leg and extended the target leg. The movement consisted of a backward kicking motion. To stretch the hip extensors, the participants performed a thigh-to-chest movement. The participants stretched the calf muscles by assuming a push-up position with one foot beside the trunk. In this position, they were instructed to touch the heel of the back leg to the floor while keeping the knee and hip in extension. The participants performed a hurdle step-over movement that involved abduction and lateral rotation of the lifted thigh. To stretch the quadriceps, the participants kicked their buttocks with the heel of the same foot. The researchers analyzed the data by paired t-tests. The researchers found that there was no remarkable difference in jump height between the control group and the ballistic stretching and dynamic stretching groups.

The researchers discussed plausible neural explanations for the results found for their experiment. They proposed that the stretches had no effects because of decreased H-reflex. However, in this study, neither the dynamic stretch nor the ballistic stretch was held for the period required for reducing the H-reflex. The researcher compared the study design and protocol of this experiment with studies done by Unick et al. (2005) and Avela et al. (1999).

Robbins and Scheuermann (2008) compared the effects of two sets, four sets, and six sets of active static stretches on vertical squat jumps. Twenty healthy and active college students participated in the study. Out of the 20 participants, 10 were athletes at a collegiate level, and the other 10 were recreationally active. All participants participated in three treatments and a control-data-collection meeting. Each visit was separated by a period of two to four days.

On experiment days, the participants warmed up on a commercial upright bicycle ergometer for 5 min at the rate of 70 rpm. The warm-up was followed by a 4-min rest period, followed by three trials of pretreatment vertical jumps. The participants then performed two repetitions, four repetitions, or six repetitions of stretches, or no stretches, depending upon the group they were assigned to. This was followed by a rest period of 4 min. The static stretching targeted the hamstrings, quadriceps, and plantar flexors. Each stretch was held for 15 s with a rest of 15 s between each repetition. The participants were instructed to stretch to a point beyond which they would feel pain. The participants stretched their hamstrings muscles by assuming a bilateral long sitting position and trying to touch the feet with the hands. The quadriceps muscles were stretched in a unilateral standing position. The participants touched the heel of the target leg to the gluteus maximus, and extended the hip. The participants leaned toward the wall and slid the target leg back by extending the hip to stretch the gastrocnemius muscles. The participants in the control group were given a 15-min rest.

The participants performed three trials of posttreatment vertical jump tests. To perform the squat jumps, the participants assumed the starting position with their knees flexed at approximately 100°. They were allowed to jump with full arm swing. The squat jumps were performed on the Just Jump mat (Probotics, Huntsville, AL). The researchers used one-way ANOVA to analyze the data.

The researchers concluded that the height of the squat jumps after six sets of stretching was lower than the pretreatment jump height. However, the researchers did not find any statistically significant difference between any of the posttreatment jumps. The researchers also concluded that after 90 s of stretching, the jump height reduced as it did after six sets of stretches. The researchers noticed that the decrease in the temperature for the control group after the 15 min rest also reduced jump height; it ended up equivalent to the jump height for participants who performed four sets of static stretches.

Robbins and Scheuermann designed a protocol that provided enough rest periods after each set of stretches in this study to increase understanding of the physiology of the muscles after stretches. They noted that, in previous studies, the decrease in the motor neuron excitability was suspected of reducing vertical jump height or force production for any other dependent variable. The motor neuron excitability is measured by the H-reflex. However, many researchers have suggested that the H-reflex is recovered soon after stretching. Unick et al. (2005) explained that decreased H-reflex recovers within 4 min of stretching, which means the detrimental effects of stretching should only last for 4 min after stretching. Hence, the decreased motor neuron excitability or decreased H-reflex theory does not explain the results of this study. The amount of time after the stretching and the participants' activities during the time between stretching and testing may determine the mechanism that affects the stretching. Since the neuromuscular theory is inapplicable, the theory of decreased musculotendinous stiffness and the theory of increased compliance prevent improvement in the jump performance after 4 min of stretching.

Vetter (2007) studied the effects of six different warm-up protocols on 30-m sprint and countermovement jump performance. Four of the six warm-up protocols included stretching. Twenty-six participants volunteered for the study. All were active and participated in physical activity for at least 30 min for 3–5 days per week. The participants visited the testing site on seven different days. On the first day, the participants were acquainted with experiment protocol and procedures. Participant age, height, and weight were recorded for the demographic data. The next six visits were separated by 48–78 hr; on those days, participants were randomly assigned to different warm-up groups to test the effect for that warm-up. The six potential warm-ups were: walking and running; walking, running, and performing small jumps and exercises; walking, running, and performing small jumps and exercises and dynamic active stretches; walking, running, and performing dynamic active stretches; walking, running, and performing small jumps and exercises and static stretches; and walking, running, and performing static stretches.

For the walking protocol, the participants walked once for 4 min on a 25-mile (40.23 km) walkway. For the running protocol, participants ran on the same walkway for 2 min. The exercises accompanying the small jumping activity were toe raises, marching 20 steps with high knees, marching 20 steps with kicks to the buttocks, and 10 repetitions of small jumps. The above sets of four exercises were repeated three times. All exercises were performed to beat of one movement per second. For example, participants took 1 s to raise the toe, 1 s to lower the toe, and 1 s each to lift and lower the knee. The dynamic stretches included stretches for the muscle gastrocnemius, the adductors muscle group, the quadriceps, and the hamstrings. The adductor muscle group was targeted via demi-pliés. Each muscle was stretched eight times. The participants were instructed to count to three second to get into the stretch position and count 3 s to get out of the stretch position. The demi-pliés were performed with a three ft (91.44 cm) distance between the feet. To stretch the quadriceps, participants brought the heel to the buttock in a standing position without externally rotating the hip; to stretch the gastrocnemius, they slid the target leg backward while keeping the heel on the ground. To stretch the hamstrings, participants flexed at the hip while extending the knee and the foot in dorsiflexion. During this stretch, participants were advised not to flex the back. The static stretching targeted the same four muscles as the dynamic active stretching. The static stretches were held for 30 s. During the hamstrings and gluteus maximus stretches, a partner or a bar was used to hold the limb in position. The countermovement jumps were performed barefoot to avoid any benefit provided by participants' shoes. The participants were instructed to jump with their arms flexed at the shoulder and extended at the elbow so that the hands were straight above their shoulders, to prevent arm swing. The participants were allowed to select a comfortable knee flexion for the jump with the condition that the heels of the feet must stay in contact with the floor. The researchers analyzed the data by repeated measures ANOVA.

The researchers found no significant difference in the jump heights of any of the warm-up protocols. The researchers mentioned that, within the minor differences found, the warm-up with static stretching resulted in the lowest jump height. The researchers noted that the results were in accordance with the results of previous studies. The researchers did not discuss the mechanism behind the results of this study.

Bradley, Olsen, and Portas (2007) set out to compare the effects of ballistic stretching, static stretching, and PNF stretching on the vertical jump test. The researchers also wanted to determine the duration of potential stretch-induced deficits on jumping performance over a period of 60 min. Eighteen university students participated in the study. The selection criteria for the participants were that they should be free from injury, able to attempt a maximum vertical jump, and able to stretch without pain.

The participants reported to the laboratory on five different occasions. In the first session, the participants were familiarized with the laboratory and the research protocols. In each stretch condition, the quadriceps, the hamstrings and the plantar flexor muscle groups were stretched. Stretches included the supine gastrocnemius stretch, butterfly stretch, supine hamstring stretch, prone quadriceps stretch, and kneeling quadriceps stretch. All subjects performed the conditions in a randomized order on different days, with a minimum of 72 hr of rest between days. The warm-up for all the stretching protocol was standard cycling.

During static stretches, participants were held in the stretch for 30 s for each muscle group, at a point slightly beyond discomfort level. The ballistic stretching procedure was similar to the static stretch one except it incorporated the end ROM. The researcher stretched the participants' muscles by moving forward and backward at a rate of approximately one bob per second for 30 s. In the PNF condition, the contract-relax technique was used. The researcher stretched the agonists to the end ROM, and then the participant performed 5 s voluntary isometric contraction of the antagonists, followed by a 30 s stretch to the agonists by the researcher. For the control condition, the participants performed cycling warm-up and then rested for 10 min. After the control condition, all participants rested for 30 s, followed by six vertical jumps: three static jumps and three countermovement jumps. The first set of static jumps was initiated from a static squatting position, maintained for 3 s before launching the body vertically. The participants performed countermovement jumps in the second set with the hands on the hips. The countermovement jump incorporated a preliminary movement of rapidly flexing the knees before jumping off the ground. The knee angle was measured at 90° for both jump sets. To assure that the participants bent 90°, after the knee was measured at 90°, a string was tied at the position of the hips. The vertical ground reaction force generated during each jump was collected using a Kistler force platform. The effect result data were collected once immediately after the intervention and after an interval of every 15 min up to 60 min. The data were collected immediately after the stretching, 5 min after the stretching, 15 min after the stretching, 30 min after the stretching, 45 min after the stretching, and 60 min after the stretching. A three-way repeated ANOVA was used for data collection. The researchers concluded that static jump height was significantly lower than countermovement jump height in general. It can be understood that, as the participants did not perform a countermovement in this kind of jump, the static jumps would yield lower vertical heights. There was significant reduction in jump height after static, PNF, and ballistic stretches. After PNF stretching and static stretching conditions, the jump heights were almost similar to those after 15 min.

The researchers suggested that static and PNF stretching affect the muscle activity with similar mechanisms of action. The reduction in the performance was because of reduced musculotendinous unit stiffness, altered reflex sensitivity, and decreased muscle activation. The researchers explained that there is positive correlation between the maximal concentric phase of bench press and musculotendinous stiffness. Static and PNF stretches decrease the stiffness of the musculotendinous unit, increasing compliance. Thus, the researchers deduced that static and PNF stretches cause reduction in muscle force production due to the neurological mechanisms responsible for decreases in strength production. The researchers also explained that the possible neurological mechanisms responsible for the decrease in strength production were change in reflex sensitivity and motor unit activation. The contract-relax type of PNF stretching stimulates autogenic and reciprocal inhibition. Autogenic and reciprocal inhibition reduces the motor neuron activation. The static stretch reduces the motor neuron activation in the muscle with the myotactic reflex. Autogenic inhibition and reciprocal inhibition decrease the motor neuron activation more than the myotactic reflex. Hence, the researchers suggest that the greater decline in the jump performance after PNF stretching compared to static stretching could be because of autogenic and reciprocal inhibition stimulated by PNF stretching.

The purpose of the study by Ross (2007) was to ascertain the effects of 15 days of a practically applicable hamstrings stretching program on lower limb performance in participants with limited hamstring flexibility. The effects were measured by single hop for distance test. Eight male and five female U.S. Air Force cadets participated in the study. The criteria to participate in the study were: no lower-back or lower-extremity injury in the prior 12 months, an active knee extension of less than 70° in a supine position with the hip at 90°, and full recovery from any previous back or lower extremity injury. Participants were involved in organized athletics, but no participants were intercollegiate athletes. The active knee extension was tested for participants positioned supine with the hip and knee in 90° flexion. They were asked to extend the knee from that position with the foot relaxed in plantar flexion. The distance for a single hop was measured by a tape measure; participants stood with the toe on zero of the starting line. Then participants hopped on one leg. The distance up to that leg's heel was measured. The participants performed two practice trials before they performed two test trials with a break of 30 s between each hop. The participants were randomly divided into a left- or right-lower-leg group for the stretching of that limb; the other lower limb was considered the control. The participants stretched their hamstrings by placing one foot at a time on a desk, and bending the spine and retracting the scapulae while reaching the toes. The participants were instructed to repeat the stretch five times and hold it for 30 s each time. They were asked to stretch to a point where tightness was felt in the hamstrings region. Once subjects were able to demonstrate the correct stretching technique, they were asked to stretch one lower limb but not the other limb once a day for 15 consecutive days. The researcher observed the participants once a week to check for correct stretching technique. The participants also received an illustrated instruction booklet and daily e-mail reminders to stretch. The participants stretched on the day of the test; they walked around the testing area for 10 min after their last session of stretching to leave a delay between stretching and testing. The data were analyzed with two-way ANOVA. The researcher concluded that there was significant posttest increase in hamstring flexibility and an increase in distance hopped compared to pretest. There was no significant change in the measurement of the control lower extremity in the single-hop-for-distance test when measured by Tukey's post hoc test.

The results of this study verified the suggestion of Shrier (2004) and the observation of Unick et al. (2005). The experimenter explained the relation between jumping and stretching the lower-extremity muscles by explaining the sequence of movements that take place during the jump. The lower limb prepares for the jump first by rapidly lengthening to perform the countermovement and then by rapidly shortening to take flight for the jump. This series of movements takes place in a very quick and reactive fashion. The propulsive force the athletes are able to produce before the feet leave the ground determines the jumper's duration of flight. When the participants bent forward, they eccentrically contracted their hamstrings and quadriceps. At that time, the potential energy was stored in their muscles. As participants hopped, the potential energy was converted to kinetic energy as they contracted their hamstring and quadriceps muscles to extend their legs and take flight (Cavagna, Dusman, & Margaria, 1968; Cavagna, 1970). The length of the muscle plays a role in storing the energy, which is used for jumping. The researcher derived that if the length of the muscle can be increased, the jump performance or any movement requiring rapid lengthening and shortening to produce explosive movement can be increased. The muscle would be able to absorb more force during the eccentric phase and generate more force during the concentric phase. Based on the aforementioned review, the researcher suggested that the 15 days of static stretching protocol helped improve the elastic nature of the muscles. This in turn may have led to improved performance.

Behm and Kibele (2007) studied the effects of three different static stretching conditions on different parameters of jump performance. The three conditions were varied stretching intensities, with participants stretching to 50%, 75%, and 100% of the point of discomfort. Behm and Kibele hypothesized that stretching at 50% of the point of discomfort would increase ROM and would not be detrimental to jump performance. Ten healthy college students participated in the study.

The testing began with warm-up on a cycle ergometer at 0 W for 5 min. The participants performed two repetitions of three different stretches and two repetitions of five different jumps before and after the stretching protocol. Before stretching, participants performed a stoop-and-reach test, a supine hip flexion with knee extension test, and a prone hip extension with extended knee test. The participants also performed two repetitions each of a 24 cm drop jump, a countermovement jump with fast stretch-shortening cycle, a countermovement jump with slow stretch-shortening cycle from 70° knee flexion, and a countermovement jump at a self-selected pace and from a self-selected depth, and one concentric–only squat jump.

The participants held the stretches for 30 s each, with 30 s of recovery between the three stretches. The three stretch conditions were conducted on three separate days with 48 hr of rest in between testing days. The participants stretched the quadriceps muscle group by standing on the contralateral limb and flexing the knee until the instructed intensity of the stretch was felt. The participants lay supine and flexed the hip and extended the knee extension to stretch the hamstrings muscle group. The participants stood on an elevated platform with their heels hanging outside the platform to stretch the ankle plantar flexors. It is to be noted that the researchers wrote, “with soleus emphasis,” but failed to mention that participants flexed the knee 15° while stretching the ankle dorsiflexor. The participants performed the stretch and jump tests 5 min after the stretching protocol. The jump tests were performed on Kistler force plates (type 9281, Kistler Instrument Corp., Amherst, NY, USA as cited by Behm & Kibel). The control group stretched the same muscle groups for 5 s. The mean of the stretch time for 50% point of discomfort group decreased the jump height by 5.3%. The jump height decreased by 3.8% and 5.6% for the 75% point of discomfort group and 100% point of discomfort group respectively.

The researchers suggested a few mechanisms that could explain the failure of their hypothesis. The researchers mentioned that stretching to 100% of the point of discomfort could have an inhibitory effect on the neural pathways stimulating muscle activity. The decrease in resting discharge results in decreased excitation of motor neuron pools. Stretching reduces this excitation of neuromuscular motor units, and they are believed to recover immediately after the stretching maneuver.

The researchers explained another theory, that there could be an inhibitory effect from the long duration of pushing or pulling force on the joint capsule. The force exerted to stretch the muscles of the lower extremity produces torque that compresses the patella on the knee joint, and the force of the tibia to push toward the pelvis may create dislocating torques. These torques may produce inhibitory effects on the activating motor neuron to protect joint integrity. The stress on the joint during the stretching at an intensity less than to the point of discomfort would have been perceived as very light. Hence, evidence suggests that the light stresses would not have any significant effect that would lead to prolonged inhibition of motor neurons. The researchers suggested that, regardless of the intensity of the stretches tested in this study, all stretch conditions would have the same effect on muscle compliance. They explained that an acute set of stretches changes the length and stiffness of the muscles involved; this change in the stiffness and length of the musculotendinous unit affects the rate of force production and the rate of transmission. The process of desensitization due to prolonged stretch holds of more than 20 s may lead to delay in the electrical conduction and mechanical properties of the muscle, preventing optimal overlap of the cross-bridge. An optimal overlap between the actin and myosin filaments is an important factor in producing strong contractions, according to filament sliding theory. This mechanism could result in weaker contractions and thus jump performance. The researchers suggested that the increase in muscle compliance, not the intensity of the stretch, hindered the vertical jump height.

The researchers pointed that the participants with greater ground contact time had more compliant muscles; that also contributed to the detrimental effects on drop jump performance; hence, the most valid reason for reduced jump performance was increased muscle compliance. The researchers note that muscle compliance increases with any intensity of stretching. The reduction in jump performance may have been attributed to the inhibitory effect of neuromuscular conduction, in addition to the changes in the muscle's mechanical properties.

Brandenburg et al. (2007) sought to determine the immediate effects of static stretching on vertical jump performance. The researchers also wanted to determine the effects of various time lapses between the stretches and jump performance. Eighteen participants volunteered for the study; all participants were trained or participating in a sport involving jumping, such as volleyball, gymnastics, or lower-limb plyometric exercises.

The participants visited the laboratory on three separate days. On the first day, the participants were acquainted with the experimental design. The participants performed 15 countermovement jumps with maximum effort; after a 5 min break, the participants performed another set of five jumps with maximum effort. The participants were also taught the three stretching techniques that they would have to perform on the experimental day.

The other two days of laboratory visits were dedicated to experimental and control group data collection. At least 24 hr but not more than six days separated the experimental data collection and control data collection days. On the day of data collection, the participants performed warm-up for 5 min on a cycle ergometer. After the warm-up, prestretch vertical jump data were collected for all of the participants. Then, the participants were randomly divided into the stretch group or the control group. The stretch group participants performed three stretching exercises for the lower limbs. The participants in the control group stood for 9 min. Immediately after either stretching or standing, participants from both groups performed vertical jumps; they performed vertical jumps again after 3 min, 6 min, 12 min, and 24 min had lapsed.

The participants performed static stretches for the plantar flexors, the quadriceps, and the hamstrings. They held each stretch for 30 s, performing each stretch three times per leg, one leg at a time. The participants were instructed to stretch until they felt a strong stretch in the targeted muscle group. To stretch the plantar flexors, they assumed a unilateral standing position, placing the target limb on an inclined plane in dorsiflexion; they were asked to bend at the hip while maintaining complete knee extension. To stretch the hamstrings, the participants assumed a unilateral standing position with the target leg on a 60 to 70cm high bench and assumed hip flexion and knee extension. In this position, the participants bent to reach the toes of the target leg, with the knee extended. The participants assumed a unilateral standing position to stretch their quadriceps; they stood on the contralateral limb, flexed the target leg, and brought the heel to the buttock. The participants were instructed to maintain the hip in extension while stretching the quadriceps. To stretch the plantarflexors, participants stood with one leg on a slant board and leaned forward while maintaining a straight knee.

The jump height was measured by using a Just Jump mat (Just Jump System, Probiotics Inc., Huntsville, AL. as cited by Brandenburg et al., 2007). To perform the countermovement jumps, the participants stood with the feet shoulder-width apart and the hands on the hips; they self-selected the countermovement depth. During the jump performance measurement, pre-gelled disposable electrodes were used to measure electrical activity in the vastus lateralis and gastrocnemius muscles.

The researchers analyzed the data using 2 x 6 analysis of variance. There was no significant difference between the stretch group's and the control group's jump height. The jump height 12 min after stretching was significantly higher than the jump height 24 min after stretching. The control group's jumps were higher than the stretch group's throughout the trials. The mean EMG activity during the jump showed that the stretching group had more activity in the quadriceps at 3 min and 12 min, as compared to the control group. The stretching group's EMG activity was equal to the control group's pretreatment and after 24 min. However, despite the increased EMG activity at 3 min and 12 min, the stretching group saw no positive difference in jump performance. The EMG activity for the quadriceps was only higher than pretreatment EMG activity at three min after the treatment. The EMG readings right after the treatment and after 6 min, 12 min, and 24 min were not significantly different. The EMG activity for the gastrocnemius was higher in the control group than the stretching group, except after 24 min posttreatment. The stretching group's posttreatment EMG activity for the gastrocnemius was reduced from the pretest level; it returned to the pretreatment level after 24 min.

Brandenburg et al. (2007) suspected that 30 s stretches were not long enough in duration to cause posttreatment changes. For the participants, who participated in sports requiring jumping, their regular high-impact activities may have caused some structural and neural changes; thus this study's regular static stretch activity may not have showed any effect on the results. There was no significant difference in results between the two groups. The researchers also speculated that jumping might not be a sensitive enough test for measuring changes produced by stretching. They also suggested that if participants are trained, they might experience fewer effects from stretching if the dependent variable were an activity of the sport they play.

The purpose of the study by Kokkonen et al. (2007) was to determine the effect of an exclusive, intensive, chronic lower-extremity static stretching routine on strength, endurance, 20 m sprints, vertical jumps, and standing long jumps. Forty university students participated in the study. Recreationally active participants were included in the study, but anybody participating in physical activity or training formerly was not included. Pretests were conducted over the course of 3 days; they included tests of sit-and–reach, 20-m sprints, vertical jump height, standing long jump length, knee flexion, one repetition maximum extensions to measuring strength, knee flexion and extension endurance, and VO_2 peak.

On the first two days, participants started with a 5 min warm-up. They stood with their feet hip-width apart and extended the arms behind the body. From this position the participants flexed the hips and knees to a self-selected depth and jumped as far as possible with an arm swing. After 5 min of rest, each participant took a sprint test. The best sprint time from among three trials was recorded. A 3 min rest was given to each participant between sprint trials. Following the sprint trial, participants underwent a knee flexion and extension strength test, measured in terms of one repetition maximum. Between the testing of the knee's flexion and extension, the participants were given a 10 min break.

On the second day, after the warm-up, vertical jump measurements were taken using a Vertec testing device (Questtek Corp., Northridge, CA as cited by Kokkonen et al., 2007). The participants were allowed to jump with self-selected countermovement depth and arm swing. The height of the jump was determined by measuring the displacement of the marker on the Vertec. After the jump measurements, the participants were given a 5 min break. After the break, they were tested for knee flexion and extension endurance, by performing as many repetitions as possible at 60% of the pretest one repetition maximum.

On the third day, each participant's body mass was recorded. Oxygen consumption (the VO_2 peak) was measured using graded exercise testing. For this protocol, the participants started by walking slowly; their speed was gradually increased at regular intervals until the participants expressed that it was the maximum they could run. The highest average of the 20 s oxygen utilization measurements obtained during the last 4 min of testing was recorded as the VO_2 peak.

As a part of the 10 wk stretching program, the participants performed 15 different active stretches to stretch the hamstrings, quadriceps, adductors, external rotators, internal rotators, plantar flexors, and dorsiflexors. To ensure adherence to the protocol, they also performed 12 passive stretches. The participants stretched each muscle three times for 15 s. This protocol was followed three days per week for 10 wk. The participants in the control group were asked not to perform any stretching exercise.

Two-way ANOVA to analyze pretest and posttest results and post hoc analysis indicated an average improvement of 6.7% in vertical jump height and of 2.3% in standing long-jump length. The one repetition maximum, which represented power output, improved considerably. Knee flexion improved by 15.3% and knee extension by 32.4%. Kokkonen et al. concluded that regular stretching exercise could improve components that may help enhance overall exercise performance.

The researchers discussed the findings of literature by Lieber (2002), who found increase in the mass and area of rat soleus muscles after 4 weeks of performing three stretches a week. Lieber suggested that the improvement in the test measuring power output could have resulted in increases in muscle length; increased muscle length leads to increased contractile velocity and generates force at the given shortening velocity of the contracting muscle.

The purpose of the study by Woolstenhulme et al. (2006) was threefold: to determine the effects on flexibility and jump performance of playing basketball with warm-up for 6 weeks, to determine the acute effects of four types of warm-up on jump height, and to determine the acute effects of four types of warm-up combined with a game of basketball on vertical jump height. Forty-three healthy and active participants, who did not have any prior jump training, volunteered for the study. Before week one and after week six, participants underwent a sit-and-reach test and vertical jump height measurement without a warm-up. The subjects were assigned randomly to one of the four experimental groups.

The warm-up consisted of jogging for 5 min followed by ballistic stretching, static stretching, sprinting, or basketball shooting for 8 min. The participants performed the stretching 12 times biweekly over a period of 6 weeks. The participants performed the sit-and-reach test by removing their shoes and bending forward in a long sitting position. In this position, the participants bent forward with the sit-and-reach box in front. The vertical jump was measured on a jump mat (Probotics, Inc., Huntville, AL as cited by Woolstenhulme et al., 2006). The participants were instructed to bend their knees to a comfortable depth and jump as high as they could.

The static-stretching participants targeted four different muscle groups. The participants stretched their hamstrings by assuming the long sitting position on the floor and bending forward, in a movement similar to the sit-and-reach test. They stretched the quadriceps muscles by assuming a lunge position, and lowering the anterior hip toward the ground. They performed a gastrocnemius stretch by placing the ball of the foot on a stair and lowering the heel while maintaining a straight knee. The participants stretched the soleus by assuming the same position as for the gastrocnemius stretching. In this position, the participants lowered the heel with a slightly bent knee. For the static stretching protocol, the participants were instructed to hold the stretch for 30 s to a point where they felt tightness in the target muscle group but not pain. Participants in the ballistic stretching group performed stretches for the same muscles or muscle groups. Each muscle was stretched to the end ROM with a bounce of 60 beats per min. The participants in the sprint group performed five sprints, each of 35-s on the basketball court with 30 s of rest in between each sprint. The control group practiced shooting basketballs with a partner for 8 min. Each condition was analyzed using one-way analysis of variance.

The researchers concluded that after the period of 6 weeks, there was no improvement in vertical jump height after any of the warm-up conditions. However, the ballistic stretching group improved in vertical jump height after 20 min of basketball activity, as compared to the post-warm-up and no-warm-up groups.

The researchers backed up the findings by using Fletcher and Jones' (2004) theory. Fletcher and Jones found that static stretching had detrimental effects on sprint performance, whereas dynamic active stretching with warm-up improved sprint performance.

The purpose of a study by McMillian et al. (2006) was to compare the effects of dynamic warm-up with those of static stretching warm-up and no warm-up on certain determinants of power and agility. Sixteen men and 14 women from the United States Military Academy participated in the study. They attended a two-day orientation for participating in the study. The participants received instruction on the first day. On the second day, the participants performed all the dependent-variable tests and the researchers provided feedback for improving their performance in the tests. The tests were performed at 6:00 a.m. on three days following the orientation. The participants performed dynamic warm-up, static stretching warm-up, or no warm-up. The dependent variables for the experiment, performed after the warm-up conditions, were the T-drill, the five-step jump test, and the medicine-ball throw-for-distance test. Based on previous literature, researchers believed that the five-step jump was a valid and reliable measure of power. The T-drill was used to test agility and throwing the medicine ball for distance was used to measure total body power. The no-warm-up group rested for 10 min as part of the experimental protocol. The dynamic warm-up included bends and reaches, rear lunges and reaches, turns and reaches, squats, rower exercises, power jumps, prone rows, push-ups, windmills, diagonal lunges and reaches, and movement drills. The movement drills included vertical and lateral knee-to-chest types of movements, but the participants were asked to bring the knees to waist-high; crossing over the legs and moving sideways; skipping on one leg and then repeating with the opposite leg; and shuttle sprints, in which participants ran at a moderate pace and, at the end of the line, touched down, took a quarter-turn clockwise, and headed back toward the starting line. The participants performed these movements in a circular fashion on a 20–25 m track. The other dynamic exercises mentioned in the warm-up were independent of the movement drill. In the bend and reach activity, participants reached high above the head and then bent down to reach between the feet while keeping the heels in contact with the ground. In the rear lunge exercise, the participants started with hands on hips and then lunged backward while reaching up high at the same time. In the turn and reach exercises, the participants had to side flex the trunk, keeping the arms abducted and the palms facing up and the body facing forward throughout the movement. The participants performed the squat exercise with hands on hips, flexing the hips and knees until the thighs were parallel to the floor. The participants maintained this position as long as they could, with their hands out to the side for balance. They performed the rower exercises by lying on the back and coming up to a sitting position, bringing the legs close to the trunk until the feet lay flat on the floor. The participants performed rowing movement in prone position by lying on the stomach with arms positioned straight overhead, followed by bringing the arms to the sides of the shoulders without letting them touch the floor and maintaining the forearms parallel to the ground through out the movement. The participants performed the power jumps by squatting down and then jumping, performing a rowing motion at the same time. To perform push-ups, participants were instructed to keep their hands shoulder-width apart or slightly farther apart and flex at the elbows and horizontally abduct at the shoulders to lower the torso and bring it back up. They were instructed not to go lower than the point where the trunk was parallel to the ground. To perform the windmill exercise, the participants assumed a wide stance, with arms out to the side, palms facing down. In this position, they squatted and bent forward to touch the left foot with the right arm and vice versa. The participants performed diagonal lunges by placing the front foot diagonally ahead, with the foot pointing diagonally out and lunged in that direction. The participants were instructed not to bend the knee past the foot, in front or laterally.

The static stretching protocol consisted of over-arm pulls, turns and reaches, rear lunges and reaches, hamstring stretches, calf stretches, quadriceps stretches, posterior hip stretches, and trunk flexion/extension stretches. Each static stretch was performed for one repetition, and held for 20 s to 30 s except for the turn and reach stretch activity. To perform the over-arm pull exercise, the participants placed the left hand behind the head, and with the right hand they held the left elbow from over and across the body, and pulled to the right to lean on the right side. This performed on both sides. For the turn and reach stretch activity, the participants assumed a wide stance and abducted the arms. From there, the participants rotated the trunk so that the arms were positioned perpendicular to the frontal plane. The participants were instructed to hold this stretch for 15–20 s to prevent shoulder fatigue. The rear lunge and reach was similar to the dynamic warm-up rear lunge and reach. To stretch the hamstrings, participants were instructed to take a step forward with the target leg, bend, and reach to touch the toes of the same leg. To stretch the calf muscles, the participants stepped eight to 10 in (20.32 cm to 25.4 cm) forward with one foot and grasped the forefoot with the knees slightly bent. From this position, they slowly extended the knees. They performed the quadriceps stretch by bring the heel to the buttocks in side-lying position. They performed the posterior hip stretch by assuming a supine position and bringing the right ankle over the left knee. From this position, the participants held the right knee with both hands and brought it toward the left shoulder at the same time, flexing the left hip and knee. The stretching was performed for both sides, one after the other. To stretch the trunk flexors, the participants assumed a quadruped position and flexed the hips and knees to move backward, keeping the hands at the same place. Trunk extension was performed in the prone position; participants attempted to perform arm or hand press-ups and keep the thighs and pelvis on the floor.

The researchers analyzed the data with 2 x 3 repeated measures ANOVA for the two genders, and three warm up protocols. The researchers concluded that the performance was improved after the dynamic warm-up, compared to no warm-up or static warm-up. The researchers mentioned that the participants performed better in the five-step jump after a static warm-up than after no warm-up. The researchers speculated that the static warm-up resulted in reduced neural activation because of the repeated stretching, which may explain why the performance was less after static warm-up than dynamic warm-up.

Burkett, Phillips, and Ziuraitis (2005) determined the effect of task-specific and general warm-up on the vertical jump test in male athletes. The participants were 29 football players between the ages of 18 and 23 years.

Burkett et al. tested four different warm-up protocols. The first warm up protocol was submaximal jump warm up, as a task-specific warm-up. The second warm up protocol was a weighted jump, also considered a task-specific warm-up. The third warm up protocol consisted of stretching, which was considered general warm-up activity. The fourth warm up protocol consisted no activity, for the control group. The submaximal-jump warm-up consisted of five countermovement jumps at 75% maximum intensity, based on their pretest 100% maximum. The weighted-jump warm-up consisted of each participant jumping on a box with dumbbells weighing 10% of the participant's total body weight. The box used for the weighted jump was 63.5 cm high. For the stretch warm-up, the participants performed 14 different stretches for the lower-limb muscles. For the hamstrings, participants performed standing straddles while touching the ground, standing toe-touches, standing toe-touches with the right leg crossed over the left, and standing toe-touches with the left leg crossed over the right. The latter two exercises enabled focusing on one hamstring at a time. To stretch the gluteal muscle groups and higher hip muscles, they performed the following lunge positions: standing right side, standing left side, standing with the left leg forward, and standing with the right leg forward. To stretch the quadriceps, they performed standing quadriceps stretches. To target the soleus muscle, they performed standing toe raises with leg bends, and with straight legs to stretch the gastrocnemius muscle. The participants bent to the right and then the left to stretch the lateral trunk muscles. Participants held each stretching position for 20 s. They performed the vertical-jump test within 2 min after the stretching protocol. The vertical jump was measured using Vertec (Questek as cited by Burkett et al., 2005).

Post hoc analysis was performed using Bonferonni to determine the effectiveness of the different warm-up protocols. The researchers concluded that the weighted-resistance warm-up group participants had statistically significant improvement in the vertical jump height, compared to the other groups. There was not a significant difference between the effects of the submaximal warm-up protocol and the stretching protocol on the jump height.

The researchers discussed their findings in regards to the theories suggested in previous studies. They explained that stretching, submaximal warm-up, and no warm-up had same effect on vertical jump performance, but that activity-specific warm-up improves performance. The researchers used a stairs metaphor to explain the effect of using the overload principle as a task-specific warm-up. As an athlete performs the task-specific activity mimicking actual game movements with increasing weight, the nervous system prepares for the movement and recruits more motor units because of the additional weight in each repetition. Each repetition is like a stair to the top, for the muscular system and the muscle groups get warmed up with increased blood flow. As the athlete loses the additional weight for the game, the increased recruitment of the motor units and warmed-up muscles are at the top of the flight of stairs, ready to perform. The increased motor unit recruitment would lead to powerful contraction.

Unick et al. (2005) compared the effects of static stretching and ballistic stretching on the countermovement jump in women involved in athletic activities. Sixteen trained women participated in the study; all were taking part in preseason training exercises for NCAA Division III basketball teams. The three independent variables were no stretching, static stretching, and ballistic stretching. The no-stretching measurement readings were used as control readings.

The participants jogged for 5 min at a self-selected pace to warm-up, followed by 30 s rest, followed by the independent variable for the day. The participants walked for 4 min after stretching. Then, participants performed three trials each of countermovement jumps and drop jumps. The participants were given a 15 min rest after the jumps. Each testing day, the participants performed a sit-and-reach test before warm-up and after the jumping trials. The static stretches were held for 15 s and repeated three times. The participants were asked to stretch to the point of just before discomfort. The participants performed ballistic stretches by reaching the stretch position for the target muscle, and then following through a quick, short, up-and-down movement, at a rate of one up and one down movement per second. The participants stretched hamstrings in long-sitting position, bending at the hip while maintaining extension of the knee. The participants stretched the gastrocnemius muscle by sliding the target leg back with the knee extended and bending the front leg to give some room for the target leg to slide back until they felt the stretch. The participants stretched the soleus muscle similarly, but slightly bending the target leg while sliding it back so that they felt the stretch deeper in the lower leg. The participants performed quadriceps stretches by standing and bringing the heel to the buttock by flexing the knee and without taking the hip into abduction.

The participants performed regular countermovement jumps in this study with arm swing and self-selected hip and knee bending. The hand-swing position started with extension when the participants bent at the hip, knee, and trunk. The arms were in flexion when the participants reached the maximum height of the jump. There was no pause between the countermovement and the jumping action. The average of the three jumps was used to determine the results of this study. The drop jumps were performed from a height of 26.5 cm with neutral arm movements beginning from the drop of the jump. Like the countermovement jumps, an average of the three jumps was used to determine the results. The researchers concluded that the effect of stretching with respect to time on either of the two types of jumps was insignificant. The two types of stretching did not have any effect the countermovement jump or drop jump performance.

To explain the results of the study, Unick et al. suggested the decrease-in-stiffness mechanism. They suggested that the increase in the slack of the tendon as a result of stretching causes a decrease in muscular stiffness, which might reduce jump height. However, the researchers argued that from previous studies, it was not clear if the detrimental effect were because of the neurological mechanism or mechanical reasons. The researchers explained that Hoffman's reflex is used to measure the excitability of the motor neuron of the muscle undergoing the stretching maneuver. The Hoffman's reflex is depressed for approximately 4 min, and then the motor neuron recovers from the effects of stretching. In this study, the participants were given 4 min for walking after the treatment, which may have led to no different effects between static stretching or ballistic stretching.

Guissard and Reiles (2005) determined the effect of static stretching and the contract-relax method of PNF stretching on jump performance. The participants included 14 males and females between the ages of 20 and 25. For the squat jump and the countermovement jump, the rebound height was calculated before and after the stretching protocol. The jump height was measured by a platform connected to the timer called ergo jump (as cited by Guissard & Reiles). Each participant performed a set of low intensity stretching for 6 min, followed by set of dynamic exercises for 3 min. The authors did not provide any parameters regarding the stretching or dynamic exercises.

The researchers did not find any significant detrimental effects of stretching on the participants' calf muscles' force production capacity. The authors concluded that if stretching exercises are performed before dynamic warm-up, then stretching does not have a detrimental effect on performance. The researchers did not discuss any mechanism for the results.

Papadopoulos et al. (2005) conducted a study to determine the effects of static and dynamic stretching exercises on maximal knee flexor and extensor isokinetic strength at different angular velocities. Thirty-two healthy physical education students who were not athletes volunteered for the study. The participants performed a 5-min warm-up on a cycle ergometer at 50 W resistance on three consecutive days. The stretching protocol followed the warm-up. One day, the participants performed static stretching; on another day, they performed dynamic stretching; and on a control day, participants warmed up and tested their knee flexors and extensors. The stretching treatment was followed by measurement of the knee flexors' and extensors' maximal isokinetic torque, using an isokinetic dynamometer. The measurements were taken at 60° and 180°. Two-way ANOVA for repeated measures showed that there was a significant effect on maximal isokinetic torque of the knee extensor and knee flexor muscles. The maximal isokinetic torque was reduced after static stretching, but it remained unchanged after the dynamic stretching.

The researcher suggested that a stiff musculotendinous system allows for improved force production because the muscle's contractile elements are in more favorable positions on the length-force curve. This study explained a possible mechanism for the reduced strength production presented after static stretching: the limited activity of the knee extensor and flexor motor neurons. They noted that peak force, which originates from percussion of the Achilles' tendon, is significantly lower after stretching. They also observed that H-reflex is limited immediately after stretching exercises because of reduced sensitivity of the muscular spindles. However, it remains unclear how much time is needed for recovery between stretching and physical performance in the game. Static and dynamic stretches have different effects on musculotendinous stiffness, as the stretching maneuvers entail different neuromuscular mechanisms for autogenic inhibition. Dynamic stretching affects the muscles by a reverse H-reflex mechanism. In this mechanism, the Golgi organs work as inhibitory mechanisms.

The speed at which a musculotendinous structure is stretched is directly proportional to the mechanical effect the stretch has on musculotendinous stiffness. The H-reflex greatly impacts the mechanical properties of the muscle tissue; the potential for this impact depends directly on the speed at which the musculotendinous unit is stretched. Fast stretch leads to greater action potential and slow stretch lowers the action potential.

This is a useful and significant insight into a mechanism that works toward stronger action potential; it can be supported by other literature when choosing which type of stretching should be performed in order to achieve proper strength production.

Wallmann, Mercer, and McWhorter (2005) conducted a study to determine the effect of static stretches to the gastrocnemius muscle on vertical jump performance. Fourteen healthy participants volunteered for the study.

To measure the jump performance, Kistler built force plates were used (type 9281B, Kistler Instrument Corp., Amherst, NY as cited by Wallmann et al., 2005). The vertical jump performance was also measured based on muscle activation, recorded with electromyograph. A pretest vertical jump measurement was taken after a short warm-up. The warm-up consisted of walking at 3 mph (4.82 kmph) for 5 min on a treadmill. The participants performed three countermovement jumps with maximal effort with hands on the hips. The gastrocnemius's lateral head was shaved and wiped with alcohol to prepare the participant for electromyographic data collection. The participants were also instructed on how to jump correctly on the force plate. After the baseline testing, the participants rested for 15 min. The participants stretched their gastrocnemius muscles using a slant board. The participants performed three repetitions of stretches, and held each set for 30 s to the point just before the point of discomfort. The participants performed three countermovement jumps again, 30 s after the stretching protocol. The poststretch jump heights were compared with the prestretch, baseline jump heights. Wallmann et al. concluded that the jump height was reduced 5.6% after the static stretching. They also noted that the muscle activity during poststretch jumps was 17.9% higher than prestretch jump muscle activity. To explain the mechanism behind the results of the study, the researchers brought up a few important topics related to jump performance. The participants might stretch to the point of discomfort or pain, which stimulates the nociceptor stimulus, a response that inhibits full muscular contractions as a protective mechanism for the nervous system. Moreover, the researchers suggested that coordination and the timing of segmental movement contribute to good jump performance. The increase in muscle activity with the reduced jump height could have been because the stretching caused an increase in compliance and a reduction in the muscle contraction's efficiency, which in turn resulted in recruitment of more motor units in order to use the stored elastic energy of the muscle. The increased muscle activity could be a replacement for the stiffness of the muscle. The stiffness of the muscle is required to protect the ankle joint's integrity during a jump; the increase in the muscle activity could be a neural mechanism to perform the same function after stretching for the dynamic activities.

Power et al. (2004) conducted the study to determine the effects of regular static stretching on jump performance and other dependent variables. The researchers was also sought to determine how long the effects of static stretching persist would persist after following the same stretching routine. Twelve participants volunteered for the study.

The participants visited the laboratory for 5 days. On the first day, the participants were acquainted with the test procedures. They also performed three trials of all the dependent variable activities. The remaining four testing days were randomized, so that all participants performed the experimental protocol as well as the control protocol. The testing days were distributed so that there was a 24-hr gap between each test day. On the four test days, participants performed one of four interventions between the pretest and posttest activities. On the two control days, the participants did not perform quadriceps or plantar flexor stretches, but performed the pretest activities, rested for the time the intervention would have taken, and then tested for the posttest activities. On the experiment days, participants stretched the plantar flexors one day and the quadriceps the other, as well as performed the same pretest and posttest activities. The warm-up included bicycling for 5 min at the rate of 70 rpm. The warm-up was followed by pretests measuring the dominant leg’s ROM of hip flexion, hip extension, and ankle-plantar flexion. The results of a high-voltage stimulator, which evoked peak twitch torque, were recorded for the quadriceps and plantar flexors. Two maximum voluntary contractions were recorded with a rest period of 2 min between each contraction by interpolated twitch technique. The treatment was static stretching, which was executed by assuming six different positions that targeted the gastrocnemius muscle, the soleus muscle, the hamstrings, and the quadriceps. The posttreatment tests were the same as the pretreatment tests. The tests were recorded immediately after stretching and after 30 min, 60 min, 90 min, and 120 min. The researchers used the concentric jump and the drop jump to measure the vertical jump height. To perform the concentric jump, the participants assumed a standing position on the jump mat with their knees flexed to 90° for 2 s, after which the participants jumped as high as they could. The participants used only the dominant leg, keeping the nondominant leg flexed. The drop jumps were performed from a 30 cm high step with the hands on the hips. To perform the drop jumps, the participants dropped from the box with the dominant leg straight, to prevent any advantage. The participants assumed six different positions to stretch the target muscles; each stretch was held for 45 s with a 15 s break between stretches. The participants were instructed to stretch to the point of onset of pain. They stretched the gastrocnemius muscles one leg at a time by sliding the target limb backward, with the heel constantly in contact with the ground. The contralateral limb maintained a 90° hip and knee flexion. In a similar position, the participants slightly bent the target limb at the knee, to stretch the soleus muscle. The participants assumed a figure-of-four long sitting position, and bent at the hip to reach the toes to stretch the back muscles and hamstrings. The tester assisted the participant in maintaining hip flexion with knee extension for the target limb while maintaining the contralateral limb in hip and knee extension to stretch the hamstrings. The quadriceps stretches were performed in a prone position. The tester pushed the heel of the target limb into the buttocks, leaving the contralateral leg relaxed in hip and knee extension. For the second quadriceps stretch, the participants assumed a partial-kneeing position with the target limb extended at the hip. In this position, they held the heel of the target limb to the buttocks.

The statistical analysis was performed for 2 x 6 repeated measures ANOVA. The two treatments were, experimental and control and the six types of data collection were, pretreatment, post-treatment, after 30 min, after 60 min, after 90 min and after 120 min. The researchers concluded that the decreases in drop jump as well as concentric jump height after the treatment were statistically insignificant.

Contradictory to other studies (Cornwell et al., 2001; Young & Elliott, 2001), the study by Power et al. (2004) suggested that an increase in muscular compliance is beneficial to jump performance compared to when the muscles are stiff. A decrease in series elastic component stiffness helps in increased load lifting. Wilson et al. (1994) found that the increase in compliance of the series elastic component improves the release of stored elastic energy in performing rebound bench press lifts. Walshe and Wilson (1997) studied drop jumps and applied the same theory. They suspected that participants with stiff musculature were at a significant disadvantage compared to those with more compliant musculature. The researchers explained that stiff musculotendinous structures are unable to alleviate the severity when high loads are encountered; thus, the

GTO would be stimulated to inhibit the facilitation reflex stimulated by the stretch. The protective reflex would be manifested because of the high force stimulated by the inhibition reflex. In this study, the drop jumps were performed unilaterally from a height of 30 cm. They might have made the inhibitory reflex dominate the facilitation. In this condition, the compliant muscles would benefit more compared to their stiff counterparts. Hence, the researchers suggested that the compliant musculotendinous unit benefits when the load is higher and the stiffer musculotendinous unit benefits when the load is lower.

Goodwin (2002) compared the effects of controlled massage and submaximal exercise combined with stretching as a regular warm-up on vertical jump performance. The participants were 10 sprinters. After massage and stretching, the submaximal exercise and stretching, or the control protocol, all participants performed three countermovement jumps with the hands on the hips.

The independent-variable testing sessions were conducted in a random order. The massage warm-up protocol consisted of rapid effleurage at 120 Hz and tapotment at 40 Hz to the quadriceps, hamstrings, and calf muscles. The massage was performed for a total of 10 min. The protocol used for the submaximal exercise was 5 min of jogging at 60–70% of age-adjusted maximum heart rate. The control warm-up consisted of 5 min of sitting. The participants stretched the hamstrings, the quadriceps, and the calf muscles after all the three warm-up conditions. The participants were instructed to perform four repetitions of each stretch, holding the stretch for 10 s. The researcher failed to describe the type of stretch performed or the instructions regarding the intensity of the stretch. The data was analyzed using multivariate analysis of variance and Pearson correlation. The room temperature was maintained at the same temperature for the entire warm-up; however, after the massage regime, the muscle temperature rose and the leg-skin temperature decreased. The jump performance improved during the third trial for the control group, and after the submaximal exercise warm-up group. The participants, after the submaximal exercise warm-up protocol, had the maximum jump height average in the first trial. The researcher proposed that the reason for poor jump performance after the massage warm-up protocol was due to reduced muscle stiffness and decreased neural activation. The author also suggested that neural activation might play a significant role in the relation between warm-up and sports-related activities.

Hunter and Marshall (2002) studied the effects of power training and stretching on unrestricted jump performance. They considered their countermovement jumps and drop jumps unrestricted jumps, because participants were not given directions to limit knee bending or contact time. The jumps were performed with the hands on the hips. There were 60 participants initially; 50 participants completed the study. All were active and healthy. The participants were not involved in any plyometric exercise or stretching training outside the study.

They were divided randomly and equally into four groups. One group followed a protocol to improve the power. The second group followed a stretching protocol. The third group followed both the power and the stretching protocols. The fourth group was the control group. The participants in the control group were asked to refrain from any structured physical activity. They were asked to fill out a form to indicate their physical activity in the last 3 weeks of the 10 week treatment duration. The power training group participants had two supervised sessions per week out of four total sessions. The stretch protocol group participants had one supervised session out of the four sessions per week. The power training included components of resistance training and plyometric exercises. The resistance training included countermovement jumps with dumbbells in the hand, deadlifts, and squat hybrid exercises. The plyometric exercises included drop jumps and countermovement jumps. The lower limb stretching included stretches for the hamstrings, quadriceps, hip extensors, hip adductors, hip abductors, and plantar flexors. The participants were asked to stretch to a point of mild discomfort. Every 2 weeks, the participants increased the duration of the stretch hold by 10 s; the participants started with a stretch hold of 20 s in the first 2 weeks, and at the end of the 10th week, they held the stretch for 60 s per set. After the 4th week, participants were assisted in PNF stretching, added during the supervised sessions only. Each stretch was kept at three repetitions consistently throughout the 10 weeks. The researchers took various measures to make sure that all the participants followed the treatment protocol.

The participants were tested before starting and after 10 weeks of treatment. The stretch-tolerance test for quadriceps and hamstrings was recorded before the warm-up. For measuring stretch tolerance, the pelvis was strapped and the Leighton Flexometer (Leighton Flexometer, Spokane, WA as cited by Hunter and Marshall, 2002) was used to measure the angle between the pelvis and the thigh. To prevent overstretching, constant communication with the participant regarding the tolerance of the stretch was maintained. The jumps were recorded on the force plate (Bertec 6090; Bertec Corporation, Columbus, OH as cited by Hunter and Marshall, 2002). The participants performed four variations of a vertical jump, a countermovement jump, a drop jump from a height of 30 cm, a drop jump from a height of 60 cm, and a drop jump from a height of 90 cm. Only the jump height was measured. To understand the springlike effect of the muscle, Hunter and Marshall calculated the stiffness of the muscle during the eccentric loading phase. The researchers concluded that stretching had no significant effect on the height of any of the vertical jumps. However, the results showed that the group trained for power and stretch had the significant improvement compared to any other group. The group that performed stretching also had noticeable improvements compared to the control group, but the stretching group had less improvement than the group that was only trained for increasing power.

Hunter and Marshall discussed the plausible reasons for the results of this study. They explained that, depending upon the goal, specific phases of the jump or any movement should be trained for to improve the overall movement. The researchers suggested that, to increase countermovement jump height, adding increased countermovement phases of the jump with a stiffer lower-limb musculature during the eccentric movement would increase the storing and transferring elastic energy. The researchers' hypothesis holds true, based on the results of this study. According to their findings, the group that practiced both stretching and power training showed an advantage over the groups that performed only power training, or only flexibility activities, in terms of countermovement jump height. The researchers noted that the countermovement jump was the only vertical jump variation for which the power and stretching group had increased stiffness during the eccentric loading phase. The researcher proposed that during the eccentric loading phase if the musculotendinous junction had more length, then it would have been enabled to store and release more energy, meaning greater force production and jump height. The researchers suggested that different mechanisms and physiology apply to different type of jumps. For example, Farley et al. (1991) compared the muscle action during two-legged hopping on a place to a spring. To understand this spring-like muscle behavior effect, Hunter and Marshall calculated the stiffness of the muscle during the eccentric loading phase. The calculation of stiffness helps reveal the state of the muscle during different phases. Since the goal is to increase vertical jump height, the countermovement phase of the jump until the foot leaves the ground is of most importance to the study. The theory proposed by Farley et al. explains why the participants who added a stretch component to their power training had greater countermovement jump heights. However, it does not explain why participants of the same group had decreased stiffness but not increased countermovement jump height. The decreased stiffness of the series elastic component caused by the stretching, which would result in increased storage and release of the elastic energy, needs further evidence. However, increased stiffness during the eccentric loading phase explains the why the participants did not benefit from the stretch component for the drop jump activity.

Cornwell et al. (2001) determined the acute effects of passive muscle stretching on vertical jump performance. The purpose of this study was to form a firm basis to show that stretching has detrimental effects on the muscles' maximum-force-production capacities. The researchers also wanted to know if stretching has similar detrimental effects on stretch-shortening movements.

This study included two types of jumps: static jumps and countermovement jumps. The static jump was used to measure the jump performance without the prestretch effect, as performed in countermovement jumps. Active, healthy males (n=10) volunteered for the study. The participants visited the laboratory on five different days. On the 1st day, the participants were acquainted with the protocol of the study. The experimental data was collected from the 2nd through 5th days. The participants were randomly divided into the stretch or control groups. The stretch group stretched both legs' hip and knee extensors, followed by two different types of jumps. On the data collection days, the same experiment protocol was followed. Participants performed each type of jump after 10 min of passive stretching or quiet sitting. The next 4 days were divided equally between the stretching and no stretching protocols. Three different static stretching positions were performed to stretch the hip and knee extensors. The first position stretched the quadriceps group of muscles. The entire back and buttocks were firmly supported on the treatment table, except the target leg. The researcher flexed the knee while simultaneously extending the hip joint, similar to a stretch performed by pressing the heel into the buttocks while standing. The researcher held the position for 10 s, and then increased the stretch every 10 s, until the researcher could not further stretch the muscle. The stretch was held at the point of maximum tolerance for 30 s, as informed by the participant. Second, the participants lay on the stomach with the distal part of the hip higher than the pelvis, putting the quadriceps in a stretched position. The experimenter flexed the knee, bringing the heel to the gluteus tuberosity, increasing the quadriceps stretch. Third, participants assumed a position targeted to stretch the ipsilateral upper hamstrings, the gluteus maximus, and the contralateral quadriceps. The participants lay supine with one leg stabilized on the testing table. Next, the researcher bent the target leg at the knee and hip, and brought the knee toward the chest. All three stretch maneuvers included movement to increase the stretch intensity. Participants performed static jumps and countermovement jumps three times each with a 30 s break between each repetition. The researchers made sure that the stretch-shortening cycle did not take place during the data collection of the squat jump trials. If the force versus time curve fell below body weight, the data were discarded and a new trial was recorded. The jump performance was measured using a force platform (AMTI, Newton, MA as cited by Cornwell et al., 2001).

The jump height for the static jump and the countermovement jump was significantly lower in both stretch conditions. Two types of jumps—static jump and countermovement jump—and two types of conditions—static stretch and no stretch—were analyzed using repeated measures ANOVA. The researcher found that peak power production was significantly lower in both the stretch and control condition. The researchers discussed theories providing mechanical reasons and neurological reasons to support the results. The authors explained the concept of elastic potentiation: according to Cavagna et al. (1971), "The stretch-shortening phenomenon might be partly explained by the release of elastic energy that is stored in the musculotendinous structures during the eccentric phase," (p. 166) which is called the mechanism of elastic potentiation. According to the elastic potentiation mechanism, the static jump and countermovement jump would be affected differently because the countermovement jump consists of the eccentric contraction (active lengthening) before the concentric contraction for the jump. In the static jump, there is no eccentric lengthening before the concentric contraction that changes the state of the muscle in terms of stiffness and compliance. For example, the countermovement jump might be impaired if the musculotendinous system became more compliant, as it would have decreased ability to store elastic energy. Another mechanical cause the authors described was based on the length of the musculotendinous unit. A stiffer muscle unit has less slack, which is an optimal state for force production. Hence, for the static jump, the muscle was not in an optimal position to produce force.

Young and Elliott (2001) compared the acute effects of static stretching, PNF stretching, and isometric maximum voluntary contraction on explosive force production and jump performance. Athletes who had experience playing collegiate-level sports for at least one season were included in the study. Fourteen males volunteered for the study. The participants performed slow jogging as part of a 5 min warm-up. After the warm-up, participants performed one of four treatments: static stretching, PNF stretching, maximum voluntary contraction, or the control treatment, followed by 4 min of slow walking as an active rest. The participants performed one squat jump and one drop jump. They performed the former with 10 kg of weight on the shoulders with 100° knee flexion on a modified Smith machine. They performed the drop jump from a 30-cm-high box. The participants were instructed to step off the box with one leg straight, and jump off the ground after a minimum of ground contact time. The jump height and contact times were measured by the contact mat system (Swift

Performance equipment, Lismore, New South Wales, Australia as cited by Young & Elliott, 2001). The Kistler force platform (Kistler, Winterthur, Switzerland as cited by Young & Elliott, 2001) was used to measure the force generated by the participant at the time of takeoff.

The experimenter performed the static stretching until the onset of pain. Each muscle group was stretched three times, and each stretch was held for 15 s, with a 20 s rest between each repetition. The contract-relax type of PNF stretching was performed. The participant performed maximal isometric contractions against the resistance provided by the experimenter for 5 s, followed by relaxation. During the relaxation, the experimenter passively put the joint in a stretch position up to the onset of the pain. At this point, the stretch was held for 15 s. After 20 s of rest, the procedure was repeated.

The repeated measures multiple ANOVA method was used to analyze the significant effects of different warm-up protocols used in this study on the jump performance. The height-versus-time score for the static stretching group was lower than for all the other groups. There was no difference in height versus time between the other groups. The researchers attributed the decrease in drop jump performance after static stretching to the inverse myotactic reflex.

Nelson, Cornwell, and Heise (1996) determined the effects of passive assisted static stretching on the muscle's elastic properties using countermovement jump and squat jump measurements. The study was published as an annual meeting abstract, so the details of the procedures are not available. The participants consisted of 10 healthy college students. They performed three countermovement jumps and three squat jumps on four different days. On the first 2 days, the participants performed the jumps after passive assisted stretching, and on the other 2 days, the participants performed the jumps after a rest of 10 min. The participants were instructed to perform the squat jump from a starting knee position of 90°. To keep the jumps consistent, the participants were allowed to perform the countermovement depth only up to 90°. The AMTI force plates were used to measure the vertical jump heights. Descriptive statistics was used to determine the effect of the stretching on jump performance.

Nelson et al. (1996) concluded that the vertical jump height was reduced by 4.3% ± 4.1 for the squat jump. The height of the countermovement jump was reduced by 4.4% ± 4.8 after static stretching. The researcher noted that the elastic properties remained the same. However, stretching proved detrimental for both the jumps.

Summary

This section of the chapter consists of only the conclusion of the studies that are reviewed above. The effects of the stretching are divided based on the type of stretching; effects of static stretching, effects of the dynamic stretching, effects of the ballistic stretching, and effects of the PNF type of stretching. The effects of each type of the stretching are further divided in to the types of jumps;

for example, effect of each stretch on the countermovement jump, the squat jump, the drop jump, the static jump, and the jump for distance tests. As mentioned earlier, since the instructions for stretching is inconsistent in different studies, the instructions for the stretching and the type of the jump will be mentioned in parenthesis to facilitate better comparison and understanding.

The Effects of Static Stretching

The effects of static stretching on the countermovement jump.

Carvalho et al. (2012) concluded that the height of countermovement jump, performed with a self-selected eccentric phase depth with the hands on the hips, was slightly higher immediately after active static stretching compared to immediately after the dynamic stretching, or immediately after the passive static stretching (held for 15 s to a point of mild discomfort for both passive static stretching and active static stretching). However, the difference in jump height was not statistically significant. Sandberg et al. (2012) concluded that the vertical height of the countermovement jump (with self-selected countermovement depth and possible arm swing) increased significantly after static stretching of the antagonist muscle group. This stretching consisted of three sets with each stretch held for 30 s, to a point of mild discomfort. Pearce et al. (2012) concluded that two sets of 30-s static stretches decrease the vertical jump height for the first jump. The second vertical jump height returned to the baseline value. Mikolajec et al. (2012) found that the static stretching consisting of three repetitions held for 10 s each, at an intensity of 80–90% of the full ROM, does not improve the height of the countermovement jump. The participants in the strength-training group did have improved countermovement jump height. Vanderka (2011) found that the height of the countermovement jump with the hands on the hips decreased by 4.58% when static stretching of six major muscle groups, holding each stretch for 30 s, was performed before the countermovement jump test. Perrier et al. (2011) concluded that the countermovement jump height was not affected by a static stretching protocol that stretched seven major lower-limb muscles with gradually increasing intensity as tolerated, held for 30 s, or by participating in the control group. The static stretching group participants had the same jump height as the control group participants. Pacheco et al. (2011) concluded that countermovement jump height decreased slightly after static stretching, where the stretch intensity was gradually increased and held for 30 s). Frantz and Ruiz (2011) concluded that static stretching did not have any detrimental effect on the posttreatment countermovement jump (they did not provide details); however, the jump height was lower compared to the jump test performed after a dynamic-stretching-movement warm-up. Bubanj et al. (2011) concluded that four sets of static stretches to the major muscle groups of the lower limbs, held at a point of discomfort for 30 s, did not have affect the countermovement jump, which was performed by a self-selected half-squat followed by a vertical jump with the hands on the hips. The researchers did not provide parameters regarding the stretches or the jump. Dalrymple et al. (2010) concluded that there is no difference between the effects of three sets of static stretching, held for 15-s, dynamic stretching performed through the full ROM, and no stretching (only a jogging warm-up) on countermovement jump performance (with arm swing). Cagno et al. (2010) concluded that the average flight time increased for the countermovement jump, performed with a knee bend to 90° in the countermovement phase and the hands on the hips, after static stretching (three repetitions, held for over 30 s to a point of mild discomfort). Murphy et al. (2010) concluded that there was no effect from static stretches, repeated six times and held for 6 s at an unknown intensity, on countermovement jump height (with arm swings and self-selected countermovement depth). The researchers also concluded that there was no effect from static stretching when a treadmill warm-up was performed before or after the stretching protocol. Fletcher and Monte-Colombo (2010) concluded that the height of the countermovement jump, with the hands on the hips, did not decrease, but did not improve after static passive stretching. The experimental group did a 5 min treadmill warm-up, followed by stretching held for 15 s to the point of discomfort. The control group, who only performed 10 min of treadmill exercise, and the static dynamic stretching group, who performed two repetitions of a full ROM while walking on an indoor court, had more improvement in countermovement jump height. Chaouachi et al. (2010) concluded that static stretching to the point of discomfort or slightly less than to the point of discomfort does not affect the height of the countermovement jump, performed with a self-selected comfortable countermovement height. Galdino et al. (2010) concluded that stretching, held for 10 s at the end of normal ROM, significantly reduced countermovement jump height, with the jump performed with the hands on the hips. Tsolakis et al. (2010) concluded that static stretching held for 20 s to a point of mild discomfort does not have a statistically significant effect on the countermovement jump (the researchers did not provide details on the countermovement jump). The researchers mentioned that the jump height was lower after static stretching than ballistic stretching, which consisted of three different flicking movements. Taylor et al. (2009) concluded that two repetitions of static stretches, held for 30 s to a point of minor discomfort, decreased the vertical height of the countermovement jump by 4.2% as compared to the dynamic movement protocol, consisting of 16 dynamic movements stretching the antagonist muscles to the end ROM. After a sport-specific skill practice, the countermovement jump height improved. The static-stretching group and the dynamic-stretching group saw no difference in vertical jump height after sport-specific skill practice. Walter and Bird (2009) concluded that countermovement jump, performed with the hands on the hips and self-selected countermovement depth, decreased acutely in height by 5.5% after a set of static stretches, held for 30 s to a point of slight discomfort. Pearce et al. (2009) concluded that two sets of static stretches, held for 30 s each with no information on the intensity of the stretch, caused a decrease of 7.7% in the height of the countermovement jump, performed by bending the hips and knees

60–80° with the hands on the hips. The decrease in the jump height was statistically insignificant. Gonzalez-Rave et al. (2009) concluded that the vertical height of the countermovement jump (the researchers gave no information on the arm swing or specific countermovement depth) increased after the first set and plateaued after the second and the third static stretching sets. All were held for 15 s at an unknown intensity. The countermovement jump height remained unchanged after the first set of the heavy-load resistance plus stretching protocol but decreased after the second and the third sets. The effects were not statistically significant. Curry et al. (2009) concluded that the vertical height of the countermovement jump, which was similar to the Sargent jump, at 5 min and 30 min posttest was significantly lower after static stretching, held for 15 s to a maximum tolerance level. The researchers did not provide details regarding the countermovement depth or arm swings. Samuel et al. (2008) concluded that three repetitions of static stretches, held for 30 s to a point of strong stretching sensation, do not have any effect on countermovement jumps performed with a self-selected countermovement depth with arm swing. Cronin et al. (2008) concluded that three sets of static hamstrings stretches, held for 30 s to a point of comfortable stretch, do not affect the height of the countermovement jump, performed with the hands on the hips and self-selected countermovement depth. Kinser et al. (2008) concluded that static stretching, held for 10 s at a point of discomfort, does not cause any change in countermovement jump height (with the jump performed with the hands on the hips and a self-selected countermovement depth) in young gymnasts. Behm and Kibele (2007) concluded that static stretching, held for 30 s with a 30-s rest between stretches at 50% of the point of discomfort, 75% of the point of discomfort, and 100% of the point of discomfort, significantly decreases countermovement jump height In this study, they examined countermovement jumps with fast stretch-shortening movement and knee flexion up to 70°, slow stretch-shortening movements with knee flexion up to 70°, and self-selected depth and speed. All three types of countermovement jumps were performed with the hands on the hips. Bradley et al. (2007) concluded that four repetitions of static stretching held for 30 s to a point of mild discomfort, reduced countermovement jump height. The countermovement depth was not specified. The jump was performed with the hands on the hips. The decrease in the countermovement jump height was statistically insignificant; the countermovement jump height after 15 min was equivalent to the pretreatment jump height. Brandenburg et al. (2007) concluded that static stretching, held for 30 s at a point of mild discomfort, in participants who engage in a sport involving regular jumping does not cause significant reduction in the countermovement jump height. The jumps were performed with self-selected countermovement depth and speed and with the hands on the hips. Vetter (2007) concluded that static stretching, held for 30 s to a point where the stretch was felt, does not have any significant effect on countermovement jump height (the jumps were performed with a self-selected countermovement depth and the arms raised over the head to mark the highest point on the wall. The researcher mentioned that warm-up including a stretch component resulted in a lower jump height than the other warm-ups lacking a stretch component. Bazett-Jones et al. (2008) concluded that 6 weeks of static stretches, held for 45 s to a point of mild discomfort, in collegiate-level track and field athletes does not increase or decrease the height of the countermovement jump performed with the hands on the hips at an unmentioned depth. Kokkonen et al. (2007) concluded that three sets of 15-s static stretches per week for 10 weeks increase the vertical countermovement jump height by 6.7% (a statistically significant difference. The jump was performed with self-selected countermovement depth and arm swing. The researcher also mentioned that the change in the vertical jump was minor in the control group. Woolstenhulme et al. (2006) concluded that 6 weeks of static stretching, consisting of two sets of stretches held for 30 s to the point where tightness was felt in the target limb, do not have any effect on countermovement jump performance (not described by the researchers). Burkett et al. (2005) concluded that there was no difference in vertical jump height, measured by marking the highest point reached, after one repetition of 14 static stretches held for 30 s during warm-up, after submaximal warm-up (including countermovement jumps to a preset height), or after no warm-up. The jump was not described in detail. Unick et al. (2005) concluded that static stretching (consisting of three repetitions held for 30 s to a point of discomfort) does not have any significant effect on a countermovement jump performed with a self-selected eccentric phase depth and arm swing. Guissard and Reiles (2005) concluded that 6 min of low-intensity static stretching followed by 3 min of dynamic exercise does not have a significant effect on countermovement jump performance. The researchers did not provide details on the stretches or jump performance. Wallmann et al. (2005) concluded that the height of the countermovement jump from a self-selected eccentric phase depth and with the hands on the hips, decreases by 5.7% after three sets of static gastrocnemius-muscle stretches, held for 30 s to a point just before discomfort. They also concluded that the gastrocnemius muscle activity as measured by EMG increased 17.5% after static stretching. Goodwin (2002) concluded that 10 s static stretches do not improve countermovement jump performance; however, they do increased the countermovement jump height compared to a massage warm-up. Hunter and Marshall (2002) concluded that 6 weeks of static stretching, to the point of mild discomfort, held for 20 s and increased the hold time by 10 s every week, leads to increased muscle stiffness during the eccentric phase of the jump and the depth. There was not a statistically significant increase in the countermovement jump height (performed with the hands on the hips), but it was a greater increase than in that of the drop jumps measured in the study. Cornwell et al. (2001) found that static stretching decreases the countermovement jump height. The countermovement for the jump was performed with the knees at up to 90° and with hands on the hips; the stretch intensity was gradually increased in every set, to the point of the onset of pain, and the stretch was held for 30 s in the third set.

The effects of static stretching on the drop jump. Pacheco et al. (2011) concluded that the height of drop jumps from 40 cm decreased slightly after static stretching, where the stretch intensity gradually increased and stretches were held for 30 s. Fletcher and Monte-Colombo (2010) concluded that drop jumps from a height of 0.3 m and hands on the hips showed the least improvement after static passive stretching, compared to static dynamic stretching and the control group's protocol. Tsolakis et al. (2010) concluded that static stretching (held for 20 s to a point of mild discomfort) does not have a statistically significant effect on the drop jump. The researchers did not give details about the jump. They mentioned that the jump height was lower after static stretching than ballistic stretching (three different flicking movements). Yuktasir and Kaya (2009) concluded that static stretching, held for 30 s as tolerated by the participants, performed 4 days a week for 6 weeks, does not affect drop jump performance, with jumps performed from a height of 60 cm with the hands on the hips. Behm and Kibele (2007) concluded that static stretching held for 30 s with a 30-s rest between stretches, performed at 50%, 75%, and 100% of the point of discomfort, significantly decreases drop jump height. The jump was performed from a height of 24 cm with the hands on the hips. Unick et al. (2005) concluded that three repetitions of static stretches held to a point of discomfort do not significantly affect on a drop jump from a height of 26.5 cm, performed with arm movement. Power et al. (2004) concluded that the height of a vertical drop jump, from a height of 30 cm with the hands on the hips, decreases after two repetitions of static stretching (held for 45 s to the point of discomfort). The decrease was statistically insignificant. Hunter and Marshall (2002) concluded that 6 weeks of static stretching (to the point of mild discomfort, held for 20 s originally and increased 10 s every week) leads to decreased leg stiffness during the jump's eccentric phase, increasing the countermovement phase of the drop jump and the ground-contact time. Young and Elliott (2001) found a statistically significant decrease in a 30 cm drop jump height and time after three repetitions of static stretches, held for 15 s.

The effects of static stretching on the squat jump. Carvalho et al. (2012) found that active static stretching or passive static stretching, held for 15 s to a point of mild discomfort, did not have statistically significant effect on vertical squat jump height. The jump was performed with the knees at 90° and the hands on the hips. Vanderka (2011) found that the height of a squat jump—described as a countermovement jump without the countermovement phase, but with the hands on the hips—decreases by 2.8% when static stretching was performed before the test. Pacheco et al. (2011) concluded that squat jump height decreases slightly after static stretching in a study where participants increased the stretch intensity gradually and held the stretch for 30 s. Cagno et al. (2010a) concluded that the average flight time of a squat jump increases after a bout static stretching. The jump was performed with the knee at 90° and the hands on the hips; participants did three repetitions of stretches, holding them for over 30 s to a point of mild discomfort. Tsolakis et al. (2010) concluded that static stretches, held for 20 s to a point of mild discomfort, do not have a statistically significant effect on the squat jump (the jump details were not provided by the researchers). The researchers mentioned that the jump height was lower after static stretching than ballistic stretching consisting of three different flicking movements. Hough et al. (2009) concluded that static stretching (held for 30 s to a point of mild discomfort) significantly reduces squat jump height. The jump was performed with a self-selected knee flexion angle, held for 2 s before the jump, and done with the hands on the hips. Gonzalez-Rave et al. (2009) concluded that vertical jump height improves after the first set of static stretching, held for 15 s at an unknown intensity, and plateaus after the second and third set. However, the improvement was not statistically significant. The squat jump height after heavy-load resistance combined with stretching remained the same after all three sets. The researchers took the best of three jumps, performed with the knees at 90° and with the hands on the hips. Robbins and Scheuermann (2008) concluded that three sets of static stretches, held for 15 s to a point just before pain, do not cause a statistically significant increase or decrease in vertical jump height for the squat jump (performed with the knees at approximately 100° and with full arm swing). They also noted that the jump height decreased the most for the group that performed six sets of static stretches, although the difference was not significant. Kinser et al. (2008) concluded that static stretches, held for 10 s to a point of discomfort, do not cause any change in the height of young gymnasts' squat jumps, performed with the hands on the hips and starting with the knees flexed to 90°. Behm and Kibele (2007) concluded that static stretching significantly decreases squat jump height. The stretches were held for 30 s with a 30-s rest between stretches, performed to 50%, 75%, and 100% of the point of discomfort. The squat jumps started with the knees flexed to 70° and the hands on the hips. Bradley et al. (2007) concluded that four repetitions of static stretches, held for 30 s to a point of mild discomfort, reduced static jump height. The jump was started with the knees kept at 90° for 3 s before the jump. The decrease was statistically insignificant; the jump height returned to pretreatment levels after 15 min. Guissard and Reiles (2005) concluded that six min of low-intensity static stretching, followed by 3 min of dynamic exercise, does not have a significant effect on the squat jump performance. The researchers did not describe the details of the stretching and jump performance. Power et al. (2004) concluded that the height of the concentric jump decreases after two repetitions of static stretches, held for 45 s to the point of discomfort. The test was started with the knees at 90° for 2 s, followed by a jump to achieve maximum vertical height. The decrease in height was statistically insignificant. Young and Elliott (2001) concluded that there was no effect of three repetitions of 15 s static stretches on the squat jump, which was started with the knees bent at 100° for 2 s before jumping and a 10-kg bar on the shoulders in a Smith's machine. Cornwell et al. (2001) found that the change in height of the static jump (with a knee angle of 90°) was significantly less than the height of the countermovement jump (with a knee angle of 90° during the countermovement phase). Nelson et al. (1996) concluded that passive stretching significantly decreases the vertical height of the squat jump (started with the knees at 90°). They did not provide details about the stretches.

The effects of static stretching on uncategorized jumps. Hobara et al. (2011) studied the effects of stretching held for 3 min, concluding stretching does not have any effect on the last six hops out of 15 nonstop hops with short ground contact time. They did not provide details on stretch intensity. Bird et al. (2010) concluded that static stretching, held for 30 s at a point of mild discomfort, does not have any effect on jump performance. Cagno et al. (2010a) concluded that the flight time of a technical split leap in elite gymnasts was significantly reduced after static stretching. Ross (2007) concluded that 15 days of static stretching increases jump distance. The stretching routine consisted of five repetitions held for 30 s to a point where tightness was felt in the area being stretched; the effect was tested after 10 min. The jump was performed on one leg with a goal of jumping as far as possible. Kokkonen et al. (2007) concluded that static stretching performed in three 15-s sets per week for 10 weeks increases the length of the long jump by 2.3%. The jump was performed with both feet and an arm swing, with the goal of covering the longest distance possible. McMillian et al. (2006) concluded that a static stretching warm-up (one repetition each of eight different positions, all held for 20–30 s) significantly improved the five-step jump performance, compared to no warm-up. The participants were allowed to measure and take five steps before the jump.

The Effects of Dynamic Stretching

The effects of dynamic stretching on the countermovement jump.

Pearce et al. (2012) found that dynamic stretching (moving the target limb through the entire ROM) improved vertical jump height. The effect was similar to that of the control group. Carvalho et al. (2012) found that the height of the countermovement jump, performed with self-selected eccentric phase depth and with the hands on the hips, was slightly higher after active static stretching followed by dynamic stretching, as well as after passive static stretching followed by dynamic stretching. The dynamic stretching was performed in the same position as the static stretching, but included a rebound movement. However, the difference in jump height was not statistically significant. Fletcher (2013) found the greatest increase in countermovement jump height came after including dynamic stretches, consisting of two sets of 10 repetitions of the full ROM with self-selected countermovement depth and the hands on the hips. Vanderka (2011) found that the height of the countermovement jump with the hands on the hips increased by 2.46% when dynamic stretching was performed before the jump test. Turki et al. (2011) found that dynamic stretching and dynamic stretching with resistance training increase countermovement jump height. Their dynamic stretches consisted of a full ROM with movements to target a particular muscle or group of muscles. Perrier et al. (2011) concluded that countermovement jump height increases after dynamic stretching (they described activities without any mention of the full ROM), compared to static stretching or the control activity. The static stretch targeted seven major lower-limb muscles and gradually increased in intensity as tolerated; stretches were held for 30 s. Frantz and Ruiz (2011) concluded the jump height was significantly greater after a dynamic-stretching-movement warm-up. The details pertaining to the stretches and jumps were not mentioned. Fletcher (2010) concluded that fast dynamic stretching consisting of seven different flicking movements at a rate of 100 beats per min increases the height of the countermovement jump (performed with a self-selected countermovement depth with the hands on the hips) more than slow dynamic stretching, consisting of the same seven flicking movements, but performed at a rate of 50 beats per min). Fletcher and Monte-Colombo (2010) concluded that countermovement jump, performed with the hands on the hips, improved the most after static dynamic stretching, compared to static passive stretching and the control group's 10 min of treadmill exercise. The control group saw the next most improvement; the least improvement was recorded after static passive stretching (5 min of warm-up on the treadmill followed by stretches held for 15 s to the point of discomfort). Chaouachi et al. (2010) concluded that dynamic stretching movements do not increase or decrease the height of the countermovement jump, performed with a self-selected comfortable countermovement depth. Dalrymple et al. (2010) concluded that there is no difference between the effects of static stretching (three sets held for 15 s each), dynamic stretching (movements encompassing a full ROM) and no stretching (just 5 min of jogging) on countermovement jumps performed with arm swing. Taylor et al. (2009) concluded that 16 movements included in the dynamic stretching warm-up increased the vertical jump height of the countermovement jump (performed with self-selected countermovement depth) by 2.0%. There was no further improvement in the vertical jump height after the sport-specific skill practice. There was also no difference between the static stretching group and the dynamic stretching group after the sport-specific skill practice. Pearce et al. (2009) concluded that seven swinging movements involved in the dynamic stretching routine increase by 3% the height of the countermovement jump (performed by bending the hips and knees 60–80° and putting the hands on their hips). The increase was statistically insignificant. Curry et al. (2009) concluded that the vertical height of the countermovement jump after 5 min and 30 min posttest was significantly lower after dynamic stretching (two sets of 10 repetitions of nine dynamic movements similar to those used in Fletcher and Jones' (2004) study). No details were given regarding countermovement depth or arm swing. Christensen and Nordstrom (2008) concluded that there is no effect from dynamic stretching, consisting of eight kicking and flicking activities to the end of the ROM, on countermovement jump, performed with self-selected countermovement depth and with arm swing. Jaggers et al. (2008) concluded that there is no statistically significant effect from dynamic stretching (five movements performed 10 times slowly and five times fast) on countermovement jump height. The researchers also concluded that countermovement jump power (measured using a force plate) increased after the dynamic stretching movements. Vetter (2007) concluded that dynamic stretching, performed as movements taking the limbs into the end ROM, does not have any significant effect on countermovement jump height. The jumps were performed with self-selected countermovement and the arms raised over the head to mark the highest point on the wall. The researcher mentioned that the warm-up with a stretch component resulted in a lower jump height than the other warm-ups without stretch components. Woolstenhulme et al. (2006) concluded that 6 weeks of ballistic stretching performed in the same position as static stretching but including bouncing movements at a rate of 60 beats per min, when combined with 20 min of basketball activity, improves the vertical height of the countermovement jump.

The effects of dynamic stretching on the drop jump. Fletcher (2013) concluded that the height of the drop jump, performed from a height of 0.2 m with the hands on the hips, increased after a warm-up including resistance training and dynamic stretching (two sets of 10 repetitions with a full ROM). Fletcher (2010) concluded that fast dynamic stretching (consisting of seven different flicking movements at a rate of 100 beats per min) increases vertical drop jump height more than slow dynamic stretching (consisting of the same seven flicking movements at a rate of 50 beats per min). The jump was performed from a height of 0.3 m with the hands on the hips. Fletcher and Monte-Colombo (2010) concluded that a drop jump from a height of 0.3 m with the hands on the hips improved the most after static dynamic stretching rather than static passive stretching or the control group activities.

The effects of dynamic stretching on the squat jump. Fletcher (2013) found that the vertical height of the squat jump, performed with the knee in a 90° position and the hands on the hips, increased, but the increase in the squat jump was less than the increase in the countermovement and drop jumps. Carvalho et al. (2012) concluded that dynamic stretching performed in the same position as the study's static stretching but with a rebound movement did not signifcantly affect squat jump performance. The jump was performed with the knees at 90° and the hands on the hips. Vanderka (2011) found that the height of the squat jump (described as a countermovement jump without the countermovement phase and with the hands on the hips) increased by 6.3% when dynamic stretching was performed before the jump test. Fletcher (2010) concluded that fast dynamic stretching, consisting of seven different flicking movements at a rate of 100 beats per min, increases the height of the squat jump (from) more than slow dynamic stretching, consisting of the same seven flicking movements at a rate of 50 beats per min. The jump was started with the knees bent to 90° and the hands on the hips. Hough et al. (2009) concluded that the height of the vertical jump (with self-selected knee flexion held for 2 s before the jump and with the hands on the hips) was significantly higher after dynamic stretching compared to static stretching. The dynamic stretches consisted of bouncing movements produced by the antagonist muscle group, held for 2 s before releasing to full ROM.

The effects of dynamic stretching on uncategorized jumps.

McMillian et al. (2006) concluded that dynamic warm-up, including 10 calisthenics and five flicking movements, improved the five-step jump more than a static warm-up. The participants were allowed to measure and take five steps before the jump. The static warm-up consisted of one repetition of stretching in eight different positions, each held for 20–30 s.

The Effects of Ballistic Stretching

The effects of ballistic stretching on the countermovement jump.

Tsolakis et al. (2010) concluded that ballistic stretching, consisting of three different flicking movements, does not have a statistically significant effect on the countermovement jump (details not provided by the researchers). The researchers mentioned that the jump height was lower after static stretching (held for 20 s at a point of mild discomfort) as compared to ballistic stretching. Samuel et al. (2008) concluded that ballistic stretching, consisting of bouncing movements at a rate of one per s for 30 s, does not affect the height of the countermovement jump (using a self-selected countermovement depth and arm swing). Jaggers et al. (2008) concluded that there was no statistically significant effect from ballistic stretching (bouncing at a pace of 126 beats per min for two sets of five movements similar to the dynamic stretching movements) on countermovement jump height. They did not provide details on the jump. Bradley et al. (2007) concluded that ballistic stretching (four repetitions of five exercises, held for five s each, with bobbing movement for 25 s) does not reduce countermovement jump height. Unick et al. (2005) concluded that ballistic stretching does not have any significant effect on countermovement jump height. The jump was performed with self-selected depth of the eccentric phase and with arm swing; the stretches consisted of three repetitions with a rate of one up-and-down movement per second.

The effect of ballistic stretching on the drop jump. Tsolakis (2010) concluded that ballistic stretching (three different flicking movements) does not have a statistically significant effect on the drop jump (details not given by the researchers). The researchers mentioned that the jump height was lower after static stretches held for 20 s at a point of mild discomfort than after ballistic stretches. Unick et al. (2005) concluded that three repetitions of static stretches held for 30 s to a point of discomfort do not have any significant effect on a drop jump performed from a height of 26.5 cm with arm movement.

The effect of ballistic stretching on the squat jump. Tsolakis et al. (2010) concluded that ballistic stretching (three different flicking movements) does not have a statistically significant effect on the squat jump (details not provided by the researchers). The researchers noted that the jump height was lower after static stretches held for 20 s at a point of mild discomfort than after ballistic stretches. Bradley et al. (2007) concluded that ballistic stretching, consisting of four repetitions of five exercises held for 5 s each with bobbing movement for 25 s, does not reduce static jump height. Before the jump, the knees were maintained at 90° for 3 s).

The Effects of PNF Stretching

The effects of PNF stretching on the countermovement jump. Place et al. (2012) concluded that PNF stretching does not affect the countermovement jump. The stretches consisted of contractions of the hamstrings for 5 s, passive stretching of the quadriceps for 5 s, and isometric holds of the quadriceps for 5 s; the jump was performed with the hands on the hips and knee flexion of 60–80°). Pacheco et al. (2011) concluded that countermovement jump height improves significantly after PNF stretching (isometric contractions for 4 s, 4 s of relaxation, and static passive stretching for 15 s), static active stretching with active tension (contracting and stretching the agonist muscle at the same time, held for 4 s) and static active stretching in passive tension (the agonist stretched by antagonist contraction, held for 6 s). Christensen and Nordstrom (2008) concluded that there is no effect from the contract-relax type of PNF stretching on countermovement jump performance. The stretching protocol consisted of contraction of the target muscle group to the count of two, followed by a passive stretch to the count of five; the jump started with self-selected countermovement depth and included arm swing. Bradley et al. (2007) concluded that contract-relax PNF stretching (passive stretching by the researcher to the end point, 5 s of voluntary isometric contraction of the antagonist, and 30 static passive stretches) reduces countermovement jump height (the countermovement depth was not specified; it was performed with the hands on the hips). The decrease in height was statistically insignificant. Guissard and Reiles (2005) concluded that 6 min of low-intensity PNF stretching, followed by 3 min of dynamic exercise, does not have a significant effect on countermovement jump performance. The researchers did not give details regarding the stretches or jump performance.

The effects of PNF stretching on the drop jump. Young and Elliott (2001) found that there was no significant effect of PNF stretching on drop jumps performed from a height of 30 cm. Participants performed three repetitions of contract-relax stretches, 5 s isometric contractions against maximum resistance—a passive stretch applied by researcher to a point of pain, held for 15 s. Place et al. (2012) concluded that there was no effect of performing PNF stretching on drop jumps from a 30 cm height, performed with the hands on the hips and knee flexion of 60–80°. In this study, the stretches consisted of hamstrings contractions for 5 s, passive quadriceps stretching for 5 s, and isometric quadriceps holds for 5 s. Pacheco et al. (2011) concluded that drop jumps from a height of 40 cm improve significantly after a PNF stretching routine consisting of isometric contractions for 4 s, 4 s of relaxation, and static passive stretching for 15 s; after a static active stretching routine with active tension, consisting of simultaneously contracting and stretching the agonist muscle for 4 s; and after static active stretching in passive tension, with the agonist stretched by antagonist contraction and held for 6 s. Yuktasir and Kaya (2009) concluded that 30 s of contract-relax PNF stretching does not affect on the drop jump, performed from a height of 60 cm with the hands on the hips). Phase 1 of the stretching consisted of 90° hip flexion with knee extension and ankle dorsiflexion for 10 s; phase 2 was 5 s of the hip positioned in extension and the ankle in plantar flexion against resistance provided by the researcher, followed by a 5-s relaxation; and phase 3 was 15 s of the researcher providing stretching force to the hamstrings and gastrocnemius.

The effects of PNF stretching on the squat jump. Young and Elliott (2001) found no significant effect from PNF stretching on the squat jump performed with a 10-kg bar on the shoulders in a Smith's machine. The PNF stretching routine involved three repetitions of contract-relax, 5 s of isometric contraction against maximum resistance—passive stretch applied by the researcher to the point of pain, held for 15 s. Pacheco et al. (2011) concluded that squat jump height improves significantly after a PNF stretching routine consisting of isometric contractions for 4 s, 4 s of relaxation, and static passive stretching for 15 s; after a static active stretching routine with active tension, consisting of simultaneously contracting and stretching the agonist muscle for 4 s; and after static active stretching in passive tension, with the agonist stretched by antagonist contraction and held for 6 s. Bradley et al. (2007) concluded that contract-relax PNF stretching (passive stretching by the researcher to the end point, 5 s of voluntary isometric contraction of the antagonist, and 30 static passive stretches) reduces static jump height. The knees were maintained at 90°

for 3 s before the jump. The decrease in the jump height was statistically insignificant. Guissard and Reiles (2005) concluded that 6 min of low-intensity PNF stretching followed by 3 min of dynamic exercise does not have a significant effect on squat jump performance. The researchers did not provide details regarding the stretching or jump performance.

Chapter 5 Discussion

Introduction

This chapter interprets the results of the effects of static stretching, dynamic stretching, ballistic stretching, or PNF stretching on various types of jumping in terms of this study's problem statements. This chapter consists of a table that compares protocols and the results of all the studies included in the review, discussion of issues concerning the research on stretching, the benefits of stretching, and suggestions for future research.

The table 1 provides a clearer picture of the different types of stretching instructions and their effects, as well as the parameters of the studies. The rows are arranged in the order that the study was conducted: authors, warm-up (if performed), type of stretching (with instructions), activities between stretching and jump performance measurement (if applicable, and with as much as detail as is available), type of jump (with instructions) and finally, conclusions (as described in the study). The phrase "not described" means that the study either does not mention the activity being performed, or does not provide parameters. An example of the former is the study by Cronin et al. (2008), which did not mention if there were any activities between the stretching and the jump measurements. In other cases, activities are mentioned but the details were not provided. For example, the study by Gonzalez-Rave (2009) provided details on the squat jump performance; however, they mentioned that a countermovement jump was performed but do not describe it. Regarding the formating of the table, the parameters that were used in general for the entire study are centered. The parameters that were different for different portions are separated into different colums within the same citation block. For example, Taylor et al. (2009) utilized the same warm-up for static stretching and dynamic stretching—different stretching methods with different details—then the same protocol was followed for the activities between the stretch and jump; next, they provide different results for the different stretching techniques. A blank block means either the information was not given or the parameter is not applicable to that particular study. The information for the conclusions was gleaned from the conclusions section of the study; if the study did not have a conclusions section, then the information was drawn from the results section. The details of the results are mentioned as provided in the study's conclusions or results section; no additional interpretation from the discussion section or statistical analysis is presented. In cases where a study has special information such as a specific protocol, the information is mentioned in the same column with the study citation. For example, Dalrymple et al. (2010) used collegiate volleyball players as their study's participants.

Table 1: Summary of the Stretching Parameters and their Effects on Different Jumps

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
1	Carvalho et al., 2012	5 min running in a tennis court at a heart rate of 140 beats/min	Passive stretching: 3 stretches, 3 sets, held for 15 s to the point of mild discomfort	Immediate	CMJ: self-selected eccentric phase, hands on the hips	No significant effect of any type of stretching on any jump performance
			Active stretching: 3 stretches, 3 sets, held for 15 s to the point of mild discomfort		SJ: knees flexed to 90°, hands on the hips	CMJ was higher than SJ in general
			Dynamic stretching: bobbing movement at the rate of 1 movement per s for 30 s			Both jumps were higher after dynamic stretching compared to active stretching and passive stretching
2	Sandberg et al., 2012	No warm-up (stretched antagonist muscle group)	Static stretching: 3 stretches, 3 sets, held for 30 s to the point of mild discomfort	Isokinetic knee extension: slow knee extension at a rate of 60°/s and fast knee extension at a rate of 300°/s. Stretching protocol. 90 s of rest	CMJ: self-selected eccentric phase, possible hand swing	Significant increase in jump height and jump power. Stretching antagonist muscle groups relaxed the neuromuscular reflex.
3	Mikolajec et al., 2012	15 min warm-up. Continuous running, agility drills, general acceleration measurement skills.	4 stretching exercises, 3 repetitions each, held for 10 s to 80–90% full ROM. 3-week protocol divided into weekly microcycles of different warm-up protocols. Stretching included in the first week only	Strength training exercises. 80–85% of 1RM voluntary contraction isometric hamstrings	CMJ: from standing position (instructions not mentioned)	No improvement in jump performance after the stretching protocol. The jump height increased significantly after the week that included strength training.
4	Pearce et al., 2012	Jogging for 5 min at 65% maximum heart rate + maximum height vertical jump from knees at 60–80° and hands on the hips.	Static stretching: 5 exercises, 2 sets, with 30 s hold (no information on stretch intensity)	1 min rest	CMJ: from knees at 60–80° and hands on the hips.	After static stretching, the vertical height of the first and second jumps was reduced but the third jump was equal to the baseline jump.
			Dynamic stretching by performing full ROM movements.			After the second bout of dynamic stretching, the vertical height of the jump improved (statistically insignificant).

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
5	Vanderka, 2011	Mentioned specific warm-up without details (random jumps) Protocols: 1) static stretching-dynamic stretching-jump. 2) dynamic stretching-static stretching-jump	Static stretching: 6 exercises, held for 30 s (no information on the intensity of the stretch)	3 min break between two different stretching protocols. Jumps were measured immediately after the last stretching	CMJ from standing with countermovement (no other details mentioned)	After the static stretching the vertical height of both the jumps reduced (statistically insignificant).
			Dynamic stretching by rapid swinging movements to the end ROM		SJ performed similarly to the CMJ but without the eccentric phase.	After the dynamic stretching, the vertical height of both jumps increased slightly (statistically insignificant).
6	Perrier et al. 2011	Treadmill jogging at a self-selected pace	7 exercises, 2 repetitions, held for 30 s with gradually increasing intensity as tolerated	3 trials of sit-and-reach test	10 CMJ with 1 min break between each	No effect of static stretching on the CMJ Compared to the control group and the static stretching group, the CMJ height was significantly higher after the dynamic stretching protocol.
			Dynamic stretching achieved by activities. No mention of full ROM.			
7	Pacheco et al., 2011	Low intensity, continuous running for 10 min	Static passive stretching: 30 s hold (no information on the intensity of the stretch)	No mention of rest period or immediate activity. 3 repetitions of each jump with 20 s break and 1 min break between different types of jumps		
			Static active stretching in active tension.		No details mentioned about CMJ	CMJ and SJ performances were significantly higher after static active stretching in passive tension
			Static active stretching in passive stretching		DJ from 40 cm. No mention of hand positioning.	Static stretching with active tension had a positive effect over all the jump performances.
			PNF stretching, contract-relax method. Isometric contraction for 4 s, voluntary relaxation of the muscle group for 30 s, static passive stretching for 15 s.		No details regarding the instructions for the squat jump	PNF increased the height of the CMJ and SJ (statistically significant). The jump height after PNF stretching was less compared to the no stretching group.

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
8	Frantz and Ruiz, 2011	No warm-up	19 dynamic exercise movements (details not mentioned)	Participants had to wait in line, but an accurate or exact wait time is not mentioned.	CMJ: started from standing flatfooted and then performed a CMJ (no other details)	The jump performances were improved after the dynamic stretching protocol, compared to the jump performances after the static stretching protocol.
			21 static stretching positions (details not mentioned)		Standing long jump was performed from a standing position to cover a longer distance.	There was no effect from the static stretching on any of the jump performances.
9	Bubanj et al., 2011	Running and skipping	4 sets, held for 30 s to the point of discomfort	Immediate	Hands on the hips with self-selected eccentric phase	No effect on the CMJ
10	Murphy et al. 2010	Running 5 min on a treadmill	6 repetitions held for 6 s	The poststretching data were gathered 1 min and 10 min after the last aerobic activity	Self-selected eccentric phase and with arm swing	No effect on the jump
11	Fletcher and Monte-Colombo, 2010	Jogging for 5 min at a self-selected pace	Static passive stretching: 2 sets of bilateral stretches held for 15 s per muscle group to the point of discomfort	Poststretching activity was not mentioned	CMJ: with hands on the hips (no other information on the eccentric phase of the jump)	The static passive stretching group had significantly lower jump heights than the control group.
			Static dynamic stretching: flicking movements performed 12 times per limb (total 144 movements)		DJ: from a height of 0.3 m	The static dynamic stretching group had significantly higher jump heights than the control group.
12	Chaouachi et al., 2010	Running for 5 min at a self-selected pace, and aerobic activities like sidestepping.	5 exercises as described by Yamagucchi and Ishii (2005) at different intensities. Point of discomfort or slightly less with the dynamic stretching	5 min of specific explosive warm-up, 2 min of rest, and sprint (counterbalanced test before the jump)	3 maximal CMJ with the hands on the hips and self-selected eccentric phase	The combination of dynamic stretching and static stretching did not affect the jump performance.

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
13	Tsolakis et al., 2010	Self-selected, slow-paced jogging for 8 min	Static stretching: 3 sets of 3 different exercises held for 20 s to a point of mild discomfort.	5 min rest + the time required for the sit and reach test + the fencing maneuver	CMJ, SJ, and DJ details were not mentioned.	No significant effect of any type of stretching on any jump performance
			Ballistic stretching: 3 sets of 3 different exercises performed in rapid stretching movements in alternating fashion.			Overall the jumps after ballistic stretching were higher than those after static stretching.
14	Taylor et al. 2009	Running 300 m in 2–3 min and vertical jump test	Static stretching: 2 repetitions of 8 stretching exercises held for 30 s at a point of minor discomfort	The testing protocol included: warm-up-stretching-performance test-skill-performance test.	CMJ performed with a self-selected eccentric movement depth, but the arm movement is not described	The CMJ was reduced after the static stretching protocol (statistically significant). There was no significant improvement in the jump after the skill activity.
			Dynamic stretching: 2 or 3 repetitions of 16 different exercises with emphasis on achieving full ROM			The CMJ increased after the dynamic stretching protocol (statistically insignificant).
15	Walter and Bird, 2009	Submaximal cycling for 5 min with a resistance of 120 W	4 stretching exercises, each held for 30 s, to a point of slight discomfort	Acute (immediate)	CMJ performed with a self-selected eccentric movement phase with the hands on the hips	The jump height decreased significantly
16	Gonzalez-Rave et al. 2009	3 min light cycling and 3 min rest	3 static stretching exercises with 15 s hold at an unknown intensity	3 min rest between each set of stretching and CMJ and SJ	No details were mentioned regarding the CMJ	Height increased in the first set of CMJ. The CMJ plateaued after the second jump. The increase was statistically not significant.
					SJ: Knees flexed to 90°, hands on the hips	The results were similar for the SJ.

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
17	Pearce et al., 2009	5 min warm-up on the treadmill at 65% max heart rate	Static stretching: 2 sets of 5 static stretching exercises with 30 s hold to an unknown intensity	No rest or activity mentioned	CMJ were performed from knee 60–80°	The CMJ decreased significantly after the static stretching (mean decrease of 7.7%).
			Dynamic stretching: 2 sets of 10 repetitions of full ROM movements			Insignificant increase in jump height after the dynamic stretching
18	Curry et al. 2009	5 min light aerobic cycling at a RPE of 10-11	Static stretching: 5 min of cycle + 6 static stretching exercises with 12-s hold at a maximum tolerance level.	Thomas test	Sargent jump: no details on the depth or arm swing	The CMJ height was significantly decreased after 5 min and 30 min compared to the warm-up condition.
			Dynamic stretching: 5 min cycle + 9 exercises with 20 repetitions for each leg to perform controlled movement through full active ROM			
19	Samuel et al. 2008		Static stretching: 3 repetitions with 30-s hold to a point of strong stretch sensation		CMJ: self-selected eccentric phase with arm swing	No effect on the jump
20	Cronin et al. 2008	5 min warm-up light jogging at 40% max	3 sets of hamstrings stretches held for 30 s to a point of comfortable stretch	Not described	CMJ: self-selected eccentric phase with hands on the hips	No effect on the jump
21	Kinser et al. 2008	Not mentioned (Participants were young gymnasts)			CMJ: self-selected eccentric phase with hands on the hips	No change of stretching on the CMJ
			Stretch was held for 10 s to a point of discomfort	Not described	SJ: from knees at 90° and hands on the hips	No change of stretching on the SJ

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
22	Behm and Kibele, 2007	5 min cycle ergometer at 70 W + 3 stretches + DJ from 24 cm height + CMJ with fast stretch shortening cycle + CMJ with slow stretch shortening cycle from 70° knee + CMJ with self-selected knee bending and speed + SJ	Static stretching: 4 exercises held for 30 s with 30 s recovery at 50% point of discomfort	5 min	CMJ with fast stretch shortening cycle with knee bending up to 70°	After all the stretching intensity protocols, the jump height decreased significantly
			Static stretching: 4 exercises held for 30 s with 30 s recovery at 75% point of discomfort		CMJ with slow stretch shortening cycle with knee bending up to 70°	
			Static stretching: 4 exercises held for 30 s with 30 s recovery at 100% point of discomfort		CMJ with self-selected speed and knee bending	
					DJ from 24 cm with the hands on the hips	
			Control group performed a 5-s stretch to a maximum tolerance point of discomfort		SJ from knees in 70° with the hands on the hips	
23	Bradley et al. 2007	5 min cycle	Static stretching: 4 repetitions of 5 stretching exercises, each held for 30 s to a point of mild discomfort	30 s rest interval. CMJ and SJ were tested on the same day; so one type of jump was before the other. The effect of the first jump may have added to the effect of stretching protocol.	CMJ with knees up to 90° and hands on the hips	Overall, SJ height was lower than CMJ height. No significant difference between the jump height after static stretching and PNF stretching.
			Ballistic stretching: 4 repetitions of 5 exercises for 5 s hold, and 25 s of bobbing movement			The CMJ and the SJ height were reduced (insignificant) after the ballistic stretching.
			PNF stretching: passive stretching to the end ROM for 5 s, 5 s of maximum voluntary isometric contraction of the antagonist, passive stretch of the agonist held for 30 s		SJ was performed from a squat position with knees in 90°	15 min after the static stretching and the PNF conditions, the height for both jumps were equal to the prestretch jump height.

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
24	Brandenburg et al. 2007	(Participants were athletes of a sport that included jumping as a major activity	Static stretching: held for 30 s to the point of discomfort		CMJ with self-selected eccentric phase and arms raised overhead to mark the highest spot.	Insignificant reduction in the jump height
25	Bazett-Jones et al. 2008	Self-selected exercises for 10 min. Participants were college track and field athletes	Static stretching: 6 weeks protocol held for 45 s to a point of mild discomfort	Not described	CMJ with hands on the hips (eccentric phase depth not mentioned)	No effect
26	Kokkonen et al. 2007	Slow jogging for 400 m, and general ROM leg swings	Static stretching: (10-week protocol) 3 sets per week held for 15 s	Not described	CMJ with self-selected depth and arm swing	Increased the jump height significantly
					Long distance jump from a self-selected depth, using both feet and arm swing.	
27	Woolstenhulme et al., 2006	Light jogging for 5 min	Static stretching: 6 weeks protocol for 2 sets (per week or day is not mentioned) held for 30 s to a point of tightness.	20 min of basketball game immediately followed by the jump	No details about the type of jump	Improved the CMJ performance after the basketball game but no effect after the stretching protocol
28	Burkett et al. 2005		Static stretching: 1 repetition of 14 exercises held for 30 s		No details	No effect
29	Unick et al. 2005	Sit-and-reach test measurement, jogging for 5 min, and a rest period for 30 s	Static stretching: 3 repetitions of 4 exercises held for 30 s just before the point of discomfort	4 min walk + 3 CMJ trials + 3 DJ trials	CMJ: with self-selected eccentric phase and arm swing	Both jumps remained same as prestretch jumps; there was very insignificant decrease.
			Ballistic stretching: 3 exercises performed by bobbing movements. Each exercise was performed for 15 s at a rate of 1 bob per s		DJ: height of DJ is not mention. Arm swing was allowed.	
30	Guissard and Reiles, 2005	General warm-up for 10 to 15 min	PNF stretching: 6 min low-intensity stretching (no details mentioned)	Dynamic activity for 3 min	CMJ: No details mentioned	No significant change

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
31	Wallmann et al. 2008		Static stretching: held for 30 s to a point just before point of discomfort		CMJ: with a self-selected eccentric phase and hands on the hips	There was decrease in the jump height (5.6%) after stretching. The EMG of the gastrocnemius muscles increased by 17.9% during the post stretch jump.
32	Cornwell et al. 2001	No mention	Static stretching: 1 repetition of 3 static stretching exercises. Each stretching was held for 30 s to a point of maximum tolerance.	A break of 10 min, and either SJ or CMJ were performed in a random and counterbalanced manner	CMJ from standing with eccentric phase up to knees in 90°. Information regarding arm swing was not provided.	The height of both jumps was significantly reduced
					SJ: from knees in 90° flexion	SJ height was less compared to CMJ for both stretch and control conditions.
33	Wallmann et al. 2005	Walk on treadmill at a speed of 1.34m/s for 5 min. Rest between baseline jumps and stretching	Static stretching of gastrocnemius on slant board held for 30 seconds at moderate intensity repeated 3 times.	No mention of rest or activity between stretching and jump performance measurement	Vertical Jumps with hands on the hips	Jump height was reduced static stretching as compared to the baseline jumps.
34	Young and Elliot, 2001	5 min jogging	Static stretching: 3 repetitions held for 15 s each to the point of pain	Rest + 4 min walk + 4 trials of SJ	DJ from a height of 30 cm with the hands on the hips	The jumps after the static stretching were the lowest compared to the PNF and control conditions.
			PNF stretching: Contract-relax. Maximum isometric contraction against resistance for 5 s. Voluntary relaxation. 15 s of passive stretching to the point of pain	Rest + 4 min of slow walking	SJ: from knees in 100° held for 2 s with a weight of 10 kg on the shoulders	There was very insignificant decrease in the jumps after the PNF stretching condition.
35	Hunter and Marshall, 2002	Cycle ergometer for 5 min at a resistance of 120 W	Static stretching: protocol of 6 weeks held for 20 s (duration increased every week) to a point of mild discomfort	On the day of data collection: jump specific warm-up by the practice jump	CMJ: with hands on the hips	Longer jump time for both the jumps and lower jump height
					DJ: from a height of 30 cm	
					DJ: from a height of 60 cm	
					DJ: from a height of 90 cm	

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
36	Dalrymple et al. 2012 (female collegiate volleyball players)	5 min of jogging on an indoor track	Static stretching: 3 sets of 4 exercises held for 15 s	1 min rest period	CMJ with arm swing	None of the stretching protocols produced significant increase in jump performance.
			Dynamic stretching: 2 sets of 4 exercises for a full ROM			7 out of 12 participants increased their jump height after dynamic stretching.
37	DiCagno et al., 2010	4 min jogging + 4 min plyometric hopping + 10 ballistic stretches + 2 min abdomen and back muscle strength training	Static stretching: 3 sets of 4 exercises held for more than 30 s to a point of mild discomfort	2 min rest	CMJ: Knees allowed to flex to 90° with hands on the hips	No effect on flight timing of any of the jumps
					SJ: from knees at 90° with hands on the hips	Hop time was significantly reduced.
					Hopping: 7 quick hops with less ground contact time and flight time	
38	Yuktasir and Kaya, 2009	No mention of warm-up	Static stretching: protocol of 6 weeks. 4 days/week to a point tolerated by the participants	No mention of rest period or immediate activity	DJ: from a height of 60 cm (the picture shows the hands on the hips)	Static stretching and PNF stretching did not have any effect on DJ performance.
			4 sets of PNF stretches: contract-relax method. 1) Hip 90° ankle 90°, ankle held in dorsiflexion for 10 s. 2) 5 s hip extension and ankle plantar flexion against submaximal resistance followed by 5 s of relaxation. 3) Hip flexion with ankle dorsiflexion held for 15 s.			
39	Galdiino et al., 2010	10 min on a cycle ergometer at 60% of age-adjusted max heart rate	Static stretching: held for 10 s at the end ROM	No mention of rest period	CMJ: with a self-selected eccentric phase with the hands on the hips	No significant changes in the jump height after the stretching protocol or the flexibility group
			The participants in the flexibility group had the same stretching procedure with greater pressure			

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
40	Power et al. 2004	Submaximal cycle ergometer for 5 min at 70 rpm with resistance of 1 kg	Static stretching: 3 repetitions of 2 exercises held for 45 s (No information on the intensity of the stretching was mentioned.)	ROM test, twitch, maximum voluntary contraction by interpolated twitch technique, tetanus, SJ (2 repetitions), DJ (2 repetitions)	SJ: from knee flexed to 90° (hand position was not mentioned)	SJ and DJ decreased insignificantly.
					DJ: from a height of 30 cm with the hands on the hips	
41	Hough et al. 2009	Submaximal cycle ergometer for 5 min at 70–75 rpm with a resistance of 1 kg	Static stretching: 1 set of stretches performed for 5 muscle groups held for 30 s to a point of mild discomfort	2 min break (not mentioned as a scheduled break)	SJ: from self-selected knee flexion held for 2 s with the hands on the hips	The jump height significantly reduced after the static stretching compared to the dynamic stretching or the no stretching group The EMG activity increased 85% (significantly) between the static stretching and the dynamic stretching.
			Dynamic stretching: the same muscle groups' were targeted in a bouncing manner, 5 times slowly and 10 times fast			The jump height decreased significantly after dynamic stretching compared to the no stretching group. The jump height was significantly higher after dynamic stretching than static stretching.
42	Robin and Scheuermann, 2008	Cycle ergometer for 5 min at 70 rpm + 4 min slow walking	Static stretching: 2 repetitions held for 15 s followed by 15 s of rest	4 min rest	SJ: with knees in 100° with arm swing. An average of 3 trials was considered.	
			Static stretching: 4 repetitions of stretch held for 15 s followed by 15 s of rest			
			Static stretching: 6 repetitions of stretch held for 15 s followed by 15 s of rest			The jump height decreased the most for participants who performed 6 sets of stretches.

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
43	Hobara et al. 2011	Warm up for 5 min by 2 legged hopping on a force plate	Static stretching: positions not mentioned, but held for 3 min	Few s to move from the stretching for the immediate data, 1 min post stretching, 2 min post, 3 min post	15 hops performed with the metronome. 6th to 10th hops were considered for analysis	No difference in hopping frequency, ground contact time, and flight time
44	Bird et al. 2010	Cycle ergometer for 5 min at 120 W + 2–4 warm-up jumps followed by 3 pretest jumps	4 stretching exercises according to the NSCA guidelines (Baechle and Earle, 2000) to a point of slight discomfort but not pain	3 jumps, immediately after stretching	Countermovement depth not mentioned, with the hands on the hips	No significant difference between males' vertical jump height and females'
45	Ross, 2007	No mention of warm-up	5 repetitions of practical hamstring stretching protocol for 15 days held for 30 s to a point of tightness felt at the target region. 10-s break was given between the repetitions.	10 min of walking around the testing area	Single-leg hop to cover the longest distance	The experimental lower extremity improved significantly in the hop test
46	McMillan, Moore, Hatler, and Taylor, 2006	No mention of warm-up prior to stretching	Dynamic stretching: 10 calisthenics performed at slow to moderate pace for 10–15 s + 5 movement drills performed on a 20–25 m track Static stretching: 1 repetition of 8 stretching exercises held for 20–30 s (intensity of the stretch was not mentioned)	2 min rest	5 step jump: participants were allowed to measure 5 steps, and take 5 steps before the jump	The jump improved most after the dynamic warm-up compared to the static warm-up protocol. The no-stretching group had the least improvement..

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
47	Fletcher, 2013	Active warm-up by 10 min on the cycle ergometer at 100 W, and 5 min of seated rest	10 repetitions of 2 sets of dynamic stretches, a deep squatting movement at a rate of 100 beats/min	4 min of rest + the jumps were repeated 3 times with 1 min rest between each trial	CMJ: from a self-selected eccentric phase, with hands on the hips	The greatest increase in height was in the CMJ.
					DJ: from a height of 0.2 m, with the hands on the hips	The DJ improved in height (insignificant).
					SJ: from knees flexed to 90° and the hands on the hips	The SJ height did not improve as much as the CMJ height.
48	Turki et al., 2011	Light jogging for 5 min	Full ROM by performing 5 active dynamic exercises while walking 20 m	During PAP (postactivation potential), as described in the study, the jumps were measured by CMJ immediately after dynamic stretching	CMJ from a self-selected depth and the hands on the hips	The CMJ height improved.
49	Fletcher, 2010	No mention of a warm-up	Fast dynamic stretching: 7 movements in a flicking pattern at a rate of 100 beats/min	2 min of seated rest	CMJ: from a self-selected countermovement depth with the hands on the hips	The jump height improved more in the group that performed fast dynamic stretches compared to those who performed slow dynamic stretches.
			Slow dynamic stretching: 7 movements in a flicking pattern at a rate of 100 beats/min		DJ: from a height of 0.3 m with the hands on the hips	
50	Christenen and Nordstrom, 2008	600 m jog	Control group	2 min after the stretching protocol	Vertical jump: performed from a self-selected countermovement depth with arm swing	No effect from either warm-up
		600 m jog + dynamic stretching	Dynamic stretching: 8 kicking and flicking activities to the end ROM			No difference between any warm-up conditions
		600 m jog + PNF stretching	PNF stretching: contract-relax method by contracting the stretched muscle group for a count of 2 followed by partner assisting for a count of 5 s			

	Study	Warm-up	Stretching Parameters	Activities Between Stretching and Jump Performance	Jump Parameters	Results
51	Jaggers et al. 2008	5 min of brisk walking at a comfortable self-selected pace	Dynamic stretching: 5 movements performed in a flicking pattern. 10 repetitions slow and 5 repetitions fast	No mention of a rest	Not described	No significant effect of any type of stretching on any jump performance
			Ballistic stretching: rapid bouncing movement at a rate of 126 beats/min for 30 s			Jump power improved significantly.
52	Vetter, 2007	4 min walking + 2 min jogging + 4 min walking	End ROM movements	Immediately followed	CMJ: performed barefoot with self-selected countermovement depth and with arms raised over head to mark the highest point	No significant effect from any conditions. Participants in the only-warm-up group had more improvement in jump than the participants in the warm-up-with-stretching group.
53	Place et al., 2012	Submaximal warm-up on a cycle ergometer at 70 rpm and 1 W/kg for 5 min	PNF Stretching: PNF stretching performed on self	Immediately + tests	CMJ: from knee flexion up to 60° - 80° with hands on the hips	No effect of self-PNF on the vertical jump height
			Step 1: Hamstring contraction for 5 s	Active ROM of knee flexors and hip extensors		
			Step 2: Quadriceps passive stretching for 5 s	3 repetitions of muscle twitch		
			Step 3: Quadriceps contraction for 5 s	Maximum voluntary contraction of quadriceps	DJ: from 30 cm with hands on the hips	
				Maximum voluntary contraction of the hamstrings		
				Random trial of 2 CMJ and 2 DJ		

Discussion

The first problem statement refers to the differing procedures, or to instructions given for the same kind of stretching. For example, in the study by Curry et al. (2009), the participants held the stretches for 12 s; for 10 s in the study by Mikolajec et al. (2012); for 15 s in the studies by Gonzalez-Rave et al. (2009), Carvalho et al. (2012), Kokkonen et al. (2007), Unick et al. (2005), Young and Elliot (2001), and Cagno et al. (2010); for 30 s in the studies by Behm and Kibele (2007); Bradley et al. (2007); Brandenburg et al. (2007); Bubanj et al. (2011), Burkett et al. (2005), Di Cagno et al. (2010), Hough et al. (2009), Pacheco et al. (2011), Pearce et al. (2009), Pearce et al. (2012), Perrier et al. (2011), Ross (2007), Samuel et al. (2008), Sandberg et al. (2012), Taylor et al. (2009), Unick et al. (2005), Vanderka (2011), Wallmann et al. (2005), Woolstenhulme et al. (2006); and for 45 s in the studies by Bazett-Jones et al. (2008), and Power et al. (2004). All these studies contained the same type of stretching, termed "static stretching". The participants in the studies were instructed to execute the full ROM (Pearce et al., 2012; Perrier et al., 2011; Vanderka, 2011) to perform dynamic stretching. The activity mimics the movement pattern of the joint. The property of reciprocal inhibition of a muscle states that the antagonist muscle relaxes and lengthens from its normal resting state to let the agonist muscle contract, facilitating a smooth movement. In that case, any regular movement can be considered dynamic stretching for the antagonist muscle group, or dynamic stretching as performed in the studies

(Pearce et al., 2012; Perrier et al., 2011; Vanderka, 2011). The flicking movements are difficult to consider as stretching maneuvers. In the study by Vetter (2007), the participants performed dynamic active stretching by taking 3 s to reach a stretched state (for the target muscle), 3 s hold at the stretched state, and 3 s to come out of the assumed stretched position. Given a good explanation of the effects this stretching technique, it could be considered a type of stretching. The participants were instructed to perform deep squats to stretch the quadriceps in the study by Fletcher (2013). This is a good example for the above argument. The deep squat stretches the quadriceps group of muscles, but it could be explained as the quadriceps relaxing to facilitate full knee joint flexion to assist the deep squat. When the stretch is performed as a maneuver, and held for the recommended time of at least 20–30 s (Holcomb, 2008; Gardiner, 1975; Ross, 2007), the stretched muscle involuntarily communicates via a primitive reflex—the stretch reflex—and the period of hold, performed to the point of a safe stretch sensation, leads to desensitisation of the stretch reflex. Ballistic stretching is an explosive movement that elicits the stretch reflex to prevent injury to the stretched muscle or muscle group and indirectly stimulates the stretched muscle. As discussed by Cronin et al. (2008), warm-up activities are important to increase the tissues' extensibility before the activities involved in the actual athletic performance. The deep squat activity performed in the study by Fletcher (2013) can be considered a good warm-up activity, but is debatable as a stretching activity. Therefore, the flicking movements, and full ROM movements not being considered as stretching maneuvers makes more sense than the alternative, which is to consider full ROM and flicking movements as a type of stretching activity. The high intensity or resisted movements will be good warm-ups because resistance activites recruit more motor units (McArdle, Katch, & Katch, 2007, pp. 509–553), and a sport-specific activity would strengthen the neural track for that movement (Adler, Beckers, & Buck, 2008). Several studies (Bradley et al., 2007; Tsolakis et al., 2010) called flicking movements "ballistic stretching." The nomenclature of stretching can be clarified based on the hold time to prevent further ambiguity regarding stretching maneuvers. Stretching in the studies can be classified into three types: static, ballistic, and PNF stretching. The stretching maneuver that holds the stretch position for 20–30 s (Baechle & Earle, 2008; Gardiner, 1975) can be considered static stretching (Kisner & Colby, 2007). As discussed earlier, holding the stretch for at least 20 s desensitizes the target muscle or muscle group. The static stretch can be further classified as passive static stretching if it is performed by a therapist or other trained individual upon the participant, and active static stretching if it is performed by the particiant him/herself with the help of inanimate objects or tools such as a staircase, a bar at hip level, or a towel. The terms active and passive indicate the state of the participant during the stretch. The hold time does not change for the static stretching. Ballistic stretching involves explosive or thrusting movements (Kisner & Colby, 2007). The PNF technique consists of two types of stretching techniques: contract-relax and hold-relax (Adler et al., 2008). The only difference between the contract-relax and the hold-relax types of stretching is that, in the former, the participant actively contracts the agonist muscle to achieve greater ROM, whereas the hold-relax stretching technique is preferred when the agonist muscle is too weak to produce enough contraction.

Studies in which participants were advised to hold the stretch less than 20 s (Carvalho et al., 2012; Dalrymple et al., 2010; Galdino et al., 2010; Gonzalez-Rave et al., 2009; Kinser et al., 2008; Murphy et al., 2010; Robbins & Scheuermann, 2008) did not result in significant effects on any of the jump performances. Thus, hold time for static stretches should be standardized to 20–30 s. The stretch can be performed actively or passively depending upon the situation and requirements. The time and the activities participants engage in between the stretches and the performance also matter. Theoretically, after a bout of stretching for 20–30 s, the muscle or the muscle group takes time to recover from the effects of stretching (Ross, 2007; Shrier, 2000). Researchers have not come to a consensus regarding the amount of time required to recover from these effects. It is possible that this time differs from person to person and depending upon their physiological states or the stretch's intensity. For example, athletes may recover faster than those who are simply recreationally active. It would be helpful to determine if the stretching intensity, the hold time of the stretch, or both, affect the time required to recover; it would also be helpful to determine if it varies according to the participants' level of conditioning. Future research on the above could be drafted. This leads to the second problem statement.

The second problem statement draws attention to the inconsistencies in the stretch hold time and intensity. The studies that included stretching intensities less than to point of discomfort tended to result in no significant effects on the jump performance (Bazett-Jones et al., 2008; Carvalho et al., 2012; Cronin et al., 2008; Galdino et al., 2010; Samuel et al., 2008). It can be inferred that stretching to the point of discomfort or further, and holding it for 20–30 s immediately before the performance may be detrimental to the performance, or does not contribute to improving the performance. This conclusion concurs with the first hypothesis. On the other hand, Brandenburg et al. (2007) expressed concerns regarding the sensitivity of the counter movement jump test to achieve higher vertical height to measure the effects of stretching. Some studies concluded that there was improvement in the jumps after the stretching because they had either a set of activities or a break period between the stretching session and the jump measurement session (Gonzalez-Rave et al., 2009; McMillian et al., 2006; Pacheco et al., 2011; Woolstenhulme et al., 2006), which might have provided time to recover from the effects of stretching (Ross, 2007; Shrier, 2000). Wallmann et al. (2005) found that the stretching to a point slightly less than the point of discomfort causesa significant increase in the electro myographic activity of the muscle. This indicates that increased motor signals were required to produce a contraction of the muscle. The contraction, however, was not as strong as compared to prestretching contractions, and not nearly as powerful as the motor signals it received. This indicates that increased motor signals were received, and a weaker muscle contraction was produced. Hence, it would be reasonable to assume that the stretches affected the mechanical and the neurological properties of the muscle. The study also concluded that the countermovement jump height decreased. On the contrary, the study by Hough et al. (2009) noted that electromyography activity increased significantly (85%) after the dynamic stretching activity in the form of bouncing movements encompassing the full ROM. The squat jump height was also found to increase significantly. The increase in the electromyographic activity after the dynamic stretching activities may have resulted from the neural activation for the target muscle groups as indicated by the improvement in the squat jump seen in the research by Hough et al. (2009), and the expected response after a warm up by activity (Baechle & Earle, 2008; McArdle et al., 2007). Hence from a neuro-physiological perspecive, dynamic stretching could be considered as an activity but can not be classified as a type of stretching maneuver.

Based on all the reviewed studies, the descriptions of the stretch intensities are listed.

List of stretch intensities arranged in five levels:

1. Feeling tightness: the point of picking up the soft tissue slack at the joint

2. Feeling stretch: the point in the ROM where the soft tissues are slightly stretched around the joint
3. Point of mild discomfort: the point in the ROM where the stretch is comfortable
4. Point of discomfort: the point in the ROM slightly beyond the point of comfortable stretch, but where the stretch is bearable
5. Point of pain: the point in the ROM beyond which the soft tissue or the anatomic structure of the joint would be injured

This litst of terminilogy used in the studies provides ordinal data based on the perception of the stretch by the participant or athlete. It is dependent on the state of the target muscle as felt by the participant in the stretched position. The same grade of the scale can vary from participant to participant. For example, while lying with flat spine and knees in extension, a person with tighter hamstrings may feel at the point of discomfort from 60° hip flexion, whereas a somewhat flexible person may feel at the point of discomfort at 80° hip flexion. Use of the scale would also help in describing stretch intensity in literature and in recording practice data for the stretching regimen.

The third problem statement addresses the research protocol used to examine the effects of stretching. As discussed earlier, in the studies (Bazett-Jones et al., 2008; Behm & Kibele, 2007; Bird et al., 2010; Bradley et al., 2007; Bubanj et al., 2011; Carvalho et al., 2012; Chaouachi et al., 2010; Christensen & Nordstrom, 2008; Cronin et al., 2008; Curry et al., 2009; Dalrymple et al., 2010;

Di Cagno et al., 2010; Fletcher & Monte-Colombo, 2010; Fletcher, 2013; Galdino et al., 2010; Gonzalez-Rave et al., 2009; Hobara et al., 2011; Hough et al., 2009; Hunter & Marshall, 2002; Jaggers et al., 2008; Kokkonen et al., 2007; Mikolajec et al., 2012; Murphy et al., 2010; Pacheco et al., 2011; Pearce et al., 2009; Pearce et al., 2012; Perrier et al., 2011; Place et al., 2012; Power et al., 2004; Robbins & Scheuermann, 2008; Taylor et al., 2009; Tsolakis et al., 2010; Turki et al., 2011; Unick et al., 2005; Vanderka, 2011; Vetter, 2007; Walter & Bird, 2009; Woolstenhulme et al., 2006; Young & Elliott, 2001), the participants are instructed to perform activity prior to the stretching protocol. In the studies (Behm & Kibele, 2007; Bradley et al., 2007; Chaouachi et al., 2010; Christensen & Nordstrom, 2008; Cornwell et al., 2001; Curry et al., 2009; Dalrymple et al., 2010; Di Cagno et al., 2010; Fletcher, 2010; Fletcher, 2013; Gonzalez-Rave et al., 2009; Guissard & Reiles, 2005; Hobara et al., 2011; Hough et al., 2009; Hunter & Marshall, 2002; McMillian et al., 2006; Mikolajec et al., 2012; Murphy et al., 2010; Pearce et al., 2012; Perrier et al., 2011; Place et al., 2012; Power et al., 2004; Robbins & Scheuermann, 2008; Ross, 2007; Sandberg et al., 2012; Taylor et al., 2009; Tsolakis et al., 2010; Unick et al., 2005; Vanderka, 2011; Woolstenhulme et al., 2006; Young & Elliott, 2001) that have another activity or a test between the stretching protocol and the jump performance, the effects of the additional activities plus stretching were measured. Such protocols keep researchers from determining the effects of stretching. Performing activity prior or after the stretching module in the research protocol produces the result of effects of stretching plus the activity; not the effect of stretching. Studies in which participants were instructed to perform warm-up prior to the stretching protocol measure the effects of the warm-up plus the stretching, instead of only testing the effect of stretching. Thus, the warm up with the stretching activity is being studied constantly. To determine the effects of stretching, it should be done so without any type of warm up activity prior, or any activity following stretching and before the dependent variable testing. Testing the effect of stretching without warm-up would not be new; a few studies (Frantz & Ruiz, 2011; Ross, 2007; Sandberg et al., 2012) have measured the effects of stretching without warm-up. Some studies have argued that it is necessary to perform a bout of exercise prior to stretching to warm up the soft tissues and prevent injury due to stretching (Chaouachi et al., 2010; Harvey, Herbert, & Crosbie, 2002; Shrier, 2004; Smith, 1994). The extensibility of the muscle can be increased by achieving greater temperature (Fletcher, 2010; Shrier & Gossal, 2000). Stretching also increases the extensibility of the muscle (Alexander, 2000; Gajdosik, 2001). Increasing extensibility is essential for increasing ROM and flexibility. Since stretching helps improve extensibility, as observed in the study by Sandberg et al. (2012), acutely stretching the antagonist muscle group could prove rewarding for high-intesity short-duration sports sich as the discus throw, the high jump, the long jump, the shotput, or the javelin throw, for example. Stretching the antagonist muscle immediately before the performance will relax it and make it more compliant to the agonist contraction. This may increase the time of application of force by microseconds. Stretching without a bout of exercise as a warm-up would not cause injury if participants only stretched to a comfortable stretch intensity (Perrier et al., 2011). Once the muscle is stretched, the resulting extensibility can be put to a gradually increased stretch. In two or three repetitions, the stretch could be equivalent to stretching after a warm-up activity, as used in the study by Perrier et al. (2011). Hence, it is not necessary to engage in a warm-up to perform a regular stretching protocol if it involves a controlled and comfortable stretch. This justifies the second hypothesis. Stretching regularly would show effect on mechanical properties (stiffness compliance, elasticity), as well as neurological properties (recruitment of motor unit immediately after the stretching, decreased H-reflex, muscle relaxation).

The fourth problem statement encompasses the overall variablity in the protocols used to research the effects of stretching. There is more than one way to stretch the same group of muscles, and slight modifications in a position will achieve stretch in the adjacent muscles. To maintain consistency in the research methods future studies should use the same stretching positions as earlier studies. The best method for this would be citing the research from which the participants were taught to stretch, as in the studies by Bird et al. (2010), and Chaouchi et al. (2010). Providing all of the details regarding the activities (muscles stretched, stretch positions, stretch hold time, intensity of the stretch, and stretch repetations, jumps in akimbo position, or with arm swings, exact position to attain stretching) used in the research is vital for the validity of the study and for understanding and comparing results.

Stretching mechanisms of action can be primarily divided into two types: mechanical mechanisms of action and neurological mechanisms of action.

Mechanical mechanisms:

1. Stiffness mechanism: stretching decreases stiffness of the muscle by decreasing the passive viscoelastic properties of the muscle (Stamford, 1995). Less enegry is required to move the limb with low-stiffness musculature (Cornwell et al. 2001). Neurologically, this state is considered a relaxed muscle; hence, more muscle activation is requred to produce a movement. This mechanism depends on the type of stretching performed, and more specifically on the hold time and intensity of the stretch. Longer stretches held to the point of discomfort cause the creep response in the mechanical properties of the muscle being stretched.
2. Compliance mechanism: stretching increases the compliance of the muscle. Compliance is the opposite of stiffness. Compliant musculature tranfers force more slowly than stiff musculature. A compliant muscle also cannot store as much elastic energy (Cornwell et al., 2001). That is the reason why the contraction is less strong, and slower, compared to the stiff muscle.
3. The muscle activities have been called “springlike” (Alexander, 2000; Hunter & Marshall, 2002) in terms of their performance of short-stretching

movements. Based on the mechanisms of action discussed in the studies, regular stretching may help maintain the springlike property of the muscle.

Neurological mechanisms:

1. Stretching reduces the motor neuron excitability, and in turn reduces the H-reflex.
2. Sustained stretches that reach a low pain threshold stimulate the GTO. The controlled and sustained stretch will inhibit the neural pathways at the motor units and decrease muscle activation. This leads to a more relaxed muscle state with limited force and power production capacity untill the effect of stetching wears off.

As mentioned in the discussion for the second problem statement, the point of discomfort might be the point of threshold to stimulate the stretch reflex. The stretch held at a point of discomfort or more would engage the stretch reflex, and thus desensitize the stretch reflex. An intensity lower than the point of discomfort may not be enough to stimulate the sttretch reflex in a compliant (less stiff) muscle, whereas for a stiff (less compliant) muscle, the point of discomfort might be achieved earlier during the ROM. A higher intensity stretch, on the other hand, might injure the mechanical structures of the muscle; based on the property of the elasticity of the muscle (Alexander, 2000).

By approaching the above discussion with a holistic view, the following points can be concluded:

1. Acute stretches (held for 20–30 s to a point of discomfort or point of pain) do not improve jump performance, and may or may not be detrimental to jump performance.
2. The use of the term “dynamic stretching” is ambigious.
3. Administering stretching with proper parameters (hold time, intensity, muscle group, stretching application time in relation to the sporting event) helps improve jump performance.
4. Neuromuscular and mechanical mechanisms work together to cause the effects on the muscle or group of muscles after stretching. By holding the stretch for 20 to 30 s, neurologically, the muscles are relaxed, and mechanically, the decrease in the stiffness impedes the energy transmission.
5. An ideal warm-up would be a short bout of cardio exercise, such as cycling or running, followed by resistant sport-specific activities. As suggested by Goodwin (2002), neural activation of the muscles that are going to be used most in the sporting event is important to improve the performance. This interpretation is also supported by Herzog (2000).

Stretching to a point of discomfort for 20 to 30 sec anytime, except directly before the sporting event, may improve neurophysiological components, which in turn may enhance the jump performance (Kokkonen et al. 2007).

Future Recommendations

The above discussed studies provide invaluable knowledge regarding the effects of different types of stretching. However, there are some aspects in the studies which could be modified to improve the quality of the research, and the value of the results. Future studies should follow and record precise static stretching protocols. Details should be given on stretch intensity, hold time, number of sets, and positions. Sandberg et al. (2012) introduced a new avenue: studying the acute effects of stretching the antagonist on sports such as vertical jumps and sprints. Vertical jumps primarily require antigravity muscles, whereas sprints require coordinated extensor and flexor action. The effects of stretching as a tool for relaxation should be studied by performing stretches in the evening or before sleeping, and then collecting data on the level of relaxation achieved. Few studies determined the long term effects of stretching. The third hypothesis can not be discussed in detail because of the lack of research. Long term effects of stretching would help in understanding the effect of stretching, at a time other than warm up, in the performance. The stretching protocol could be incorporated during spring season training, or fall season training of a particular sport by advising the athletes to stretch at a later time of the day after the practice. The effect of static stretching as a means of relaxation on performance could be studied for a long term study. That could provide valueable information regarding how stretching could help relaxing the muscle or help improve elasticity of the muscles.

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Appendices

APPENDIX A: Email to the Researchers

Dear Dr. _______________

I am Vrashank Dave, a graduate student at San José State University. I am currently working on my thesis entitled "Effects of Stretching on Jump performance: A Systematic Review". I am writing to request your comments and suggestions that could help me improve the content of my thesis. I have come across almost all of your work in the similar area. I would be honored and grateful to have your input for my thesis.

The purpose of the study is to determine the effects of stretching (all the different types of stretching studied in previous experimental researches, static, dynamic, ballistic, PNF, warm up + stretch) specifically on jump performance (counter movement jump, squat jump, single hop for distance and vertical jump).

It would be very helpful if you can go through the reference list and see if I have missed any study that I could include in my review. I will be grateful if you could refer any published or unpublished work that that I should review. I would also be interested in your opinion as to how I may focus on my study (results or synthesis of all the data particularly).

I have included a bibliography to date as an attachment in the email. I have also included a one-page summary of important points in the email.

Thank you very much for your time and help, I appreciate it.

Please feel free to contact me by phone (407) 580 6562 or by email (vrashankbdave@yahoo.com).

Best regards,
Vrashank Dave