Stretching during warm-up: Do we have enough evidence?
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Stretching During Warm-Up

Do We Have Enough Evidence?

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In prescribing conditioning, physical educators face many issues that have insufficient or conflicting scientific evidence to inform practice. One example is stretching during warm-up for activity. The traditional use of stretching in the warm-up phase of conditioning to improve performance or prevent injury may be the profession's largest "stretch" of the scientific literature. People are often told to stretch during warm-up, yet there is little scientific evidence to support its usefulness, unless the activity involves positions with joints beyond normal ranges of motion, as in the sports of diving or gymnastics. The scientific literature suggests that the use of stretching for most people should be for increasing the range of motion and should be conducted during the cool-down phase of the workout.

This article reviews recent biomechanical and clinical studies that are beginning to show that stretching during warm-up may be contraindicated for many activities. The term stretching will be used to refer to static stretching exercises.

To understand the potential benefits of stretching, several terms must be clearly defined because they are commonly misunderstood. Flexibility can be defined as "the intrinsic property of body tissues which determines the range of motion achievable without injury at a joint or group of joints" (Holt, Holt, & Pelham, 1996, p. 172). Flexibility is the property of extensibility of muscles in a joint complex and can be separated further into static and dynamic flexibility. Static flexibility is measured by linear or angular measurements of the limits of joint(s) motion, while dynamic flexibility is usually examined by biomechanical measures of muscle stiffness (Gleim & McHugh, 1997). In essence, static flexibility refers to the actual limits of the range of motion for a joint complex, while dynamic flexibility refers to how quickly the resistance (tension) in a stretched muscle group increases. See the box (opposite) for a more complete description of stiffness.

Evidence on Long-Term Benefits

Research on stretching demonstrates a five to twenty percent increase in static flexibility with four to six weeks of stretching (Bandy, Irion, & Briggler, 1997; Handel, Horstmann, Dickhuth, & Gulch, 1997; Wallin, Ekblom, Grahn, & Nordenborg, 1985). An increase in static flexibility may provide a benefit for activities where positions beyond the normal range of motion are necessary to perform certain skills. Recent studies have suggested that much of this long-term increase in range of motion is due to an increased "stretch tolerance" (ability to tolerate the discomfort of large passive tensions of a stretched position) in the person. This means that long-term decreases in muscle stiffness hypothesized as benefits of stretching do not significantly contribute to the increased static range of motion (Halbertsma & Goeken, 1994; Magnusson et al., 1996d).

If stretching increases static flexibility, does this guarantee that stretching will prevent injury? Not according to the literature. First, increased joint mobility may come at a cost of decreased joint stability (Liebesman & Cafarelli, 1994; Surburg, 1983), so improper or excessive stretching may create unwanted joint instability (Beaulieu, 1981; Kulund & Tottossy, 1983; Safran, Seaber, & Garrett, 1989). This joint stability/mobility paradox may account for studies showing a higher injury rate for athletes in the highest 20 percent of the flexibility distribution (Knapik, Jones, Bauman, & Harris, 1992). Second, several articles have identified stretching techniques that may be dangerous because they are hypothesized to create body positions that stretch ligaments or create dangerous loading (Lindsey & Corbin, 1989; Lubell, 1989). Third, there are no scientific studies that have documented the desirable ranges of motion that are related to specific decreases in injury risk. The three most recent reviews of the literature have not found conclusive support for the injury-prevention hypothesis of stretching during warm-up (Gleim & McHugh, 1997; Knapik et al., 1992; Safran et al., 1989). There have been few well-controlled studies examining the relationship between flexibility and injury (Knapik et al., 1992) that could be used to show proof of injury-protection benefits from stretching during the warm-up prior to activity.

It has been hypothesized that a long-term benefit of stretching is a decrease in muscle stiffness (greater dynamic flexibility). The predominant hypothesis is that a stiff muscle may be better suited for force transmission in concentric muscle actions, while a more compliant muscle may be better for shock absorption, stretch-shortening cycle muscle actions, and reducing risk of injury (Walshe, Wilson, & Murphy, 1996; Wilson, Wood, & Elliott, 1991; Wilson, Murphy, & Pryor, 1994). For example, stiff muscles in a powerlifter would be effective in transmitting large concentric forces in the strength dominated lifts in that sport, while a high jumper might benefit from more compliant (less stiff) leg muscles to more effectively rebound into the jump.

Unfortunately, there have been few prospective studies of the long-term effects of stretching on dynamic flexibility and sport performance. One relevant study of the long-term effect of stretching in combination with isometric training found that stretching did not prevent the increase in muscle stiffness with 13 weeks of strength training (Klinge et al., 1997). It is important to remember that any long-term effects of stretching on dynamic flexibility are still mostly hypothesized benefits. The most recent review of scientific and clinical studies on stretching and performance concluded that any *potential* performance benefits of flexibility training are likely to be highly specific and sport-dependent (Gleim & McHugh, 1997).

Evidence on Short-Term Effects

When a muscle is stretched, it behaves viscoelastically, which means that the force in the muscle is velocity/time-dependent and load-dependent. "Silly Putty" can be used as an effective demonstration of the viscoelastic behavior of muscle. A slow, low-force stretch gradually and permanently elongates the putty, while during a fast stretch, the putty has greater stiffness and usually breaks after minimal elongation. A series of biomechanical studies on the short-term (less than 2 hours) effects of stretching have now documented the viscoelastic properties of human muscle (McHugh, Magnusson, Gleim, & Nicholas, 1992; Lamontagne, Malouin, & Richards, 1997; Magnusson et al., 1996a, 1996c, 1997, 1998). These studies agree with many previous studies of the viscoelastic properties of animal muscle, and they conclusively show that static stretching is safer in theory than ballistic stretching (Sapega, Quedenfeld, Moyer, & Butler, 1981). High rates of stretching (ballistic stretches) create significantly higher muscle stiffness and larger peak forces in the muscle. Ballistic stretching of muscle is much more likely to result in injury to the muscle than slower stretching techniques like static stretching or proprioceptive neuromuscular facilitation (PNF). How the short-term changes in muscle from stretching affect performance and injury risk, however, is less clear. Biomechanical studies of short-term changes in muscle related to stretching are beginning to suggest that stretching during warm-up may not be as beneficial as was traditionally thought.

First, like any training stimulus, stretching can create a decrease in strength prior to the "recovery or supercompensation" phase of training. A five to twenty percent decrease in strength following passive stretching has been observed in animal (Lieber, Woodburn, & Friden, 1991) and human studies (Avela, Kyrolainen, & Komi, 1999; Fowles & Sale, 1997; Kokkonen, Nelson, & Cornwell, 1998; Rosenbaum & Hennig, 1995). Studies of passive stretching in animals have shown that the force that can damage (weaken) muscle can be as low as 30 percent of maximum failure force or at lengthening as small as 25 percent, relative to the resting length (Noonan, Best, Seaber, & Garrett, 1994; Tsuang et al., 1998). It is important for physical educators to remember that stretching is a training stimulus that can weaken muscle. Thus the pres-cription of vigorous stretching in the warm-up prior to events involving high-level concentric strength, like powerlifting or rock climbing, is questionable.

A second short-term effect of stretching is a temporary increase in range of motion, which has been shown to persist for up to 90 minutes (Moeller, Ekstrand, Oberg, & Gillquist, 1985; Kirsch, Weiss, Dannenbaum, & Kearney, 1995; Zito, Drive, Parker, & Bohannon, 1997). This short-term increase in static flexibility, like the long-term effects, may be primarily due to an increased stretch tolerance (Wiemann & Hahn, 1997). Stretching during warm-up could clearly benefit

Stiffness as a Measure of Dynamic Flexibility

Stiffness as a measure of dynamic flexibility sometimes has a counterintuitive meaning for many people. The higher the stiffness of a muscle, the greater its elasticity (resistance to stretch), while less stiffness means greater compliance (extensibility). Stiffness is *not* the passive tension a muscle has at a given length, but a measure of the *rate of increase* of passive tension as the muscle is stretched. Athletes are usually aware of the smaller passive tension in a muscle group at the end of the range of motion after stretching, but this lower passive tension is not the stiffness of the muscle group. The measurement of the stiffness of a muscle group has several theoretical and methodological problems (Latash & Zatsiorski, 1993), but many researchers have studied this variable because of its potential association with performance. The stiffness of muscle groups can be estimated in active or passive conditions. The passive stiffness of a muscle group is examined by simultaneous measurements of joint angle and passive torque at a joint (slope of the load-elongation curve of the muscle). The stiffness of active muscles is estimated with an oscillation (Walshe et al., 1996; Wilson et al., 1991) or stimulation protocol (Cook & McDonagh, 1996).

—D. K.

performance for events or sports requiring static flexibility beyond normal range of motion. Gymnasts or dancers, for example, may need to get their bodies into joint positions well beyond the normal range of motion in order to meet aesthetic standards of performance.

Stretching may create short-term lengthening and a decrease in passive tension (stress relaxation) in the muscle. However, there is less clear evidence that stretching will create short-term changes in dynamic flexibility (decreasing muscle stiffness). Magnusson, Simonsen, Aagaard, and Kjaer (1996b) found a significant decrease in muscle passive stiffness with hamstring stretching that returned to normal after one hour. Similar results were reported for the plantar flexors by Rosenbaum and Hennig (1995). Conversely, Halbertsma, van Bolhuis, and Goeken (1996) observed nonsignificant changes in hamstring passive stiffness with 10 minutes of stretching, and Magnusson et al. (1998) found no change in hamstring stiffness 10 minutes after static or ballistic stretching.

Several factors can account for these conflicting results, such as different amounts and rates of stretch, how stiffness was calculated, and previous muscle activity. Muscle stiffness is strongly affected by activation and previous muscle activity. Several studies have shown a "thixotropic" effect of previous muscle action on the muscle stiffness of subsequent movements (Hutton, 1992; Magnusson, Simonsen, Byhre-Poulsen, Aagaard, & Kjaar, 1995). This means that muscle stiffness even depends on the kinds of muscle actions performed immediately before testing. Since muscle stiffness is such a complicated phenomenon, changes in muscle stiffness from stretching are difficult to separate from the effects of other variables. Currently, there is insufficient evidence to support the hypothesis that stretching during warm-up will significantly decrease the short-term stiffness (improve the dynamic flexibility) of muscle. Most of any decrease in muscle stiffness from warm-up can be attributed to the increase in temperature within the muscle, not to the stretching. Increasing muscle temperature significantly decreases muscle stiffness and increases the maximum strain and stress the muscle can endure before injury (Noonan et al., 1994; Safran et al., 1989). Studies in humans that have examined both stretching and active warm-up in combination have shown that the decrease in stiffness is mainly a result of increased muscle temperature and not the effect of stretching (McNair & Stanley, 1996; Rosenbaum & Hennig, 1995).

Conclusions

There is a lack of scientific evidence supporting the injury-preventing or performance benefits of stretching during warm-up for most activities. The primary injury-prevention benefit of a warm-up seems to be related to the increased temperature of the muscle. There is even evidence that isometric muscle actions as warm-up may be as effective as stretching in creating a decrease in passive tension in muscle (Safran et al., 1989; Taylor, Brooks, & Ryan, 1997). Light to moderate muscle actions of gradually increasing intensity are more appropriate than stretching as warm-up activities for most sports.

In some activities where static flexibility beyond normal ranges is needed (e.g., diving, gymnastics, and dance), stretching during the warm-up may be indicated because of a short-term increase in static flexibility. This stretching, however, should occur only after several minutes of light movement elevates the body temperature.

There is strong evidence of long-term increases in static flexibility, but inconclusive evidence of changes in dynamic flexibility with stretching. Stretching for most physical activities should be scheduled during the cool-down phase of a workout. See Knudson (1998) for specific recommendations on how to safely stretch to increase static flexibility.

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Table 3. Advanced-Level Rubric for Student-Teaching Interns

Score	Teaching Behaviors
4	Gives lesson purpose and states critical cues during a skill demonstration.
	Effectively executes two strategies for student learning.
	Provides maximum student practice at two skill levels simultaneously.
	Assesses performance with a variety of feedback (including corrective feeback).
	Moves throughout the practice area, giving encouragement to all students.
	Shows effective use of an appropriate management system.
3	Gives lesson purpose and states critical cues during a skill demonstration.
	Executes two strategies for student learning with some success.
	Provides maximum student practice and extends tasks appropriately.
	Assesses performance by using two forms of feedback (including corrective feedback).
	Moves throughout the practice area, giving encouragement to most students.
	Uses appropriate management strategies.
2	States two cues during a skill demonstration.
	Executes one teaching strategy with some success.
	Provides maximum practice during some of the lesson.
	Assesses performance by using corrective feedback with some students.
	Encourages students.
	Shows limited use of effective management strategies.
1	Does not provide a skill demonstration.
	Uses one teaching strategy with limited success.
	Provides maximum practice for only one part of the lesson.
	Exhibits no visible sign of assessment.
	Encourages a few students.
	Lacks management skills.

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