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ABSTRACT

Physical activity is extremely important in maintaining good health. Activity is not possible without a certain amount of flexibility. This report discusses issues related to flexibility fitness. Flexibility is a property of the musculoskeletal system that determines the range of motion achievable without injury to the joints. Static flexibility tests measure the limits of the achievable motion, but these limits are subjective. Dynamic flexibility tests are more objective and measure the stiffness of a passively stretched muscle group. However, there are no recommended field tests available at this time. Normal ranges of static flexibility are well-documented for most joints. Major deviations from the norm may be associated with a higher incidence of muscular injury. While there is theoretical association between flexibility and several musculoskeletal problems, there are few prospective studies showing significant associations. Currently, there is little scientific evidence upon which to base individual prescriptions for static flexibility development beyond the maintenance of normal levels. Any recommendation for stretching to improve flexibility should be based on a valid assessment of flexibility using sound testing procedures. Recommendations for stretching procedures based on recent reviews of the viscoelastic response of muscle to stretching are presented. (Contains 85 references.) (SM)

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Introduction

Recent research has clearly shown that physical activity is one of the most important factors related to maintaining good health (Corbin & Pangrazi, 1993; USDHHS, 1996). Programmed physical activity (exercise) and sport are forms of human movement often used to achieve these positive health benefits. Human movement is not possible without a certain amount of the fitness component commonly called flexibility. Most exercise and sports programs incorporate activities for flexibility development because flexibility is thought to be important for safe and effective movement. Stretching exercises provide a training stimulus for flexibility development. In the following sections we will discuss several topics related to flexibility fitness (1) Definitions of flexibility, (2) Normal static flexibility, (3) The health-related benefits of flexibility, (4) The performance-related benefits of flexibility, and (5) Current recommendations for safe and effective development of flexibility

Definitions of Flexibility

One problem in the literature is the inconsistent use of terminology in flexibility, and the related areas of stretching and joint range of motion. Definitions of key terms are presented in Table 1. Sports medicine professions sometimes use slightly different terminology than in physical education, sport, and exercise science professions. Common classifications of stretching exercises also tend to use terminology that conflicts with current biomechanical classifications of flexibility. Even within a discipline there is potential for confusion in terminology. For example, physical therapists often distinguish between active range of motion (unassisted) and passive range of motion (therapist assisted) in assessing static flexibility. Therefore, when reporting a range of motion for a flexibility test it is important to know whether the test was active or passive. Flexibility tests can also be confused with the joint laxity tests by which orthopaedists and athletic trainers evaluate the small accessory rotations and translations in joints (Corbin, 1984). Additionally, early flexibility research suggested that there were both static and dynamic expressions of flexibility (Fleishman, 1963), giving rise to the common use of "static" and "dynamic" modifiers for two kinds of flexibility (Anderson & Burke, 1991). However, use of these "dynamic" flexibility tests stopped because they involved ballistic movements that may be more related to speed, coordination, and strength rather than flexibility.

Flexibility has been 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 et al., 1996: 172). This property of the musculoskeletal system can be examined by two kinds of biomechanical measurements: static flexibility and dynamic flexibility (Gleim & McHugh, 1997). Static flexibility is a linear or angular measurement of the actual limits of motion in a joint or complex of joints. In other words, static flexibility is a clinical measurement that defines the amount of motion at a joint or group of joints. There are, however, several complications in the interpretation of static flexibility measures. First, the limits of the static flexibility tests are subjectively defined by either the subject or the tester. Physical therapists usually classify the limits of joint motion according to various "end-feels" e.g. soft, firm or hard (Norkin & White, 1995). The "end-feel" varies depending on the type of tissue providing resistance to movement. Generally, static flexibility tests measure motions limited by the extensibility of the musculotendinous units (MTU)

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surrounding the particular joint or joints. For simplicity, the term "muscle" will be used in this paper to mean the whole MTU. The straight leg raise test is a static flexibility test thought to be limited by the extensibility of the hamstring muscle group (McHugh et al., 1998). However, ligamentous constraints and bony congruencies can also limit motions depending on the joint and the motion being tested. For most static flexibility tests, the limits of motion are determined by the subject's tolerance of the stretched position (Halbertsma & Goeken, 1994; Magnusson et al., 1996c, 1997) and are therefore not truly objective measures. Static flexibility measurements are somewhat limited by the subjective nature of the assessment of the ends of the range of motion. In contrast, measures of dynamic flexibility do not depend on the subjective perceptions of the end of the range of motion, and therefore, are believed to be more objective measures (Gleim & McHugh, 1997). Dynamic flexibility refers to the increase in resistance with muscle elongation for a given range of motion and can be quantified in terms of stiffness [see Table 1] (Gleim & McHugh, 1997). So dynamic flexibility accounts for the resistance to stretch throughout the range of motion. Tissue stiffness is usually quantified according to the slope of the load-deformation curve. The slope of the torque-range of motion curve provides an equivalent for the *in vivo* measurement of passive stiffness of muscle groups (Gajdosik et al 1990, Magnusson et al 1997, McHugh et al 1998). Dynamic flexibility measurements of relaxed muscle are important because they essentially tell how muscle passive tension increases at the limits of the range of motion, and show that muscle has viscoelastic behavior (force in stretching depends on elongation and the rate of the stretch). Research has only begun to document, in vivo, the short and long-term viscoelastic responses of human muscles to stretching (Gajdosik, Guiliani, & Bohannon, 1990; Goeken & Holt, 1993, Magnusson, 1998; Magnusson et al., 1996a,1996b,1998; McHugh et al. 1992). Consequently, little is currently known about the clinical importance of dynamic flexibility. Studies show that dynamic flexibility accounts for about 44 to 66% of the variance of static flexibility (Magnusson et al., 1997; McHugh et al., 1998). However, there is insufficient research to determine whether static and dynamic flexibility are two distinct properties or two aspects of the same flexibility component. More research on the relationship between static and dynamic flexibility is needed, especially longitudinal studies of changes in flexibility.

Although dynamic flexibility measurements may provide a more objective measurement of flexibility, there are problems with these flexibility variables. The passive measurements mentioned can only estimate the true mechanical stiffness of the individual muscles (Latash & Zatsiorsky 1993). Some studies measure the stiffness of activated muscle groups (Wilson, Wood, & Elliott, 1991a). Additionally, differences in scientific and lay terminology can result in misinterpretations. For example, the use of the term "elasticity" can be confusing. In biomechanics a greater elasticity implies a higher stiffness, which means the tissue offers greater resistance (stress) to elongation (strain). However, for most individuals, greater elasticity implies less resistance to elongation which is really compliance.

Table 1

Definitions of Key Flexibility Terms

- **Anklyosis** – Pathologically low joint range of motion.
- **Ballistic Stretching** – Fast, momentum-assisted movements used to stretch muscles.
- **Compliance** – A material that is easily elongated with low levels of force is compliant. Compliance is the opposite of stiffness or elasticity.
- **Dynamic Flexibility** – The rate of increase in tension in relaxed muscle as it is stretched. The mechanical variable that represents dynamic flexibility is stiffness.
- **Elasticity** – The property of a material to resist deformation from a force and to quickly return to its normal shape. The mechanical measure of a materials elasticity is stiffness.
- **Flexibility** – "the intrinsic property of body tissues which determines the range of motion achievable without injury at a joint or group of joints (Holt et al., 1996; 172)."
- **Hypermobility** – Excessive joint range of motion.
- **PNF** (Proprioceptive Neuromuscular Facilitation) – Specialized stretching routines that take advantage of reflexes and neuromuscular principles to relax muscles being stretched.
- **Static Flexibility** – The measurement of the range of motion in a joint or group of joints.
- **Static Stretching** – Slowing elongating a muscle group and holding it in the stretched position.
- **Stiffness** – The measure of a materials elasticity, defined as the ratio of force to elongation.
- **Viscoelastic** – Complex mechanical behavior of a material because the resistive force in the material is depending on elongation (elastic) and the rate (viscous) at which the force is applied.

Normal Static Flexibility

Normal static flexibility occurs somewhere between two pathologic extremes, anklyosis and hypermobility [Table 1] (Russek, 1999). Studies using animal models have shown that normal skeletal muscle extensibility is a function of the number of sarcomeres in series as well as the amount and organization of intramuscular connective tissue (Williams & Goldspink,1978), so muscles can increase or decrease their length to accommodate the range of motion commonly used. The early research demonstrated that static flexibility is not a whole-body characteristic, but like fitness, is specific to areas of the body (Cureton, 1941; Harris, 1969; Hoshizaki & Bell, 1984). An individual may be quite flexible in one joint motion but inflexible in another joint. Furthermore, the same joint can be flexible in one anatomical motion but inflexible in another motion. Additionally, early work identified a trend for women to have greater static flexibility than men (Harris, 1969), although much of this effect may be related to anthropometric differences (Corbin, 1984).

Several different bodies have established normal ranges for static flexibility tests of the major joints (AAOS, 1965; ACSM, 1995; AMA, 1988; Gerhardt & Russe 1975). It is not known, however, if there is an optimal or desirable level for static flexibility. It is important to appreciate that some movements involve a greater range of motion than others and therefore require greater static flexibility. There have been many reviews on flexibility and stretching (Alter, 1996; Anderson & Burke, 1991; Clarke, 1975; Corbin 1984; Corbin & Noble, 1980; Harris, 1969; Holland, 1968; Hutton, 1993; Knapick et al., 1992; Knudson 1998, 1999; Liebesman & Cafarelli, 1994; Magnusson, 1998; Spaega et al., 1981; Wilkinson, 1992).

More recently, data have clearly demonstrated that static flexibility changes across the lifespan. Prior to primary school, children are quite flexible because of limited calcification and development of the joints. Static flexibility varies with physical activity, but overall tends to remain the same or gradually decrease to about age 12 and then increases to peak between 15 and 18 years of age (Clarke, 1975). Research has shown significant decreases in static flexibility and increases in muscle stiffness with aging in adulthood (Brown & Miller, 1998; Gajdosik, 1997; Gajdosik et al., 1999; Vandervoot et al., 1992). However, the decrease in static flexibility with aging is small relative to the typical variation in flexibility between individuals and the potential for improvement in flexibility with stretching (Roach & Miles, 1991). Decreases in flexibility are primarily due to changes in activity and arthritic conditions (Adrian, 1981) rather than a specific effect of aging. Therefore, stretching programs can be effective for individuals of all ages.

Health Benefits of Flexibility

The primary theoretical reason for the inclusion of static flexibility tests in health-related fitness test batteries is that flexibility has been associated with injury risk. While it is logical that limited static flexibility will more likely result in an overstretched muscle during vigorous activity, there is little evidence that greater than normal levels of static flexibility will decrease injury risk (Corbin & Noble, 1980). If anything, people at both extremes of static flexibility may be at a higher risk for musculoskeletal injuries (Jones & Knapik, 1999; Knapik, Jones, Bauman, & Harris, 1992). There is even less known about the association between dynamic flexibility and injury risk. Wilson, Wood and Elliott (1991a) hypothesized that a less stiff musculature would be less susceptible to muscle strain injury. There is very little research in this area, but there is preliminary experimental evidence that a stiffer muscle is more susceptible to eccentric-induced muscle damage (McHugh et al., 1999).

With regard to specific injuries, it seems logical that less flexible back muscles would be related to the incidence of low-back pain, however, the direct evidence for this link is not strong. Plowman (1992) reviewed the literature and found that there was limited support (mixed results) for an association between lumbar/hamstring flexibility and occurrence of low-back pain. In support of Plowman's conclusions, a large prospective study has recently been unable to demonstrate a relationship between static flexibility and subsequent low-back pain in adults (Jackson et al., 1998). Therefore, it appears that field tests of static flexibility may not be useful in predicting future low-back injury.

Although there is little scientific evidence of an association between flexibility and muscular injuries (Gleim & McHugh, 1997; Jones & Knapik, 1999; Knapik, Jones, Bauman, & Harris, 1992), there is conflicting evidence on the effect of stretching on injury. Recent prospective studies have shown no effect of stretching on injury rate (Pope et al., 1998, 2000), while other studies have reported an effect for stretching (Cross & Worrel, 1999; Hartig & Henderson, 1999). The studies with larger samples and better controls (Pope et al., 1998, 2000), support the conclusion that flexibility and stretching may be unrelated to injury risk. Currently there is insufficient data to support the common prescription of stretching programs to modify flexibility based on the hypothesis of reducing the risk of muscle injury.

Stretching is known to relax (inhibit muscle activation) the muscle (Avela et al., 1999; Vujnovich & Dawson, 1994) and has been advocated for the treatment of various muscle problems (Clarke, 1975; Corbin & Noble, 1980). Static stretching is clearly indicated and commonly used for the acute relief of muscle cramps. Similarly, stretching is commonly practiced to relieve symptoms of delayed-onset muscle soreness (DOMS). However, recent studies have shown that stretching before (Johansson et al., 1999; Wessel & Wan, 1994) or after activity (Buroker & Schwane 1989; Wessel & Wan, 1994) has little or no effect on DOMS. Although light stretching is a valuable activity to maintain static flexibility, there is little evidence that it will decrease symptoms of muscular overuse like DOMS.

While proper stretching remains a safe physical activity, like all forms of training there are potential risks to health and performance. Ballistic or bounding stretches create large muscle forces that may cause injury (Sapega et al., 1981) and certain stretching exercises are contraindicated because of dangerous ligament and tissue loading (Liemohn, Haydu, & Phillips, 1999; Lindsey & Corbin, 1989; Lubell, 1989). Less is known about the joint stability-mobility paradox, whereby increases in range of motion may come at the cost of joint instability (Corbin & Noble, 1980; Liebesman & Cafarelli, 1994).

In summary, the consensus of the literature is that only normal levels of static flexibility are needed for a low risk of injury in most vigorous physical activities. Very high or low levels of static flexibility may represent an increased risk of injury. Tests of static flexibility in health-related fitness test batteries are likely effective instruments for identifying people at the extremes of the static flexibility distribution. There is, however, little scientific evidence on which to base precise flexibility prescriptions for these individuals. In individuals with normal static flexibility there is little evidence that stretching or increasing static flexibility will lower injury rates. There is also a lack of studies on how differences in dynamic flexibility affect the risk of injury.

Performance Benefits of Flexibility

Since many sports require vigorous joint rotations and often use extreme positions in the range of motion, there is a common belief that static flexibility is related to performance. While there is considerable anthropomteric research showing static flexibility differences between athletes from different sports, the retrospective nature of most studies limits our understanding of these differences (Clarke, 1975). The scientific evidence for the performance benefits of flexibility is not as strong as commonly believed and the claims of benefits from stretching are often exaggerated (Corbin & Noble, 1980; Gleim & McHugh, 1997). Depending on the nature of the movement, less static flexibility may actually benefit performance. For example, less static flexibility has been associated with better running economy (Gleim et al.1990; Craib & Mitchell, 1996).

Since dynamic flexibility tests measure the increase in resistance during muscle elongation, it has been hypothesized to be more related to performance than static flexibility (deVries, 1986). Several studies have found that less stiff muscles are more effective in utilizing elastic energy in stretch-shortening cycle movements (Kubo et al., 1999, 2000; Walshe, Wilson, & Murphy, 1996; Wilson, Elliott, & Wood, 1992; Wilson, Wood, & Elliott, 1991b). Stiffer muscles may have advantages in isometric and concentric movements (Wilson, Murphy, & Pryor, 1994). Unfortunately, these studies have used stiffness measurements of activated muscle groups, so it is unknown if measures of passive muscular stiffness have similar relationships to performance. With advances in muscle imaging, much is being learned about the elastic properties of human muscle in vivo (Fukunaga et al., 1997; Kawakami et al., 1998; Ito et al., 1998; Kubo et al., 1999). These kinds of studies may advance our understanding of the effects of dynamic flexibility on performance. In the future we may know if stretching truly decreases muscle stiffness and consequently improves the muscles capacity to perform in stretch-shortening cycle actions. Whatever the eventual relationships, it is likely that the effects of static or dynamic flexibility on performance are very activity specific (Gleim & McHugh, 1997).

Despite the universal practice of pre-activity stretching exercises as part of a warm-up routine, there is little evidence of a positive short-term effect of stretching on performance. In fact, recent research has shown that static stretching creates a short-term decrease (up to 20%) in several kinds of muscular performance (Avela, Kyrolainen, & Komi, 1999; Kokkonen, Nelson, & Cornwell, 1998; Rosenbaum & Hennig, 1995). There is preliminary evidence of a decrease in strength that can last up to 60 minutes (Fowles & Sale, 1997). The possibility that stretching prior to physical activities may create a short-term decrease in performance warrants further investigation.

Recommendations for Flexibility Development

Testing

Any recommendations for stretching to improve flexibility should be based on a valid assessment of flexibility using sound testing procedures. Currently, testing of dynamic flexibility is still limited to the research setting, because of problems related to expensive equipment, insufficient standardization, and data to establish norms. Static flexibility tests are based on linear and angular measurements of the motion of a joint or group of joints, and have been classified as compound (multiple joints) or single joint tests (Corbin & Noble, 1980). Single joint static flexibility tests are common clinical measures in the medical professions (AAOS, 1965; AMA, 1988; Gajdosik & Bohannon, 1987; Norkin & White, 1995; Gerhardt & Russe 1975) and usually involve angular measurements (goniometers or inclinometers), rather than linear measurements common in field tests of flexibility . Single joint tests are considered better measurements of static flexibility than compound tests because they better isolate specific muscles and are less affected by anthropometric variation (Cornbleet & Woolsey, 1996; Leighton, 1942). For example, the straight leg raise (Goeken & Holf, 1993) and active knee extension (Gajdosik & Lusin, 1983) tests are the criterion hamstring static flexibility tests used to validate field tests of hamstring flexibility like the toe touch or sit-and-reach tests. Professionals must remember, however, that the scores on these tests are subjective and highly dependent on the subject's tolerance of the high tensions (discomfort) during testing.

Most fitness professionals are familiar with several compound static flexibility tests. The most common health-related tests are the sit-and-reach, shoulder lift, and trunk lift. There has been considerable research on the sit-and-reach test resulting in quite a number of test variations (Golding, 1997; Holt, Pelham, & Burke, 1999). Fortunately, research on the sit-and-reach test has shown it to be an moderately valid measure of hamstring flexibility that is only slightly affected by anthropometric variations (Hui et al., 1999; Martin et al.,1998). Hamstring flexibility accounts for most of the variance in the sit-and-reach test. However, a recent study showed that 6% of children falsely passed, and 12% falsely failed the sit-and-reach test relative to the straight leg raise test (Cornbleet & Woolsey, 1996). People failing the sit-and-reach test should be retested with the straight leg test to ensure they have limited hamstring static flexibility. Current health-related norms for sit-and-reach tests serve to identify individuals at the extremes who may be at higher risk of muscle injuries. However, the sit-and-reach test is not correlated with low-back flexibility (Martin et al.,1998). A field test like the modified Schoeber test that uses tape measurements of spine length (Norkin & White, 1995) may be more useful in evaluating lumbar flexibility.

Stretching

The following recommendations for stretching procedures are based on recent reviews of the viscoelasctic response of muscle to stretching (Knudson, 1998, 1999). These recommendations (Table 2) are designed for group exercise prescription for normal subjects. Remember that flexibility testing and subject-specific information may require small variations in flexibility training. For best results, static stretching or proprioceptive neuromuscular facilitation (PNF) stretching should be performed at least three times per week, preferably daily and preferably after moderate or vigorous physical activity. Four to five stretches for each major muscle group should be performed, usually during the cool-down phase of a workout, with each stretch held for 15 to 30 seconds. The cool down is recommended because warmed-up tissues are less likely to be injured and the placement of stretching within the workout does not affect gains in static flexibility (Cornelius, Hagemann, & Jackson, 1988). The intensity (force) of each stretch should be minimized, slowly elongating and holding the stretched position just before the point of discomfort. Static stretching will create a short-term increase in range of motion and a decrease in passive tension in the muscle at a particular joint angle due to stress relaxation. The effect of stretching on muscle stiffness is not clear (Knudson, 1999).

It is important for professionals to remember that passive stretching does create large tensile loads in the muscle, so it is possible to injure and weaken muscle with vigorous stretching. Stretching is like other training stimuli that result in temporary weakening before the body accommodates to that activity. Assisted stretching procedures like PNF should be performed with care by trained subjects or sports medicine personnel. The practice of having athletes passively stretch partners is not recommended unless the athletes have been carefully trained in correct procedures and understand the risk of incorrect stretching.

The efficacy of stretching during the warm-up phase for most physical activities is controversial. A recent review of the literature (Knudson, 1999) noted that stretching as part of a warm-up may have a detrimental effect on performance. It was suggested that only activities requiring high levels of static flexibility for aesthetic or scoring purposes (e.g. dance, gymnastics, diving) should include some static stretching following a general warm-up. More research is clearly needed on the role of stretching prior to performance.

Table 2

Stretching Recommendations for Group Exercise Prescription

Fitness Variable	Recommendation
Frequency	At least 3 times per week, preferable daily and after moderate or vigorous physical activity
Intensity	Slowly elongate muscle and hold with low levels of force
Time	Up to 4 to 5 stretches held from 15 to 30 seconds. Stretch normally during the cool-down phase. Be sure to stretch only muscles that have been thoroughly warmed-up from physical activity. Warning: Stretching in the warm-up prior to physical activity may weaken muscles and decrease performance.
Type	Static or PNF stretches for all major muscle groups

*Adapted from Knudson (1998, 1999)

Summary

Flexibility is a property of the musculoskeletal system that determines the range of motion achievable without injury to a joint or group of joints (Holt, Holt, & Pelham, 1996). Static flexibility tests measure the limits of the achievable motion but these limits are subjective. Dynamic flexibility tests are more objective and measure the stiffness of a passively stretched muscle group; however, there are no recommended field tests available at this time. Normal ranges of static flexibility are well documented for most joints. Major deviations (top or bottom 20% of the distribution) from the norm may be associated with a higher incidence of muscular injury. While there is a theoretical association between flexibility and several musculoskeletal problems, there are few prospective studies showing significant associations. Currently, there is little scientific evidence on which to base individual prescriptions for static flexibility development beyond the maintenance of normal levels. More longitudinal studies of dynamic flexibility may provide a greater insight into the role of flexibility in health and performance.

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The President's Council on Physical Fitness and Sports

The President's Council on Physical Fitness and Sports (PCPFS) was established in 1956 through an Executive Order by President Dwight D. Eisenhower as part of a national campaign to help shape up America's younger generation. Today, the PCPFS serves as an advisory council to the President and Secretary of the Department of Health & Human Services on matters involving physical activity, fitness and sports to enhance and improve the health of Americans of all ages.

The PCPFS enlists the active support and assistance of individual citizens, civic groups, private enterprise, and voluntary organizations to promote and improve the physical activity and fitness of all Americans and to inform the public of the important link which exists between regular activity and good health.

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Physical Activity and Fitness Quote

"One important component of health-related physical activity is a static stretching program performed following moderate or vigorous physical activity. Such a program should be designed for maintenance of normal levels of flexibility."

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