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Flexibility and Physical Functions of Older Adults: A Review

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This review examines the influences of physiological aging processes on connective tissue, joint integrity, flexibility (range of motion [ROM]), and physical functions of older adults. Studies that attempted to improve older adults' ROM are also critiqued. Multiple mechanisms of musculoskeletal and soft-tissue degeneration, as well as disease processes (osteoporosis, arthritis, atherosclerosis), contribute to significant decreases in neuromuscular function and ROM in older adults, all of which can be exacerbated by disuse influences. No delineation of disuse effects on the rate of aging-related decrements in ROM can be provided, however, because long-term investigations (with physical activity controls) have not been conducted. Research efforts have documented both upper and lower extremity decrements in ROM with development of physical impairments, reductions in basic and instrumental activities of daily living, and progression of disability. There is limited research evidence that either specialized stretch-training or general-exercise intervention protocols moderately improve ROM in older adults and the frail elderly.

Key Words: range of motion, aging physiology, musculoskeletal impairments, ADL, mobility, exercise interventions

Flexibility is a general term that describes the range of movement or motion (ROM) of a single or multiple joints. The ROM of any joint is limited principally by skeletal, muscle, and periarticular or surrounding connective-tissue functions (Alter, 1996). Because the aging process affects the bone and all connective tissues, including muscle, joint flexibility decreases significantly with advancing age, and thus motor function is reduced (Alter; American College of Sports Medicine [ACSM], 1998b; Golding & Lindsay, 1989). The implications of aging-related losses in ROM for older adults' quality of life (QOL) are significant, because activities of daily living (ADL), mobility, and rate of functional decline (disability onset) can be affected (Bergstrom et al., 1985; Morey, Pieper, & Cornoni-Huntley, 1998). There is also strong conjecture that any exercise that improves ROM might contribute to reduced risk for musculoskeletal injuries and falls among the elderly (Speechley & Tinetti, 1990; Spirduso, 1995; Tobis, Friis, & Reinsch, 1989).

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Although most exercise-physiology research on aging has focused on aerobic power and muscle strength, maintaining and improving flexibility should have at least equal importance for function and QOL, especially for the frail elderly (Blumenthal et al., 1989; Shepard, 1997). This review synthesizes the research literature regarding flexibility and aging. It is organized into five sections: (a) flexibility variables throughout the life span, (b) an analysis of ROM influences on physical functions, (c) physiological influences of aging on connective-tissue and joint characteristics, (d) ROM changes with aging, and (e) a review of training studies designed to enhance ROM in older adults. *Older adult* is defined for the purpose of this review as a person 65 years or older (Shephard; Spirduso, 1995). Because of the great individual variability inherent in the aging process (Skinner, 1988), however, many of the findings developed from the review would have implications for younger, middle-aged populations.

Flexibility Variables

Clinical or therapeutic uses of stretching can be traced back to the Greek and Roman cultures, and the Asanas (yoga postures) were first described in the second century A.D. (Woods, 1914). Potential benefits accruing from stretching were described in early reviews and include muscle relaxation, injury prevention, relief of muscle cramps and soreness, postural alignment and body symmetry, reduction of psychological stress, and, for yoga disciples, union of the mind, body, and spirit (Alter, 1996; Holland, 1968; Holland & Davis, 1975). ROM is influenced by multidimensional factors throughout the life span, including gender, heredity, environment (e.g., ambient temperature), neural mechanisms (e.g., muscle-spindle stretch reflex), and residual muscle tension. Additional variables include Circadian rhythms, injury and pain, lack of strength and coordination, disease pathology, and the skeletal, neural, and connective-tissue modifications that occur as a result of physiological aging (Alter; Bertolasi, DeGrandis, Bongiovanni, Zanetta, & Casperini, 1993). It is well documented that women generally have more extensive ROM in the major joints, which reflects a different pattern of skeletal architecture and connective-tissue morphology and some hormonal differences (Bell & Hoshizaki, 1981; Gabbard & Tandy, 1988).

Over 200 inherited conditions, including Ehlers–Danlos syndrome, can result in abnormal laxity of all the joints, a condition defined as hypermobility (Beighton, Graham, & Bird, 1983). Similar changes in joint laxity can occur, however, as a result of traumatic or repetitive injury to the supportive ligaments, tendon, or muscle/fascial tissue, with resultant loss of junctional integrity. Skeletal modifications can also occur as a result of traumatic injury or disease (e.g., osteoporosis) and result in significant loss of ROM. In addition, an individual's lifestyle, including nutrition, occupational demands, and physical activity habits, is significantly related to many of the changes in bone and connective tissue that can influence functional ROM during the life span. A primary concern with flexibility of older adults is the documented increase in being sedentary with increasing age and its influence on ROM, mobility, and physical ability to live independently. One of the largest ($N = 120{,}000$) and most recent random surveys of the physical activity habits of U.S. adults reported that 36.9% of men and 47.3% of women 75 years or older do not participate in regular exercise (Pratt, Macera, & Blanton, 1999).

Flexibility and Physical Functions

One of the consequences of extended longevity is what one researcher has described as an epidemic of disability (Nagi, 1976; Vita, Terry, & Hubert, 1998). Of U.S. adults 75 years and older, 9.1% require assistance in basic ADL, and 16.7% depend on help with instrumental ADL such as shopping and housekeeping. The same epidemiologic study showed that 14.7% of adults ≥ 75 years of age are able to live independently but are physically limited in activities such as locomotion up and down stairs, stooping, bending, kneeling, handling, fingering, and reaching (Nagi). Another investigation traced 6,981 men and women 65 years and older (range 65–103 years) from various communities for 4 years with respect to changes in mobility status (Guralnik et al., 1993). Over the 4-year follow-up period, 36.2% lost mobility as defined by the ability to walk up and down stairs, as well as walk half a mile without assistance. This section of the review addresses the role of flexibility in ADL performance, maintaining mobility, and the progression of functional limitations.

ACTIVITIES OF DAILY LIVING

The results of gerontology research conducted in the latter half of the 20th century have allowed us to understand that successful aging, or sustained QOL, depends on not just avoiding disease and disability but also preserving high physical and cognitive function, as well as regular involvement in social and other productive community activities (Rowe & Kahn, 1997). A framework described by DiPietro (1996) can be used to examine (conceptualize) the relationship of physical attributes such as flexibility and strength to basic ADL (walking, hygiene and bathing, dressing, eating and drinking, transferring, toileting, rising from a chair, climbing stairs), higher physical functions, and mobility (Spirduso, 1995). Granger, Albrecht, and Hamilton (1979) developed a list of 14 groups of items rating ability to perform basic ADL. If one analyzes each of these groups, it is apparent that 12 of them significantly depend on functional levels of very specific ROM (e.g., shaving or applying makeup, drinking from a cup, putting on socks and shoes, bathing without assistance). Figure 1 illustrates the integrated hierarchical relationship among the underlying physical fitness components, ADL, and mobility.

Physical-fitness components are usually classified as either health related (e.g., muscle strength and flexibility) or skill-related (e.g., balance and agility; Casperson, Powell, & Christenson, 1985). The two categories of physical-fitness components are outlined in Table 1, and they should be viewed as the biological foundation, or building blocks, for the successive conduct of basic ADL, instrumental (intermediate) ADL (e.g., cooking, shopping, transportation, business affairs, housework), or advanced (extended) ADL (e.g., involvement in societal or community roles as a volunteer and participation in informal recreational activities, sports, hobbies, and employment, as well as social and religious groups; Reuben, Laliberte,

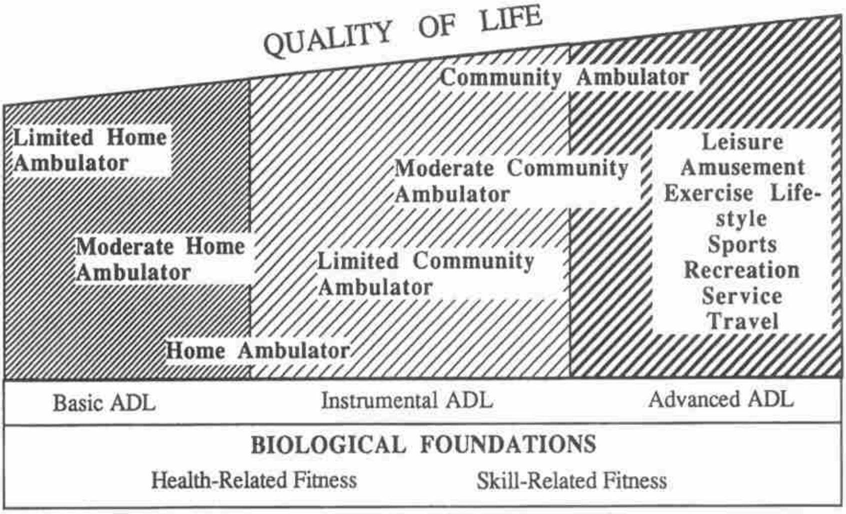

Figure 1. Integrated components of physical function and fitness. Adapted from Patla and Shumway-Cook, 1999.

Table 1 Components of Physical Fitness

Health-related components	Skill-related components
Cardiorespiratory endurance	Balance
Muscle strength	Coordination
Muscle endurance	Speed
Flexibility	Power
Body composition	Reaction time
	Agility

Note. Adapted from Casperson et al., 1985.

Hiris, & Mor, 1990). Each of the health- and skill-related fitness components makes specific contributions to the potential for and quality of performance at all levels of physical function and mobility.

Since their classification, the three levels of ADL have been somewhat compartmentalized for the practical objective of classifying older adults' degree of dependence/independence. From a functional perspective, however, they fall along a gradational spectrum, and when any of the underlying fitness components is compromised, some ADL function is attenuated. For example, maybe an individual still answers "yes" for all of the instrumental ADL items, but in reality some of these functions are very marginal and performed less efficiently as a result of a decrement in lower extremity strength and endurance or shoulder flexibility. More research is needed regarding the critical levels or thresholds of both health- and skill-related fitness elements that reflect aging degeneration and disuse effects. The integrated model just presented obviously implies that greater contributions of cognitive, sensory, and affective abilities are required as higher levels of physical function are approached. These parameters are beyond the scope of this review.

MOBILITY

Mobility is generally regarded as the ability to move safely and independently from one point to another and is critically important for the older adult both at home and in the community (Patla & Shumway-Cook, 1999). Balance and gait (walking efficiency) are critical components of locomotion, and Tinetti (1986) has developed a useful index for rating both of these components. The balance component of the assessment scale has 14 items, four of which are related to flexibility: neck ROM, back extension, reaching up, and bending over. The Physical Disability Index (PDI) was developed to evaluate physical impairment and disability in frail elderly in nursing homes (Gerety et al., 1993). The index includes multiple measures of upper extremity (elbow flexion/extension, arm supination/pronation, and shoulder flexion and internal/external rotation) and lower extremity (hip flexion, knee flexion/extension, and ankle dorsi-/plantar flexion) ROM. When evaluated in a random population of frail nursing-home residents ($N = 103$), a composite flexibility score that combined all 12 measures (PDI ROM) correlated significantly with the overall PDI score ($r = .74$, $p < .001$) and the physical self-maintenance subscale ($r = .45$, $p < .001$).

The Williams–Greene test of physical and motor function for older adults includes a section on mobility that has one flexibility item, the standard sit-and-reach test for low back and hamstring ROM (Williams & Greene, 1995). Recently, an innovative approach to evaluating a broad range of ordinary ADL has been developed: the Continuous Scale–Physical Functional Performance test (Cress et al., 1999). The test provides a total score of independence in older adults, as well as physical-domain scores (upper and lower body strength, flexibility, endurance, and coordination). The flexibility domain includes only shoulder-flexion ROM, which showed no significant improvement after 6 months of supervised strength and aerobic-stepping exercise with 49 older men and women (mean age 76 ± 4.0 years).

Traditionally, the criteria for functional mobility have focused on somewhat arbitrary abilities required to maintain independent living, such as walking half a mile (805 m), climbing a flight of stairs, and carrying a load of 25 lb (11.3 kg; DiPietro, 1996). Patla and Cook (1999) have recommended that mobility not be viewed as an absolute quality but rather as a continuum of changing function. They suggest that mobility quality varies from the bedridden nonambulator to the unlimited community ambulator, with gradations in between (e.g., limited home ambulator and limited community ambulator; Figure 1). Thus, subtle changes in mobility function can occur as a result of morbidity, musculoskeletal impairments, or changing environmental challenges (e.g., urban development and new community barriers for less adaptable older adults). We suggest that advanced (extended) ADL be broadly viewed to include measurable levels of moderate to vigorous exercise (Figure 1). An excellent scale was recently developed to assess exercise as an advanced ADL, in which participants are classified on the basis of their frequency and intensity of exercise (Reuben et al., 1990). The ratings on this scale range from nonexerciser (low) to frequent vigorous exerciser (high). Using the paradigm of Casperson, Powell, and Christenson (1985), exercise is a subset of physical activity (any voluntary movement that increases energy expenditure). From their perspective, exercise is planned, structured, repetitive, and purposive in that it is pursued in order to maintain or improve one or more fitness components. Also, from this perspective, exercise is a behavior that can be measured by applying performance or fitness criteria. Such an operational frame of reference allows for the use of physical-performance or fitness measures as an alternative approach to evaluating physical functions of older adults and making inferences regarding their related QOL (Fillenbaum, 1988).

FITNESS MEASURES OF PHYSICAL FUNCTION

A generalized view of the aging process describes the gradual diminution of physiological adaptations necessary to maintain homeostasis and the related progressive onset of senescence (Chodzko-Zajko, 1996; Shephard, 1997; Spirduso, 1995). Attempts to evaluate the rate at which these aging-adaptation changes occur, by measuring physiological functions, have provided multiple indices of "biological age." There is a growing body of aging and physical activity literature directed toward the use of physiological or physical-fitness parameters to estimate some of the qualitative variances between chronological age and so-called biological age (Skinner, 1988). These physiological-fitness indices are variously referred to as vital age, functional age, physical-fitness age, functional fitness, ADL age, or, more recently, biological vigor (Borkan & Norris, 1980; Chodzko-Zajko & Ringel, 1987; Dubina, Mints, & Zhuk, 1984; Kim & Tanaka, 1995; Lee, Matsuura, & Tanaka, 1993; Nakamura, 2000; Nakamura, Moritani, & Kanetaka, 1989; Osness et al., 1996; Rikli & Jones, 1999a; Shigematsu & Tanaka, 2000; Tanaka et al., 1995; Tanaka, Watanabe, Hiyama, Takeda, & Yoshimura, 1992).

These studies have used various measures of health- and skill-related fitness (as well as some physiological tests) and documented the fact that there is considerable individual variability in the rate at which these types of performance decline with aging (Chodzko-Zajko, 1996). These differences presumably reflect heredity, the general health of the individual, and maintenance of physical activity and other positive lifestyle factors. These types of assessment provide very different and useful information than that gained from medical profiles and self-reports of ADL (Skinner, 1988). Some of these objective approaches for assessing the qualitative functionality of the elderly have incorporated joint-ROM measures as part of their test battery. Several of these flexibility test items are discussed later in the article, in the review section on cross-sectional studies of aging and joint ROM. The specific contributions of flexibility to older adults' mobility, ADL, and ability to live independently have not been studied in depth (ACSM, 1998b), but anecdotal clinical evidence suggests that age-related loss of ROM might be significantly related to such basic functions as climbing stairs, rising from a sitting or recumbent position, and the eventual reliance on walking aids (Bergstrom et al., 1985).

ROM AND FUNCTIONAL LIMITATIONS

One study evaluated the specific minimal levels of shoulder abduction (range 70–110°) and adduction (range 40–120°) required for performing basic ADL (e.g., bathing in tub, washing hair, toileting) without difficulty (Young, 1986). A different approach to examining the relationship of limited ROM to critical physical functions was conducted through a study of 40 patients with advanced osteoarthritis, with either localized ($n = 39$) or generalized ($n = 16$) osteoarthrosis (Badley, Wagstaff, & Wood, 1984). The patients ranged in age from 28 to 84 years, and 10 different ROM measures were assessed with a standard orthopedic goniometer. Disability was evaluated by a self-report questionnaire that was scaled to 24 questions categorized for specific critical functions relating to mobility (e.g., getting in and out of tub), bending down (e.g., putting on shoes), dexterity (e.g., unscrewing lid), bending arm (e.g., washing face), and reaching up (e.g., washing high window. Correlation between these disability-group scores and the 10 ROM values were all negative and ranged from $r = -.78$ between reaching up and shoulder abduction to $r = -.51$ between bending arm and elbow supination. Through analysis of patients with specific disabilities in each category, the investigators developed a comprehensive list of minimal (threshold) ROM required for all 24 daily activities. A selective sample of these constituent activities for arthritis patients is displayed in Table 2. Because these ROM values were obtained from individuals with one or more existing disabilities, however, it is questionable whether they can be used for normative reference because of the complex synergistic and polyarticular nature of even basic ADL.

Jette, Branch, and Berlin (1990) followed a group of older adults for a period of 5 years and showed that specific losses of joint ROM and muscle strength were directly related to the progression of various disabilities and decrements of basic and instrumental ADL. Those who were under 80 years of age were more likely to have losses in wrist ROM, whereas those 80 years and older experienced musculoskeletal impairments of both the lower and the upper extremities, including the hands. Also, Morey et al.'s recent research with 161 older adults (72.5 ± 5.1 years) showed that selected flexibility measures of cervical and spinal rotation, as well as shoulder flexion, were directly associated with functional limitations as measured by self-reports of health, basic and instrumental ADL, fall susceptibility, and a timed bed-mobility test ($p < .01$; Morey et al.,1998).

Biomechanical logic would seem to dictate that a minimal level of spinal and upper and lower extremity ROM is critical for ADL, maintaining mobility, and pursuing significant recreational and leisure activities indigenous to QOL. Kinematic analyses have been conducted for such daily activities as level walking, climbing up and down stairs, and rising from a seated position (McFadyen & Winter, 1988; Naumann, Ziv, & Rang, 1982; Winter, 1987). These analyses provide gross approximations of ROM functions during normal ambulation but provide little insight to the minimal threshold level necessary for maintaining the ability to perform these ADL tasks. Fleckenstein, Kirby, and McLeod (1988) demonstrated the kinematic and kinetic differences with normal participants between rising from a seated to a standing position with the knees flexed at 105 and 75°. Performing this ADL task in the shortened ROM resulted in significantly greater hip-joint torque. The peak hip-extension moments (Nm) and impulses were significantly ($p < .0001$)

Table 2 Minimal ROM (°) for Five Functional Group Activities (40 Arthritis Patients)

		Range of Joint Movement							
Functional group	Constituent activity	Knee flexion	Hip flexion	Shoulder abduction	Elbow supination	Wrist extension	Thumb circumduction	Proximal IP	MCP
Mobility	on/off toilet	75							
	up/down stairs	110							
Bending down	shoes		30						
	cut toenails		120						
Dexterity	unscrew lid					10	40	45	45
	carve meat					0	30	0	0
Bending arm	shave/cosmetics			40	10				
	drink/cup			40	20				
Reaching up	high window			170					
	high shelves			120					

Note. IP = interphalangeal joint; MCP = metacarpophalangeal joint. Adapted from Badley et al., 1984.

greater (78%) with the knees less flexed. The implications of limited knee ROM for increased susceptibility to degenerative hip disease seem obvious, especially for older adults with hip arthrosis.

Physiology of Aging and Flexibility

There has been extensive research on biological changes coincident with aging, and detailed summaries can be found in most current exercise-physiology textbooks (Robergs & Roberts, 1997). Also, Chodzko-Zajko (1996) has provided a succinct summary of cellular, genetic, and control theories of physiological aging processes, with generalized implications for exercise programming for older adults. Shepard (1997) recently provided a detailed review of the changes in the major physiological systems at rest and during maximal and submaximal exercise that are related to the aging process. The position stand on exercise and physical activity for older adults by the ACSM (1998b) provides a good synthesis of aging physiology, as it relates to aerobic-exercise capacity, strength training, postural stability, flexibility, and psychological function. The summary that follows reviews morphological aging modifications in body composition and connective tissue. Studies of temperature effects on connective tissues and investigations of joint-stiffness and disuse syndrome are also presented, with implications for joint ROM.

BODY COMPOSITION

Tissue of the aging organism undergoes extraordinary changes. There are noticeable transformations in lean body mass, characterized by reductions in bone and muscle, along with corresponding age-related increases in body fat. For example, it has been demonstrated in a large comparative study (N = 500) that body fat increases from 33% to 44% in women and 18% to 36% in men between the ages of 18 and 85 years (Novak, 1972). Reductions in bone-mineral density with aging, coupled with joint-cartilage degeneration, can result in significant loss of height. Much of this height loss is a result of vertebral thinning and deterioration, so that a woman with osteoporosis can lose as much as 3 or 4 in. of body height. The resultant changes in posture (e.g., increased spinal curvature) can contribute significantly to loss of spinal ROM (as much as 50%) and the etiology of related postural syndromes such as chronic low back pain (Caillet, 1994; Lindsey, 1998; McKeown, 1965). Also, age-related skeletal degeneration as a result of osteoporosis and osteoarthritis is significantly related to the development of physical impairments and related mobility problems, including susceptibility to falls (Vandervoort, Hill, Sandrin, & Vyse, 1990). The most commonly affected joints are the vertebrae, knee, and hip, and by the age of 75 years, 85% of the population have osteoarthritic changes in the weight-bearing joints as demonstrated by radiography (Moskowitz, 1989). The reduction in lean body mass is estimated to be approximately 15% between 30 and 80 years of age, and much of this reflects insufficient mechanical loading of the musculoskeletal system (Evans, 1999).

Muscle atrophy (sarcopenia) is one of the most conspicuous degenerative changes with aging and is related to a reduction in muscle-fiber number (Green, 1986; Grob, 1983), fiber size (Kovanen & Suominen, 1987), and a reduction in the rate of muscle-protein synthesis (Welle, Thornton, Jozefowicz, & Riggs, 1993).

The number of motor neurons also diminishes with aging (Green; Gutmann, 1977), with the Type 2 motor units apparently being more susceptible (Fitts, 1981). As neural resources decrease and the aging muscles atrophy and become infirm, walking speed is gradually reduced (Bassey, Bendall, & Pearson, 1988) as stride length is significantly shortened (Fiatarone et al., 1990). As aging muscle fibers atrophy, the rate of corollary deposition of fatty and fibrous (collagen) tissues increases.

CONNECTIVE TISSUE: COLLAGEN AND ELASTIN

Collagen. Because collagen, which is a major component of all connective tissue, has extremely poor compliance, its increase with age results in greater joint stiffness (Alnaqeeb, Al-Zaid, & Goldspink, 1984). As muscle, ligament, and tendon tissue age, there is an increase in the crystallinity of the collagen fibers, resulting in an increase in their diameter. This increase in fiber diameter results in increased collagen intermolecular bonding, which increases their resistance to deformation (extensibility). There is also an aging-related formation of collagen-fiber cross-linkages that are related to increased free-radical activity and contribute to a further reduction in connective-tissue extensibility (Arking, 1991). Connective-tissue collagen also shows significant dehydration with age, which can affect its elastic quality (Elliott, 1965; Mohan & Radha, 1981). For example, the change in tendon-collagen percent water from young (80–85%) to old mammals (70%) is significant.

Elastin. Elastin fibers are found, in various quantities, in muscle fibers and all connective tissue, including tendon and ligaments (relatively small amounts) and fascia (relatively high amounts). All skeletal-muscle sarcolemmas have large amounts of elastin fibers interwoven longitudinally with collagen fibers. In contrast to collagen, elastin fibers possess a high degree of elasticity (low resistance to mechanical deformation) because of a very different biochemical composition and physical arrangement of their molecules. Elastin fibers provide the major quality of extensibility (elastic deformation) for muscle, fascia, and ligament and thus determine the major soft-tissue ROM for all joints (Jenkins & Little, 1974; Sapega, Quedenfeld, Moyer, & Butler, 1981).

In a classic demonstration of the relative contribution of various tissues to joint resistance using a progressive animal-dissection model, Johns and Wright (1962) showed that the ligaments and muscle-fascial capsule account for 47% and 41%, respectively, of joint resistance to passive movement (Figure 2). Because of their relatively higher concentrations of elastin fibers, it is presumed from these data that the contiguous muscle and fascia are the primary anatomical components that respond to a stretch stimulus (neural mechanisms not considered). The secondary anatomical components would be represented by the contiguous ligaments and joint capsule. Tendon is described morphologically as practically inextensible and accounts for only 10% of the joint torque resistance to passive movement.

Elastin fibers show aging-related degeneration similar to that of collagen fibers. These alterations include fiber fragmentation or fraying, calcification, and an increased number of cross-linkages with other fibers. These new linkages, along with selected biochemical changes, result in a slow loss of joint resiliency and increased joint rigidity (Bick, 1961; Gosline, 1976; Schubert & Hammerman, 1968; Yu & Blumenthal, 1967).

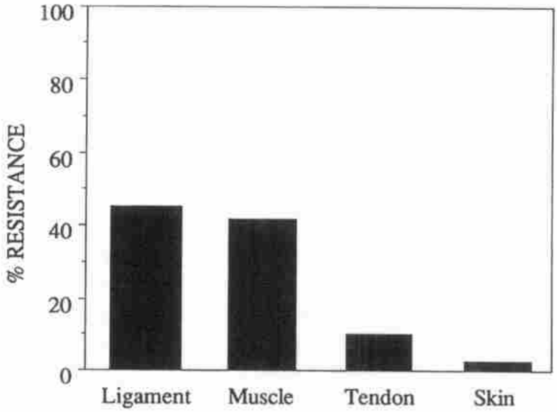

Figure 2. Relative contribution of tissue types to joint resistance. Adapted from Johns and Wright, 1962.

The changes in mammalian connective tissue summarized here have obvious implications for aging-related loss of joint ROM. The coincident changes in the neuromuscular system (e.g., sarcopenia and motor-cell degeneration) are undoubtedly related to the development and progression of musculoskeletal impairments and their related disablement among the elderly (Jette et al., 1990).

TEMPERATURE INFLUENCES ON CONNECTIVE TISSUE

There have been many attempts in the animal laboratory to examine the effects of artificial heating on the mechanical properties of connective tissues. The effects of such heat stress were succinctly summarized by Sapega et al. (1981). Apparently, the greatest effects of heat application occur when the connective tissue is under tensile stress (e.g., stretch). Relatively high temperatures (>102 °C) are required for these effects, which occur primarily through destabilization of collagen intermolecular bonding, which enhances the viscous-flow properties of that tissue (decreased viscosity of the gellike ground substances that make up the nonfibrous components of collagen).

Wright and Johns (1960a) used 2 young normal participants and tested the serial effects of ice immersion (skin temperature at 18 °C) and heating by infrared lamp (skin temperature at 45 °C) on metacarpophalangeal ROM. They reported that ROM was improved about 20% by warming and reduced 10% by cooling. Another investigation of 23 young men compared baseline ROM with mild physical activity (2 min of flexion and extension), 10 min of heat application (45 °C water), and combined heat and mild activity (Sechrist & Stull, 1969). All of the treatments proved to be effective in improving wrist, ankle, and elbow flexion and extension, with the exception of cold application. Gillette and Holland (1991) used treadmill-walking warm-up sufficient to raise body-core temperature 0.5 °C and reported a small but significant increase in hamstring ROM in young men. These studies serve as the principal rationale for the use of mild physiological warm-up before ROM stretching, including exercise-program recommendations for older adults (ACSM, 1995, 1998a; Evans & Cyr-Campbell, 1997; Rodenburg, Steenbeck, Schiereck, & Bar, 1994).

Cold application for flexibility purposes is used primarily for the analgesic influence it can provide for stretching patients with adhesions and high levels of pain (Alter, 1996). Therapeutic protocols for this purpose initiate with traction stretching combined with heat for relatively long periods, followed by cold application with continued traction. Such procedures are based on animal-morphology models that demonstrated that terminal cold treatment increases the quality of plastic reformation, or the rate at which elongated connective tissue (elastic components) returns to its prestretched length (Sapega et al., 1981). Some sports-medicine advocates have extrapolated from this concept that "cool-down stretching" (stretching conducted after aerobic exercise) will result in better retention of ROM than will stretching done before such exercise. This hypothesis has not been well studied, but there are no reports in the sports-medicine literature of any injurious effects of the common practice of stretching before and after aerobic activity.

HUMAN JOINT STIFFNESS

One of the generalized modifications in older mammalian joints is described clinically as arthrosclerosis, or an increase in joint stiffness. Stiffness is biomechanically defined as the force required to move a joint through a specified ROM, and this characteristic can increase with age (Wright & Johns, 1960b). Such increases with aging reflect the morphological changes in connective tissue reviewed earlier in the article, as well as changes in the joint proper, such as a decrease in synovial viscosity and increase in cartilaginous degeneration (Barnett & Cobbold, 1969; Jebens & Monk-Jones, 1959; Segre, 1971). One of the first experiments to compare joint stiffness in healthy young (15–19 years) and older (63–88 years) men was conducted using the animal-morphology model first developed by Johns and Wright (1962). With this method, index-finger resistance (stiffness) to passive movement was measured by a potentiometer bonded to an oscillating lever (Chapman, deVries, & Swezey, 1972). These investigators reported a 30% difference in resting passive-ROM resistance (stiffness) between the young and old. Electromyographic monitoring minimized the possible influence of residual muscle tension on joint resistance to passive force.

In 1975 (Such, Unsworth, Wright, & Dowson), another attempt was made using an arthrograph (which imparts a reproducible passive sinusoidal motion to joint) to measure knee stiffness in younger and older men and women ($N = 70$). Results showed that dissipative energy (energy lost per movement cycle of the joint) increased with age for both sexes, but the critical measure of stiffness peak-to-peak torque (elastic stiffness) did not. A similar approach was used to evaluate potential differences in ankle stiffness among 45 women ranging in age from 21 to 80 years (Chesworth & Vandervoort, 1989). Passive resistance to 10° of alternate dorsiflexion and plantar flexion was measured by use of a torque-motor system. Passive torque and passive elastic stiffness increased nonlinearly during both movements, but there were no significant age-group differences.

The same researchers repeated this study design with a much larger population ($N = 214$) that included men and women ranging in age from 55 to 85 years

(Vandervoort et al., 1992). This comparison of middle-aged and elderly participants demonstrated significant ($p < .03$) age-related differences in ankle stiffness during passive stretching at 10° dorsiflexion (approximately midrange). The youngest women (55–60 years) had the lowest mean value, 5.96 ± 1.65 Nm, which increased to 8.74 ± 2.48 Nm in the 81- to 85-year-old women. Corresponding men's values went from 8.8 ± 2.14 Nm for the youngest (55–60 years) to a high of 9.94 ± 2.63 Nm in the 71- to 75-year-olds and a value of 9.35 ± 4.00 Nm in the oldest men (81–85 years). The main effects of gender for stiffness values were highly significant ($p < .001$). The authors reported that the larger stiffness values for the men were probably related to the observed larger muscle mass in their lower extremities, as contrasted with the women. These study results imply that moving the foot up during walking (dorsiflexion) requires more strength as one ages from the middle years to the 70s and 80s. These same participants, however, demonstrated a 30% difference in dorsiflexor strength between the youngest and oldest age groups. Decreased strength and flexibility of the muscles around the ankle joint have been identified as risk factors when elderly people with a history of falling were compared with nonfallers (Studenski, Duncan, & Chandler, 1991). Data that document the apparent age-related decrement in ankle dorsiflexion are presented in another part of this article.

Active stretching of the plantar flexors was accomplished with isometric contractions of 20–60% of maximum to ascertain possible differences between 16 young (20–29 years) and 14 elderly (57–71 years) women (Blanpied & Smidt, 1993). A microcomputer was used to analyze forceplate-resistance values to the two stretch forces. Variable results precluded any age comparisons for absolute elastic stiffness, but after 6 weeks of strength training both age groups showed small decreases in stiffness.

DISUSE MODIFICATIONS

When one reviews the research literature relative to biological aging of the musculoskeletal system, it is obvious that there are many similarities to the physiological changes associated with physical inactivity or disuse phenomena (Bortz, 1982). These similarities have led to some speculation regarding the potential modification or reversibility of selected aging processes at the cellular level that might be accomplished through lifestyle changes such as exercise, improved nutrition, smoking cessation, weight reduction, and stress reduction (Chodzko-Zajko, 1996; Evans & Cyr-Campbell, 1997; Wilmore, 1991).

The influences of disuse modifications on connective-tissue morphology are well documented. These mechanisms have been described primarily through the experimental immobilization of animal limbs. One of the most fundamental changes within several weeks of immobilization is abnormal collagen-fiber cross-linkages at their end junctures, which result in restricted stretch quality of the affected muscle, fascia, or ligament. These abnormal cross-linkages are accompanied by increased loss of tissue water and selected changes in chemical structures (Akeson, Amiel, & Woo, 1980; Donatelli & Owens-Burkhart, 1981; Gross, 1961). The end result of these deviant collagen linkages is diminished extensibility and elevated joint stiffness. Older adults who are bedridden or suffer from serious physical impairment probably incur similar tissue degeneration that is further complicated by the natural consequences of connective-tissue aging.

Flexibility Changes and Aging

This section of the article is devoted to investigations that attempted to associate changes in human ROM with chronological age. It is generally organized by specific joint movement. More details are provided for the studies that used more valid measurement techniques and reported reliability coefficients (e.g., test–retest for intertester or intratester reliability). If passive ROM was the measurement mode, it is so indicated; otherwise it can be assumed that active ROM was used. It can also be assumed, unless otherwise indicated, that when results are presented in degrees of ROM, traditional protractor goniometry was used. The first part of this section of the review is devoted to several studies of multiple-joint ROM, which is followed by studies of discrete-joint ROM listed anatomically.

MULTIPLE-JOINT ROM

Maximum ROM is achieved in the mid- to late 20s for both men and women and gradually decreases with advancing age, but apparently it decreases more rapidly in some joints than others (Bell & Hoshizaki, 1981). One study measured 190 participants ranging in age from 18 to 88 years on 17 variables at eight different joints, using a well-validated Leighton gravity flexometer (Leighton, 1942, 1955). Analysis of ROM data for male and female participants across age revealed a general decline as age increased for both sexes, with women demonstrating better ROM throughout the adult life span. The largest differences between the women and men were after 75 years of age for cervical rotation; shoulder flexion/extension; and trunk flexion/extension, lateral flexion, and rotation. Significant negative correlations between individual ROM measures and age ranged from –.17 to –.62. The loss of flexibility with age was more pronounced in lower rather than upper extremity ROM. It is interesting that in this study, 17% of the 60- to 74-year age group and 7% of the 75-year and older age group self-reported difficulty in performance of basic ADL. No information was reported, however, for the possible association between these perceived difficulties and specific ROM measures.

One of the more comprehensive analyses of ROM compared 15 men and women (60–69 years of age) with an older group of 15 men and women (75–84 years; Walker, Sue, Miles-Elkousy, Ford, & Trevelyan, 1984). Multiple measures (degrees) were conducted for five shoulder and four wrist ROM, as well as elbow flexion and radioulnar pronation/supination. Lower extremity ROM included six hip and three metacarpophalangeal ROM, as well as knee flexion, subtalar inversion/eversion, and ankle plantar and dorsiflexion. MANOVA analyses did not support any significant differences in ROM between the two age groups, but 12 motions were significantly different between the sexes. This study recruited volunteer participants from a community recreation center, however, and might have represented selection bias. Passive ROM was compared for a younger group (20–32 years) and older group (59–75 years) of women ($N = 22$; Hubley-Kozey, Wall, & Hogan, 1995). The 7% lower hip flexion (–7.4°) and 21% lower knee flexion (–31.2°) in the older group were significant ($p < .025$). These findings are in general agreement with those of other investigations that are reported later in this section of the article.

LOW BACK/HAMSTRING

Tests of hamstring flexibility have been an intrinsic component of the ROM segment of fitness-test protocols for many years (ACSM, 1998b). Even though such tests have some inherent limitations because of the difficulty of estimating complex multijoint ROM linearly, they are useful clinically because of the importance of hamstring ROM in maintaining spinal integrity (Caillet, 1994; Holland & Davis, 1975). A dramatic example of changes in ROM with age is seen on the YMCA sit-and-reach test of low back and hamstring flexibility (Table 3). With data from over 33,000 participants from centers throughout the United States, it represents the largest available normative scale of adult ROM (Franks, 1989; Golding, Meyers, & Sinning, 1989). This test procedure was recently recommended as part of a clinical battery of fitness tests for use by physicians for preexercise prescription screening (Kligman, Hewitt, & Crowell, 1999). Both sexes lose about 1 in. per decade (14.5%) in performance on this test. These data also vividly reflect the concept that selected ROM in women is significantly better than in their male counterparts. This was identified in early and more recent reviews of the flexibility research literature (Alter, 1996; Holland, 1968). In a sample of 250 Korean women 60–90 years of age, a modified version of the sit-and-reach measure yielded a mean value of 18.03 in. (corrected value for different heel placement; Kim & Tanaka, 1995). The range of reliability for this version of the sit-and-reach test is reported as .93 (Shigematsu, Kim, Kim, & Tanaka, 1998) to .96 (Shigematsu & Tanaka, 2000). The same laboratory has also developed a standing version of trunk flexion (hamstring ROM) as part of its functional-fitness test sequence (Tanaka, Shigematsu, Nakagaichi, Kim, & Takeshima, 2000). Test–retest reliability for this standing version of hamstring ROM is .97 (Shigematsu et al.).

A modified version of the sit-and-reach test is included in the Fullerton Functional Fitness Test (FFT), developed by Rikli and Jones (1999a). Their low back and hamstring ROM test is conducted in a seated position (chair) to accommodate older participants who have difficulty getting down on or up from the floor. Unlike the standard floor sit-and-reach test, one leg is flexed at the knee to reduce spinal compression. Test-administration procedures are provided in careful detail in the appendix of the recent report. The same authors also published the results of

Table 3 Floor Sit-and-Reach ROM, Mean Scores (in.)

	Age Group		
Sex	18–25 years	45–65 years	>65 years
Women	19	16	15
Men	16	12	10

Note. Baseline is with the heels and toes at the 15-in. mark. Adapted from Golding & Lindsay, 1989.

a national survey for the FFT with a population base of 7,183 (age 60–94 years), conducted at 267 different sites (Rikli & Jones, 1999b). Normative distribution scores by gender and age group reflected a very similar pattern to that reported for the YMCA sit-and-reach test. Women performed significantly better than men did ($p < .001$), and significant differences occurred across adjacent 5-year age groups ($p < .007$), three female age groups and four male age groups. The reported score range from age 60 to 90 years for men is 15.9–11.2 in. and for women is 18.2–14.5 in. (corrected values for different heel placement). The test procedure yielded excellent intraclass reliability estimations between multiple-day measures of $R = .95$ (Rikli & Jones, 1999a). Also, the authors have reported that the sit-and-reach FFT item helped effectively discriminate between frail and independent women age 70–89 years ($p < .01$; Jones, Rose, & Newsome, 1999).

The American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD) published the second version of their *Functional Fitness Assessment for Adults Over 60 Years* (Osness, 1998; Osness et al., 1996). The sit-and-reach test component is a variation of the YMCA test. It is conducted with the participant sitting on the floor, and measurements are made with a yardstick. Data have been collected nationwide for over 2,000 participants 60–90 years of age, and standards are expressed as average, above average, and below average for 5-year age and gender groupings. The test developers reported test–retest reliability coefficients of .978–.99 (women) and .098–.991 (men). This sit-and-reach normative database displays an age and gender pattern very similar to those of the YMCA and FFT items reviewed previously. The reported score range from age 60–90 years for men is 11.2–15.9 in. and for women is 14.5–18.2 in. (corrected values for different heel placement for comparison with YMCA norms). Shaulis, Golding, and Tandy (1994) also reported significant gender differences on the AAHPERD sit-and-reach test for older adults, with corrected values averaging 12.26 in. for men and 20.08 in. for women. Mobily and Mobily (1997) conducted an independent investigation of the AAHPERD functional fitness test battery and reported that intraclass reliability coefficients at baseline, 4 weeks, and 8 weeks for the sit-and-reach test item were .995, .997, and .998, respectively, revealing that reliability remained high despite improved participant performance.

SHOULDER ROM

A cross-sectional study of shoulder flexion in 59 individuals of both sexes with no history of shoulder disability and ranging in age from 20 days to 103 years was conducted with goniometry measures accurate to 0.2° and test–retest reliability coefficients of $r = .99$ (Germain & Blair, 1983). Subsets of the cohorts tested for shoulder flexion are displayed in Table 4. With the arm in the anatomical position (0°), full flexion to the vertical (180°) approximates normal or full shoulder ROM for this movement. Examination of Table 4 reveals the steady decrease in shoulder ROM that begins at about 10 years of age and continues throughout the life span, so that by age 70 about 20% of flexion is lost. The study yielded a mean shoulder-flexion value of 178.96° (± 14.5) and a correlation between age and measurement of $r = -.70$ ($p < .001$). Table 4 also provides a suggested clinical standard or range (in degrees) by age grouping. Self-reports of occupational demands and exercise habits that involved the upper extremities were associated with significantly

Table 4 Shoulder Flexion (°) and Suggested Clinical Standards by Age (N = 59), Men and Women

Age group (years)	n	M (SD)	Suggested standard
0–1	7	188.66 (11.96)	185–195
1–2	13	196.24 (9.58)	190–200
2–5	9	182.93 (15.90)	180–190
5–10	10	190.01 (8.00)	185–195
10–20	19	183.16 (6.91)	180–190
20–30	39	179.73 (9.83)	175–185
30–40	24	177.31 (7.94)	170–180
40–50	10	176.03 (7.22)	170–180
50–70	13	169.59 (11.11)	165–175
70+	13	151.96 (16.92)	145–155

Note. Adapted from Germain & Blair, 1983.

(p < .001) lower age-related loss of flexion ROM. There were no significant differences by gender in this report.

The FFT also includes a test item to evaluate shoulder ROM, designated "back-scratch test" (Rikli & Jones, 1999a). This test procedure is a modified version of the Apley scratch test that has been used for many years by clinicians for subjective evaluation of general shoulder ROM (Gross, Fetto, & Rosen, 1996). Briefly, the protocol involves reaching behind the head with one hand and behind the back with the other in an attempt to touch the middle fingers of both hands. A ruler is used to measure the distance between fingers. Table 5 outlines the means by age and gender for this FFT test item based on more than 7,000 observations (Rikli & Jones, 1999b). AVOVA revealed significant main effects for gender (women performed significantly better) and age group. Note also that the combined mean value for women (1.9 in.) was 60% better than the same measure for men (–4.8 in.), and Fisher's post hoc analysis indicated that significant differences occurred across adjacent age groups (p < .007; three female and two male groups). The single-trial intraclass reliability estimates (R) for the scratch procedure were .96 (Rikli & Jones, 1999b). In a cross-validation investigation of the FFT, this measure's test–retest reliability value was .98 (Miotto, Chodzko-Zajko, Reich, & Supler, 1999). The researchers who developed the FFT also reported that the scratch test, as well as the other battery items, was significantly different for physically frail independent older adults who were 70–89 years old (Jones et al., 1999). A similar version of the scratch test is included in the Purdue Lifespan project (Holcomb et al., 1999).

Another approach to evaluating upper extremity ROM involves reaching overhead, as in the movement required to access a high shelf or window. Such a test item is included in a battery of ADL-performance tests for use with older Asian adults (Kim & Tanaka, 1995). The test item specifically involves raising both arms overhead while holding a bar in both hands in a standing position. The measurement is expressed as degrees beyond the vertical shoulder-flexion position of 180°.

Table 5 Back Scratch (in.) by Age and Gender (N = 7,183)

Age group (years)	Women	Men
60–64	–0.7 ± 3.5	–3.4 ± 4.8
65–69	–1.2 ± 3.7	–4.1 ± 4.9
70–74	–1.7 ± 3.8*	–4.5 ± 4.9
75–79	–2.1 ± 4.1	–5.6 ± 5.1*
80–84	–2.6 ± 4.2	–5.7 ± 5.4
85–89	–3.9 ± 4.5*	–6.2 ± 4.8
90–94	–4.5 ± 5.2*	–7.2 ± 4.8*
Combined	–1.9 ± 4.0	–4.8 ± 5.0

Note. Adapted from Rikli & Jones, 1999b.
*Age-group mean significantly different from mean of the age group below ($p < .007$).

Another variation of the anterior shoulder-girdle ROM test involves the same movement pattern, except it is administered with the participant in a seated position so that the hip girdle is stabilized (Shigematsu et al., 1998). The test–retest reliability for this version of the shoulder-flexion test is .94.

In a larger survey, 953 independent elderly men and women were assessed for shoulder abduction using a gravity goniometer (Bassey, Morgan, Dallosso, & Ebrahim, 1989). The mean values by age group and gender were 129 ± 14° for men age 65–74 years, 121 ± 19° for men over 74 years old, 124 ± 19° for women age 65–74 years, and 114 ± 22° for women over 74 years old. These mean values are about 120° for both sexes, which is about 30° below the clinically recommended orthopedic norm (Heck, Henderson, & Rowe, 1965). There were significant effects for sex and age ($p < .001$); women had poorer ROM, and the reduction in abduction was approximately 10° per decade. Multiple-regression analysis showed that the effects of age were accounted for in part by health (self-rating), strength (hand grip), and customary use of the shoulder in everyday activities (self-report). Participants with a clinical history of shoulder disability ($N = 30$) had a much lower abduction ROM (men 87°, women 88°). Young (1986) estimated that older adults require minimal shoulder-abduction ROM of 70–110° for adequate maintenance of basic ADL. Much clinical attention has focused on the progressive degeneration of the shoulder joint with age and its relationship to upright posture, attendant biomechanical stresses, and execution of upper extremity ADL (Bechtol, 1980; Caillet, 1995). These degenerative changes are undoubtedly related to the apparent age-associated decreases in shoulder ROM outlined previously.

SPINAL ROM

Not surprisingly, cervical ROM is reduced significantly in older adults, and this has significant implications for posture and biomechanical efficiency because of age-related skeletal deformation (cervical kyphosis), which is very common in the 65-year-old and older population (Kuhlman, 1993; Lindsey, 1998). Between the ages of 65 and 75, 74% of men and 87% of women show radiographic evidence of cervical-disk degeneration (Meisel & Bullough, 1984). Kuhlman compared differences in six cervical-ROM measures between 31 young adults (20–30 years) and older adults (70–90 years). The elderly men and women had significantly lower ROM than the younger group did ($p < .01$) for all six motions (12% less anterior flexion, 32% less extension, 22% less lateral flexion, and 25% less rotation). Table 6 compares all six cervical-ROM means for the 70- to 90-year-old men and women. It is evident that the older women had significantly better cervical flexibility than the men did ($p < .05$), except for flexion, which was virtually the same for both sexes. Kuhlman's research used a relatively simple cervical gravity goniometer, which can be strapped to the head for measurement of multiple neck ROM. Intrarater-reliability coefficients ranged from .62 to .95, and interrater reliability from .73 to .92 (Kuhlman). Kuhlman's research findings corroborate the results of Bell and Hoshizaki (1981) with respect to age and gender cervical-ROM patterns.

A similar cross-sectional investigation of gross spinal ROM compared three age groups of women ranging from 20 to 84 years (Einkauf, Gohdes, Jensen, & Jewell, 1987). Spinal ROM for all three groups are exhibited in Table 7 for standing anterior flexion, extension, and sitting left and right lateral flexion. The largest differences between young (20–29 years) and old (70–84 years) were seen for posterior extension (50% lower), and the smallest, for anterior flexion (24%). All between-age-group differences as evaluated by MANOVA were significant ($p < .05$). The authors indicated that some older adults were limited in achieving a maximal forward-flexion position because of abdominal fat, which might have influenced the validity of the reported values. These researchers also hypothesized that older adults are required to assume more forward spinal-flexion positions for the conduct of everyday activities and thus retain that ROM better than others. It is also possible that some older adults with balance problems might be reluctant to lean backward (spinal extension) maximally.

In Japan, a spinal-extension measure has been used for several years as part of a functional fitness test for applications with middle-aged and older adults (Tanaka et al., 2000). The test is conducted on a mat or table with the feet stabilized, and when the individual achieves maximum thoracolumbar hyperextension, the

Table 6 Cervical ROM (°) for 70- to 90-Year-Olds ($N = 42$)

Motion	Women	Men
Flexion	69.0 ± 5.0	69.8 ± 10.2
Extension	70.6 ± 6.2	80.8 ± 6.3*
Lateral flexion left	47.6 ± 4.6	50.5 ± 4.8*
Lateral flexion right	46.1 ± 4.8	51.1 ± 4.4*
Right rotation	90.3 ± 3.4	95.8 ± 3.3*
Left rotation	90.4 ± 2.0	95.3 ± 4.4*

Note. All measures are from the anatomical upright position (0°). Adapted from Kuhlman, 1993.
*$p < .05$.

Table 7 Spinal ROM (°) for Three Age Groups of Women (N = 51)

Spinal measure	20–29 years (n = 21)	50–59 years (n = 15)	70–84 years (n = 15)
Anterior flexion	6.9 ± 1.2	6.3 ± 1.4*	5.2 ± 1.2*
Extension	36.0 ± 12.1	22.0 ± 6.8*	18.0 ± 4.4*
Lateral flexion left	33.0 ± 7.0	28.0 ± 5.1*	20.0 ± 4.4*
Lateral flexion right	36.0 ± 5.7	31.0 ± 5.8*	24.0 ± 3.5*

Note. All measures are from the anatomical upright position (0°). Adapted from Einkauf et al., 1987.
*$p < .05$.

distance from chin to base (mat or table) is measured in centimeters. A variation of this spinal measure was used in a study of controlled stretch training in older women and is reported in a later section of this article (Rider & Daly, 1991).

One investigation was identified that attempted to measure spinal-axial ROM, but it tested only 9 male and 8 female participants ranging in age from 2 to 74 years (Schenkman, Hughes, Bowden, & Studenski, 1995). This ROM is measured in a seated position with the thighs stabilized, while the participant maximally rotates the thoracolumbar spine to the right and left. There was great variability, with a minimum ROM of 92° and a maximum ROM of 190° for the 17 participants. This new test procedure yielded a test–retest reliability of .90–.95 and interrater reliability of .97. Data were not analyzed by age or gender. This little-studied ROM measurement is obviously critical for such instrumental daily activities as driving a motor vehicle. With respect to the maintenance of spinal integrity, it should be mentioned that older people who spend an inordinate amount of time sitting tend to have flatter lumbar curves and a compensatory slight flexion of the hip and knee joints, which can affect their walking efficiency (Borenstein & Burton, 1993). Such joint modifications can be considered hypokinetic adaptations.

HIP AND KNEE ROM

In a very large cross-sectional sample (N = 956) of men and women, multiple measures of hip and knee ROM all showed significant losses with aging (Roach & Miles, 1991). These researchers compared a sample of relatively young adults (age 25–39) with an older group (age 60–74) on six ROM variables (Table 8). Study results were reported as only mean values without standard deviations. Generally, the differences in average ROM between the two age groups were small, ranging from 3° to 5°. The smallest age-related difference was for knee flexion (2%), and the largest was for hip extension (20%; $p < .05$). No statistical comparisons for gender ROM differences were provided in the results. These researchers further analyzed the age-related decreases in flexibility expressed as loss of the percentage of the normal arc of ROM (Table 9). When the decrements were viewed in this way, this value ranged from –2% (knee flexion) to –23% (hip extension). Certainly the

Table 8 Lower Extremity ROM (°) for Two Age Groups ($N = 956$), Men and Women

	Age Group	
Motion	25–39 ($n = 433$)	60–74 ($n = 523$)
Knee flexion	134	131
Hip flexion	122	118
Hip extension*	22	17
Hip abduction	44	39
Internal hip rotation	33	30
External hip rotation	34	29

Note. Adapted from Roach and Miles, 1991.
$*p < .05$.

Table 9 Differences in ROM Between Young (25–39 years) and Old (60–74 years) Age Groups ($N = 956$)

Movement	Degrees	Percent arc
Knee flexion	–3	–2
Hip flexion	–4	–3
Hip extension	–5*	–23
Hip abduction	–5	–11
Internal hip rotation	–3	–9
External hip rotation	–5	–15

Note. Adapted from Roach and Miles, 1991.
$*p < .05$.

15% and 11% losses of ROM arc for external hip rotation and hip abduction, respectively, have important implications for locomotion and mobility. The relatively large loss in hip extension is undoubtedly related to the shorter stride length characteristic of older men. In a significant study of walking patterns of healthy young and old men (age range 20–87 years), stride length was expressed as percent body height (Murray, Kory, & Clarkson, 1972). For free (normal-gait) walking, the mean stride length of men younger than 65 years averaged 89% of their height, whereas for those older than 65 years it averaged 79%. Even larger differences were shown between the young and old groups during high-speed walking. These shorter stride lengths were also biomechanically related to significantly less hip rotation, knee flexion, and ankle extension (plantar and dorsiflexion) during the normal walk gait of participants 65 years or older.

ANKLE ROM

A comparison of ROM of the ankle complex in a group of younger and older men and women showed no significant age-related differences, but there was significantly higher flexibility for both groups of women (Sepic, Murray, Mollinger, Spurr, & Gardner, 1986). A more recent cross-sectional study of multiple ankle-joint ROM, however, did find small but significant age-related decrements in flexibility (Nigg, Fisher, Allinger, Ronsky, & Engsberg, 1992). A more comprehensive sample of 214 middle-aged and older adults was carefully tested for maximum ankle dorsiflexion using a rotary footplate that was attached by Velcro™ straps to the ankle for isolation of movement (Vandervoort et al., 1992). Table 10 presents the active ankle-ROM values for the various age groups. Mean values for the women decreased from 20.7° to 10.1° between the youngest and oldest groups. Corresponding values for the men dropped from 20.0° to 13.5°. Sex and age-group differences were significant ($p < .001$), and it is obvious that the women had a greater decrease across age groups than men did.

Vandervoort et al. (1992) also tested for ankle dorsiflexion strength, and this function decreased about 30% between the middle-aged and older groups ($p < .001$). The authors conjectured that these differences in dorsiflexion strength were directly related to the lower active-ROM values in the older participants. These findings are in agreement with those of one study of passive ankle-dorsiflexion ROM that also compared two age groups of women (20–32 years and 59–75 years) using a Leighton gravity flexometer (Hubley-Kozey et al., 1995). The study used only 43 participants but reported a 29% difference ($p < .02$) between the two age groups (20.7 ± 5.5° for younger, 14.7 ± 5.9° for older). Another study of 55 men and women age 60–71 years reported even lower ankle ROM, with plantar flexion averaging 38° and dorsiflexion only 8° (Brown & Holloszy, 1991).

Several cross-sectional studies with small sample sizes, high attrition rates, or insufficient description of measurement techniques were not included in this review because they might not be valid representations of the older population. Definitive longitudinal studies of chronological aging influences on ROM in the

Table 10 Ankle Dorsiflexion (°) by Gender and Age Group (*N* = 214)

Age group (years)	Men	Women
55–60	20.0 ± 4.0	20.7 ± 4.8
61–65	19.4 ± 3.6	13.8 ± 3.8
66–70	15.7 ± 2.1	12.0 ± 5.5
71–75	13.8 ± 3.5	12.3 ± 3.6
76–80	13.1 ± 4.1	10.8 ± 4.8
81–85	13.5 ± 4.1	10.1 ± 5.2

Note. Effects for sex and age group were significant ($p < .001$). Adapted from Vandervoort et al., 1992.

major joints are lacking (ACSM, 1998b). The absence of such long-term data makes it difficult to critically determine the proportionate influences of physical activity versus sedentary lifestyle (disuse) on the cross-sectional observed age-related losses of ROM.

Flexibility-Training Investigations

Studies designed to improve joint ROM can be classified into two groups: general-exercise interventions (various combinations of calisthenics, aerobics, and strength training) and specific flexibility interventions (limited to stretch-training protocols). A brief review of both categories is provided with reference to older adults.

GENERAL-EXERCISE INTERVENTIONS

General-exercise interventions can be categorized into the following areas: dance/calisthenics, general fitness, calisthenics/stretch, water aerobics, aerobic/strength, and Tai Chi. Any attempt to generalize from the use of general-exercise conditioning is complicated by the fact that many such studies included stretching-type activities as part of their training regimen. Therefore, the independent training effects of the aerobic or strength conditioning on ROM changes cannot be well established (Hurley & Hagberg, 1998). Several studies that included only older participants are reviewed here.

Dance/Calisthenics. One of the better designed studies to test the influence of a general-exercise dance program on multiple ROM for six joints was reported in 1981 (Munns). Forty volunteer participants ranging in age from 65 to 88 years ($M = 71.8$) were assigned to either a control or an exercise group. The 20 exercise participants completed a general-exercise/dance routine in sitting, standing, and lying positions for 1 hr three times per week. All activity was specifically designed to enhance maximum ROM of all joints. After 12 weeks the following improvements in ROM (measured with a Leighton gravity goniometer) were reported: cervical flexion/extension 27.8%, shoulder abduction/adduction 8.3%, wrist flexion/extension 12.8%, trunk flexion/extension 26.9%, knee flexion/extension 11.6%, and ankle plantar/dorsiflexion 48.3%. All joint improvements as compared with controls were significant ($p < .001$), with controls showing decrements of 3.6–5.1% on six joint-ROM measures. The authors of this study did not indicate the gender of the 40 elderly participants.

Rikli and Edwards (1991) followed 21 women (57–85 years of age) over 3 years of an exercise intervention. The women participated in low-impact aerobic-dance-type routines designed to meet all of the ACSM exercise guidelines (ACSM, 1995) three times per week for approximately 1 hr per session. Shoulder ROM as measured by the back-scratch test improved by 0.22 cm ($p < .01$). The sit-and-reach measure for low back and hamstring flexibility improved by 1.4 cm at study completion but did not reach significance.

General Fitness. A popular fitness program for older adults termed "elderobics" was used twice weekly over a 2-year period to determine ROM changes in 22 women (67.0 ± 4.7 years old; Hubley-Kozey et al., 1995). The 1-hr sessions included a warm-up of low-intensity activity and stretching, aerobic walking and marching and unspecified strength activities, and a cool-down relaxation

Table 11 Joint ROM (°) Before and After Two Years of Exercise (*N* = 22 Women)

Measure	Initial	24 months
Hip flexion	89.7 ± 9.5	99.5 ± 12.8
Knee flexion	114.1 ± 5.9	123.1 ± 7.3*
Ankle dorsiflexion	14.7 ± 5.9	19.1 ± 4.5

Note. Adapted from Hubley-Kozey et al., 1995.
*$p < .025$.

period. Pre- and posttraining ROM values are exhibited in Table 11. The exercise-intervention improvements in joint ROM for hip flexion (7%), knee flexion (7.8%), and ankle dorsiflexion (29%) were impressive. It should be noted that 10 of the women had initial preintervention dorsiflexion-ROM values less than 10°. By study conclusion, all of them exceeded the average dorsiflexion angular-displacement standard of 12° established by biomechanical analysis of level walking (Winter, Patla, Frank, & Watt, 1990).

Calisthenics/Stretch. A low-intensity exercise program that combined conventional slow stretching procedures with calisthenics was designed to improve general strength, muscle endurance, and flexibility in 55 men and women ranging in age from 60 to 71 years (Brown & Holloszy, 1991). The supervised exercise program lasted for 1 hr per session over a 3-month period, with compliance averaging 4.7 days per week. All activities were designed to gradually improve strength (without overload resistance), muscle endurance (repetitions were gradually increased to a maximum of 12), and flexibility (all movements emphasized maximum ROM). Results showed significant improvement ($p < .05$) in sit-and-reach (6.4 cm), hamstring (8°), and hip internal rotation (8°), and passive hip-flexor stiffness (resting hip flexion) was reduced from preintervention (–14°) to postintervention (9°). Ankle plantar flexion and dorsiflexion were unchanged.

Water Aerobics. Water-based aerobics was compared with land-based low-impact aerobic dance in a group of women 65–75 years old. The 45-min exercise sessions were conducted three times per week for 12 weeks (Taunton et al., 1996). Preintervention and postintervention trunk flexion measured by a standard sit-and-reach test showed virtually no change, even though 7 min of each training session were devoted to balance and flexibility activities (which were not described in any detail).

Aerobics/Strength. Morey et al. (1991) examined the effects of 2 years of supervised exercise (three times per week for 90 min) with 36 men 65–74 years of age. Exercise training consisted of a combination of stretching, calisthenics, stationary cycling, and strength activities (dumbbells and hydraulic resistance machines). Hamstring ROM measured by protractor goniometry improved 11% (from 57.5° ± 15.1 to 64.0° ± 11.1; $p < .02$).

Tai Chi. A more recent and innovative study examined the influence of 12 months of Tai Chi training (average attendance 1.3 sessions per week) on several fitness parameters with 18 men and women 58–70 years of age (Lan, Lai, Chen, & Wong, 1998). The mean increase (21%) in trunk (spinal) flexion of 11.0° measured with an electronic goniometer was significantly different ($p < .001$) from controls, who actually showed a small decrease in the same ROM.

Strength Training. The research issue of using overload strength training to improve flexibility for any age group is unresolved, particularly for older participants (ACSM, 1998b; Hurley & Hagberg, 1998). Much of the dilemma in sorting out the various study results is a result of inclusion of stretching activities in the warm-up component of the strength-training regimens, thus making it impossible to determine specificity of training effects. In addition, control conditions for the ROM variables were often lacking because the primary focus of these studies was on strength changes. Studies conducted with younger participants, however, generally support the contention that strength-training programs that emphasized complete ROM during overload execution did not have any deleterious effects on flexibility and, in some cases, actually showed small gains (Adams, O'Shea, & O'Shea, 1999; Alter, 1996; Wilmore et al., 1978).

One study partially addressed this strength-training research issue with older adults. Forty-six women, age 65–87 years, were randomly assigned to an aerobic program with light ankle and wrist weights, an aerobic program with no weights, or a control group (Raab, Agre, McAdam, & Smith, 1988). After 25 weeks of exercise (three times per week for 60 min), there were significant improvements in goniometry measures of ankle plantar flexion and shoulder flexion and abduction for both exercise groups as compared with the controls. The only difference between the two exercise groups was a twofold greater increase in shoulder abduction (11.8° vs. 4.8°) for the non-weight-users. Unfortunately, many of the exercise routines used by both groups included deliberate, active and passive stretching-type maneuvers, thereby confounding the interpretation of results from a specificity perspective. Because strength training plays such a critical role in improving and maintaining physical functions in the elderly, there is a need to determine the precise interactive effects of overload training with alterations in ROM.

SPECIFIC FLEXIBILITY INTERVENTIONS

There are very limited studies of isolated stretching interventions with older populations (ACSM, 1998b). Therefore, the few available studies are provided in some detail following.

Stretch/Balance. The earliest reported study of specialized stretching methods to improve ROM in 15 older women (71–91 years) was conducted with nursing-home residents (Frekany & Leslie, 1975). Stretching and balance-training sessions lasted for 30 min twice a week for 7 months. Exercises were selected to improve flexibility in the upper and lower extremities, including the ankles and feet, as well as the vertebral column and chest. Less emphasis was given to activities (unspecified) for improving muscle tone and balance. Measures of low back/hamstring ROM (sit and reach) and ankle flexibility (degrees difference between maximum dorsiflexion and plantar flexion) improved significantly. Low back/hamstring

ROM improved 1.0 in. ($p < .01$), and ankle flexibility, 8.8° ($p < .05$). Test–retest reliability was reported for the sit-and-reach, .98 (pre) and .99 (post), but not for ankle testing. Only mean measurement values were reported, so no estimations of variability could be analyzed.

Rhythmic Stretch. Another study of specificity stretching effects was conducted with 8 men and 22 women ranging in age from 61 to 85 years (75 ± 8.0; Lesser, 1978). These volunteers participated in 30-min sessions of rhythmic exercise twice per week for 10 weeks. The activity routines were completed in a seated or standing position and were designed to maximize ROM in all the major joints. They included approximately 10 min of individual stretching for all body joints, followed by 20 min of routines stressing posture and breathing, as well as ballistic arm swings, leg kicks, and full-body bend stretches. The author reported statistically significant improvement in degrees of ROM ($p < .05$) for shoulder flexion, elbow flexion, wrist flexion/extension, hip extension, knee flexion, and ankle plantar/dorsiflexion. No changes in ROM occurred for hip flexion, knee extension, and shoulder extension. The study results were presented subjectively without pre–post means or variability measures.

An excellent research design was used to determine the effects of 7 months of seated and standing calisthenics-type rhythmic ROM movements to musical accompaniment on spinal flexion, knee flexion, and knee extension in frail nursing-home patients (McMurdo & Rennie, 1993). Forty-nine resident volunteers age 64–91 years were assigned to either exercise or control. Participants engaged in twice-weekly exercise sessions of 45 min duration. The sitting movement protocols were designed to achieve full ROM of the upper and lower limbs. As the study progressed, repetitions were increased with fewer rest intervals. At completion of the study, exercise patients showed no change in knee flexion/extension ROM (degrees), but spinal flexion (measured linearly) improved by 7% ($p < .001$). Also, scores for grip strength, chair-to-stand time, ADL (Barthel Index), and self-ratings of depression all showed significant improvement.

Stretch Only. Only two studies were identified that used a purely active stretch-training intervention with some older participants. A volunteer group of 30 men and women (20–60 years of age) was divided into equal groups for experimental or control (no exercise; Germain & Blair, 1983). Experimental participants underwent daily stretch sessions of seven-repetition shoulder flexion for 4 weeks. No indication of stretch duration was provided. Pre–post measures of shoulder flexion by the same investigator showed an increase of 5.61 ± 6.05° in the exercise group, and the between-groups difference was significant ($p < .05$). The authors reported no gender-specific data, but it should be noted that the mean ages of the experimental and control groups were 34.4 and 34.8 years, respectively (no *SD*s were listed).

A very well-controlled examination of specialized stretch training was conducted with a group of 20 elderly women (71.8 years) who were assigned to either a control or an experimental group (stretch training) for 10 weeks (Rider & Daly, 1991). Supervised flexibility training (3 days/week) consisted of sit-and-reach maneuvers, knee tucks to the chest (supine), pelvic lifts (supine), and back-extension excursions (prone). All stretches were held for 10 s with three repetitions, and training sessions lasted from 30 to 40 min. Pretraining to posttraining improvements for spinal flexion (sit-and-reach test) and extension (prone hyperextension) of 4.21 cm (25%) and 7.17 cm (40%), respectively, were significant ($p < .05$), as contrasted with controls, who demonstrated little or no improvement.

Findings and Discussion

This review included 19 sets of cross-sectional data that compared younger and older adults' joint ROM, some of which analyzed gender distinctions. In addition, the literature relating ROM with physical functions of older adults was summarized. The last section of this review contrasted eight studies of general-exercise intervention with five studies of specialized stretch intervention, all directed at elderly populations. Based on analysis of the findings of these investigations and the related synopsis of aging-physiology literature as it relates to human-joint ROM, the following findings are warranted.

Multidimensional mechanisms of musculoskeletal and soft-tissue modifications related to aging processes contribute to significant decrements in neuromuscular function and joint ROM. These modifications are directly related to the development of postural syndromes, physical impairments, and related changes in physical functions, mobility, and QOL. These degenerative aging changes are exacerbated by disuse and the increased incidence of osteoporosis, osteoarthritis, and arthrosclerosis (joint stiffness) among older adults.

Significant decreases in joint ROM appear to be associated with increases in chronological age. Apparently, however, there are some joint-specific factors operative in this regard. If cross-sectional data are truly reflective of aging-related changes, spinal extension decreases about 50% between the second and seventh decades (Einkauf et al., 1987), whereas hip extension decreases about 20% and knee flexion only 2% during the same general time frame (Roach & Miles, 1991). Comparatively, shoulder flexion decreases 25% from peak ROM at about 10 years of age to the age of 70 (Germain & Blair, 1983). These decrements in age-related flexibility are difficult to interpret because of the lack of information regarding their interactive effects with the observed proclivity for being sedentary of older adults.

One study attempted to associate levels of physical activity (questionnaire on frequency and duration of leisure activities) and 28 ROM measures in the upper and lower extremities of 60 men and women age 60–84 years (Walker et al., 1994). No significant differences in ROM were found between participants with self-reported high activity levels and those with low activity levels. Also, the differential findings regarding proportional changes in ROM with aging might to some extent reflect participant-selection bias. With few exceptions, the cross-sectional studies that were reviewed did not use random methods, and oftentimes volunteer participants were recruited from community senior centers. Until longitudinal research has been conducted attempting to link periodic assessment of physical activity levels with aging-related changes in joint ROM, no clear predictions can be made regarding the precise relationship between flexibility and chronological age. Nonetheless, the preponderance of evidence suggests that the general adult population will, on average, experience aging-related loss of joint ROM that will affect to some degree their physical functioning.

The variability in older adult ROM is high, as it is with younger populations, and presumably reflects the recognized individualization of the aging processes, as well as disuse and other lifestyle differences. For example, at age 50 the standard deviation for men's and women's shoulder flexion is 7.22°, which by age 70 is 16.9° (Germain & Blair, 1983). Women's ankle dorsiflexion, which is critical for maintaining normal walking gait, decreases 50% from the fifth to the eighth decade (Vandervoort et al., 1992), but closer examination reveals that for these women in their 80s, the mean dorsiflexion value of only 10.1° has a standard deviation of 5.2°. Analyses of normal-gait walking in older adults suggest that about 12° of dorsiflexion is necessary for efficient locomotion (Winter et al., 1990). More in-depth research is required to explain these large variances and determine appropriate intervention programs for the most inflexible of these adults.

There are significant gender differences for major-joint ROM, with women registering better performance in almost all age-group studies. These gender differences are quite apparent in the cross-sectional studies of hamstring (sit-and-reach) and general shoulder ROM (scratch test; Golding , 1997; Osness et al., 1996; Rikli & Jones, 1999b). Nonetheless, these differences appear to be somewhat modulated in the older age groups. For example, ankle dorsiflexion is slightly higher for women at age 60, but thereafter the rate of decline in ROM is much higher, so that by age 76 this measure is 17% higher for men than for women (Vandervoort et al., 1992). Also, by age 65 men's shoulder abduction is significantly better than that of their female counterparts, and this difference is manifested beyond 75 years of age (Bassey et al., 1989). More research is needed with older adults to reveal what discrete lifestyle-pattern changes might be involved in these gender-specific ROM modifications. It does not seem plausible that purely aging-related gender differences are responsible for these discrepancies.

Decreased joint ROM is significantly involved in the development of musculoskeletal impairments and the progression of disabilities among the elderly. Undoubtedly, these flexibility changes are closely related to parallel loss of muscle strength, but this relationship has not been adequately studied. The study of arthritis patients by Badley et al. (1984) clearly defined the minimal ROM for both upper and lower extremities required for this population to execute basic ADL activities. Young (1986) also defined the functional shoulder-abduction/-adduction ROM critical for basic ADL performance by healthy older adults. More such studies are needed with elderly participants for clinical reference and to determine when intervention modalities are required. The most widely used orthopedic standards for all human-joint ROM are not age corrected and probably useful only as general references for clinical evaluation of the elderly (Cole, 1971; Heck et al., 1965; Norkin, 1985; Russe & Gerhardt, 1975). A 5-year study of changes in musculoskeletal function and subsequent risk for eventual disablement clearly showed that decrements in hand-ROM functions are closely related to reductions in basic ADL function (Jette et al., 1990). This finding probably reflects the fine motor coordination required for many of the basic ADL such as eating, bathing, and dressing. In contrast, progressive loss of instrumental ADL was associated with decrements in lower extremity ROM and strength. The latter finding most likely reflects the important role of the legs in arduous activities such as shopping, housekeeping, and driving. Results of this study were interpreted as showing that functional limitations (musculoskeletal impairments) precede the onset of disability, and not the other way around.

Morey et al. (1998) demonstrated the significant correlation of cardiorespiratory endurance (VO_{2max}), strength (ankle dorsiflexion and hip abduction), and flexibility (shoulder flexion, cervical flexion/extension/rotation, and spinal axial rotation) with self-report measures of difficulty with instrumental or advanced ADL, health and fall susceptibility, and a timed bed-mobility test. This study involved 161 older adults (72.5 + 5.1 years), and it was concluded that low fitness (which included specific-joint ROM) is a risk factor for functional decline, independent of disease processes. Credibility was added to these findings by the assessment of frail nursing-home residents whose composite scores for 12 upper and lower extremity ROM measures were significantly correlated ($r = .74, p < .001$) with clinical ratings of physical disability (Physical Disability Index; Gerety et al., 1993).

The most widely used functional fitness tests for older adults have provided very useful information regarding elderly ROM (Kim & Tanaka, 1995; Osness et al., 1996; Rikli & Jones, 1999b; Tanaka et al., 2000), and they have correlated these measures as part of a test battery with a variety of indices of physical function and life satisfaction. Most of these data, however, are oriented to low back-/hamstring- and general shoulder-ROM measures and to a lesser extent trunk extension. This review has delineated the need for a broader approach to include specific-joint measures that are directly related to basic and higher levels of physical function and mobility. This should include shoulder abduction/adduction, which needs to be maintained at a functional range of approximately 70–120° (Young, 1986). The critical role of ankle-dorsiflexion ROM (minimal threshold about 12°) and strength dictates the inclusion of this simple measure in routine evaluation of older adults' flexibility (Vandervoort et al., 1992; Winter et al., 1990). Because manipulative skills are required for many basic and instrumental ADL, better definition of wrist-, interphalangeal-, and metacarpophalangeal-ROM standards are needed (Badley et al., 1984; Jette et al., 1990).

In addition, much more attention needs to be directed at multiple measures of spinal and cervical ROM because of the high incidence of osteoarthritic and osteoporotic vertebral degeneration in older adults (Lindsey, 1998; Meisel & Bullough, 1984; Moskowitz, 1989). Several good research efforts have documented the significant decrease in both cervical- and spinal-ROM measures with aging—as much as 50% loss in spinal extension (Bell & Hoshizaki, 1981; Einkauf et al., 1987; Kuhlman, 1993). Morey et al. (1998) demonstrated the high factor loading of three cervical-ROM and spinal-axial-rotation (summary measure of left and right) measures with longitudinal development of physical disabilities. Loss of hip-extension ROM might be a significant factor in the shorter stride length, gait modifications, and reduced walking efficiency (mobility) of older adults (Murray et al., 1972; Winter, 1995). If the 50% reduction in hip extension between the third and sixth decades reported by Roach and Miles (1991) is a reasonable prediction, flexibility-intervention programs for the elderly should address this problem. Because the same researchers showed only a minimal difference in knee flexion between younger and older adults, this measure might not be as important. The exception would be adults with knee pathology, because toileting and going up and down stairs require a knee-flexion range of 70–110° (Badley et al., 1984).

Exercise-intervention studies that included various combinations of aerobic endurance, strength training, and specific stretch programs generally demonstrated quite positive effects on older adults' joint ROM, physical function, and QOL, including in the frail elderly (Frekany & Leslie, 1975; McMurdo & Rennie, 1993).

No investigations were identified that used a conventional strength overload-training program without some inclusion of ROM stretching activities. Thus, the potential benefits of such an intervention program to improve both strength and ROM in older adults are unknown. Because the general values of strength training for developing and maintaining physical well-being for older adults are widely recognized (Spirduso, 1995), such a research effort would be logical and significant. We hope that this article will generate interest in the pioneer study of well-controlled multiple-exercise interventions designed to improve older adult and frail elderly ROM. These research efforts should include specialized stretch protocols. New research efforts are needed to explore the use of stretch intervention with middle-aged and young-old populations to determine the potential preventive influences on age-related loss of joint ROM. This article did not include an analysis of the disparate ROM-measurement and flexibility-training regimens used with older adults.

Concluding Remarks

The results of cross-sectional research support the supposition that significant loss of joint ROM occurs between young adulthood and middle to old age, although no causal relationship has been established. The absence of longitudinal research precludes any determination of the differential influences of disuse syndrome versus purely aging-related changes in joint ROM. Aging-related changes in musculoskeletal tissue, as well as increased incidence of joint pathology, negatively affect joint extensibility and stiffness. Decreased flexibility in multiple anatomical sites is involved in the etiology of physical impairments and related disabilities among older adults. More specific measures of spinal and upper and lower extremity ROM are needed to delineate the minimal thresholds of movement required for ADL and maintenance of optimal mobility. The very limited research efforts on improving the general flexibility of older adults using specialized stretch protocols have produced small but encouraging results. Well-controlled studies of various exercise-intervention modalities should be initiated to specifically discriminate ROM versus strength or aerobic improvements in older adults, including the dependent frail elderly.

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