Sports Med 2000 Jan; 29 (1): 1-12
0112-1642/00/0001-0001/$20.00/0

Exercise, Mobility and Aging

Monica J. Daley[1] and *Warwick L. Spinks*[2]

1 Sports Science, Australian Institute of Sport, Canberra, Australian Capital Territory, Australia
2 Department of Human Movement Studies, University of Technology, Sydney, New South Wales, Australia

Abstract

The elderly population is growing both in size and in proportion of the total population. The costs to the community of the elderly being in poor health are also growing proportionately. The beneficial effects of exercise on various physiological and psychological parameters in the elderly have been well established. The effects of exercise on the mobility and independence of the elderly are also of primary concern, their maintenance being an important exercise goal. Impaired balance and gait are the 2 most significant risk factors for limited mobility and falls in the elderly. It is important to understand the effects of aging and exercise on these risk factors.

The population of elderly adults in Western societies is a growing one. Mean life expectancy has increased dramatically during the twentieth century, and it is expected that it will continue to increase. At the turn of the century in the US, males and females were expected to live to 46.6 and 49.1 years of age, respectively. In 1980 this had increased to 69.8 and 77.5 years, and by 2020 the projected mean life expectancy is 74.4 for males and 82.2 years for females. By 2040 the projected mean life expectancy for males and females is 75.0 and 83.1 years, respectively.[1,2] In Australia, life expectancy in 1971 was 68.0 for males and 74.4 for females. In 1981 this had increased to 71.1 years and 78.3 years for males and females, respectively, and in 1993 life expectancy had increased to 74.8 years and 80.8 years for males and females, respectively.[3]

With this increased mean age, the elderly population is growing as a proportion of the total population. Between 1985 and 2000, developed countries can expect an approximate 50% increase in the proportion of the population aged 65 years and over.[4] In the US, the elderly made up 4% of the population in 1900, 9.2% in 1960 and 12.4% in 1985, and in 2020 approximately 30% of the population will be aged 65 years and over. Between 1960 and 1980 alone, the population of the very old (85 years plus) increased by 140%.[5] It is anticipated that the number of very old people in the US will grow from approximately 4 million in 1999 to approximately 13 million by 2040.[2]

What will be the quality of these additional years of life? For freedom of movement and personal fulfillment, a certain level of functional independence is required. Maintenance of mobility is central to this issue.[6] For example, mobility problems in the aged may lead to falls which in turn, may result in hip fractures.[7-9] The risk of hip fractures increases after the age of 50 years. Approximately 20% of females who experience a hip fracture do not survive the first year post fracture, and another 20% do not regain the ability to walk without assistance, which often leads to institutionalisation.[1]

Forty percent of those aged 60 to 74 years or over have a chronic disorder that may result in some functional limitation, compared with 65% of people aged 75 years and over. Functional limitation is proportionally lower for females (38%) than males (48%) between 60 and 74 years of age, but is the same (65%) in the 75 years and over age group.[3] Of those aged 75 years and over, 7% are severely handicapped and 22% have a profound handicap, needing constant help with self-care, mobility and communication. Among people aged 75 years plus with a disability, almost 80% live in households, with 32% living alone.[3] Between the ages of 60 and 75 years there is a marked decrease in functional health. The most common disabling conditions are arthritis (24%), circulatory diseases (15%) and disorders of the ear and mastoid process (14%). Higher proportions of females (31%) than males (16%) suffer from arthritis.[3] The elderly have twice as many disabilities and 4 times as many physical limitations as people less than 65 years of age.[5] There is an obvious need for the health and mobility of the elderly to be maintained.

What will be the costs to society of these additional years? In 1985 the cost of nursing home care for the elderly in the US averaged $US23 600 per resident and totalled $US31.1 billion. This number is expected to increase 3- to 4-fold[1,2] by the year 2040, resulting in a significant cost to society. In Australia, only 9.4% of people aged 65 years and over live in a nonprivate dwelling such as a nursing home or retirement village.[3] However, the elderly in Australia are no healthier than their American counterparts and therefore require more at-home care.

It is estimated that the proportion of total health expenditure spent on people aged over 65 years in Australia will increase from 34% in 1990 to 52% in 2051. During this same period the total cost of health services is projected to rise from $A28.7 billion to $A126 billion. This represents an increase from 8.4 to 11.1% of the gross domestic product.[3] There is an obvious need to determine preventive measures to ensure the health of the elderly.

1. Exercise and the Elderly

In Australia, only 13% of males aged 60 to 69 years and about 12% of females the same age are vigorously active. For people aged between 70 and 78 years, 16% of males are vigorously active compared with only about 4% of females.[10] Factors influencing exercise participation patterns of the elderly include concerns about the appropriateness of physical exercise in old age,[11] the belief that exercise can be harmful, or at least not beneficial in preventing disease,[12] a lack of knowledge of appropriate exercise programmes,[13] as well as a perceived lack of physical ability.[5]

It has been suggested that people exercise less as they age because of the social-psychological process of age grading (‘act your age’).[14] As individuals over 40 years grow older they view exercise as increasingly inappropriate.[11] These beliefs need to be addressed so that the aging population can fully appreciate the benefits of exercise participation.

1.1 Benefits of Exercise

Older individuals require a level of fitness to: (i) enable the conduct of daily activities without undue fatigue; (ii) develop a reserve of energy for pleasure; (iii) make a faster and more complete recovery after debilitating illness; (iv) minimise the risks of future ill health; and (v) promote a sense of personal well-being and zest for living.[15]

Regular exercise benefits older adults through improved overall health and physical fitness, increased opportunities for social contacts, gains in cerebral function, lower rates of mortality and fewer years of disability in latter life.[4,16-20] Exercise is effective in reversing or at least slowing certain age related declines in motor and cognitive performance.[21-24] While independence in daily living is believed to be the most important goal for the elderly,[25] exercise is recognised as a major factor influencing independence through the maintenance of mobility.[6,18,26,27]

1.2 Disuse and Aging

The declines associated with advancing age are not only attributed to the aging process. The work capacity of the average sedentary person has been shown to decline by 30% between the ages of 30 and 70 years, with disuse believed to account for about 50% of this decline and aging the other 50%.[28] Others have concluded that physiological changes result from age associated cardiac hypertrophy and/or decreased levels of physical conditioning.[29] However, it has also been claimed that the reduced function of the major organ systems during aging is the result of disuse, enabling the physiology of 'aging' to be redefined as the physiology of 'disuse'.[30] Skeletal muscle is perhaps the most responsive in terms of adaptations to changes in chronic patterns of use.[31] It follows that disuse would account for a large part of strength changes with aging, considering the overall decreased level of activity in the aged population.[32] Also, after 40 years of age bone mass decreases with increasing age. However, suppression of physical activity also leads to bone loss, with exercise reversing the process of aging to a degree.[33]

A progressive decline in physical activity is observed with increasing age.[32,34] Since there has been no conspicuous increase in the number of elderly people engaging in regular exercise, it is reasonable to conclude that the elderly today will experience declines associated with both aging and disuse. The relative impacts of the aging process are outlined in section 2.

2. Age-Related Effects

2.1 Physiological Factors

The anthropometry of the elderly differs from that of young adults.[1,35] Those aged between 65 and 74 years are approximately 3% shorter than those aged 18 to 24 years. Elderly males are slightly lighter than their younger counterparts, and elderly females are approximately 11% heavier than young females.[36] These differences result from both secular trends in the population and biological changes inherent in the aging process, including a flattening of the intervertebral discs and vertebral bodies and changes in kyphosis leading to a reduction in height.[1,37] Gender differences in bodyweight in the elderly reflect disparate rates of body fat accumulation, muscle mass loss, bone density reduction and basal metabolic rate decreases.[37-39]

Morphological changes in the cardiovascular system associated with increased age include increased vascular stiffness, endothelial cell degeneration, increased left ventricular thickness, increased circumference of cardiac valves and thicker aorta and arterial tree.[37,40,41] Mechanical changes include lengthened contraction duration and increased refractory period, decreased vascular tone and decreased dilation of arterioles to the stimulus of physical activity. Increased left ventricular thickness corresponds to increases in systolic blood pressure.[37,40] Physiological changes include decreased responsiveness of cardiovascular tissues to beta-adrenergic stimulation. This results in lower heart rates at submaximal and maximal work loads and decreased arterial vasodilation. While the resting heart rate of the elderly remains essentially the same, a decline in the maximal attainable heart rate occurs.[29,37]

Postural (orthostatic) hypotension, resulting from shifts in body fluid volumes,[42] can lead to problems with static and dynamic balance possibly linking it to the increased incidence in falls among the elderly.[5] Along with a reduction in blood volume, postural hypotension can lead to thromboembolic phenomenon and myocardial infarction, which are serious health problems in elderly people.[43]

The capacity of elderly people to undertake aerobic activities such as walking and running is adversely affected by advancing age,[44] there being a decline in maximal oxygen uptake ($\dot{V}O_{2max}$) amounting to 0.5 to 1.0% per year.[3] In healthy, sedentary individuals $\dot{V}O_{2max}$ decreases to 1.3 L/min for females and 2.0 L/min for males from 25 to 85 years of age.[45] Those over 75 years of age generally have a $\dot{V}O_{2max}$ of 7 to 14 ml/kg/min (2 to 4 METS), and those under 75 years can attain a $\dot{V}O_{2max}$ of 17.5 to 24.5 ml/kg/min (5 to 7 METS). However, the 'athletic-old' have been reported to obtain $\dot{V}O_{2max}$ values of over 35 ml/kg/min (10 METS).[5] Peak oxygen uptake (VO_{2peak}) has been found to predict ability to perform activities of daily living (ADL), such as transferring from a bed to a chair, using the toilet, dressing, bathing, preparing meals and walking, in healthy older women.[46]

Cardiovascular function and aerobic demand are dependent on body composition, amongst other factors.[47] Research has focused on changes in body fat, lean body mass and subcomponents of lean body mass including protein, mineral and body water in the aged.[48] Lean body mass decreases 15 to 30% by 80 years of age.[49] Total body water declines in males at about 0.3 kg/y after 30 years and 0.7 kg/y after 70 years in females.[50] Adipose tissue accumulates (primarily in the truncal region) with increased age leading to a net gain in body weight[51] and increased risk of a number of health disorders including type 2 (noninsulin-dependent) diabetes mellitus, hypertension and atherosclerosis.[47]

The immune system undergoes significant adverse changes with advancing age with the decline in immunocompetence believed to be linked to the increased incidence of malignancy, infectious disease and autoimmune disorders.[52] Failures of the immune system may result in physiological and metabolic imbalances, leaving older individuals vulnerable to disease. For example, an unbalanced immune system may result in reduced glucose tolerance and elevated blood glucose concentrations which increase the risk of coronary heart disease.[4]

The respiratory system also undergoes several changes with aging. There is a decrease in cilia activity within the bronchi, allowing for an accumulation of pulmonary secretions and between the ages of 30 and 70 years, maximum lung capacity diminishes by up to 50%.[43] Residual volume increases 30 to 50% and vital capacity decreases 40 to 50% by the age of 70 years.[28] Due to a loss of pulmonary connective tissue elasticity, maximal ventilation is also reduced during exercise in elderly individuals. Lung weight is some 21% lower in older adults, thus decreasing functional capacity further.[53] Although these changes make ventilation more difficult, they do not impose any major problems in delivering oxygen to the working muscles. This process has been found to be more dependent on peripheral and cardiovascular function.[5]

The central nervous system (CNS) and peripheral nervous system (PNS) undergo several age-related changes. Corticol atrophy and a decline in neurotransmitter levels occurs in the CNS. Brain weight decreases by about 20% between 45 and 85 years of age primarily because of a loss of fluid rather than nerve cells.[53] There is a progressive decline in cerebral blood flow compromising brain metabolism,[43] and nerve conduction velocity slows by 10 to 15%, causing voluntary motor movement to slow and reduced reaction time.[30] The simple reaction times of old adults are approximately 20% longer than in young adults.[1] However, while age and reaction time show a positive linear correlation, the correlation coefficients range from only 0.19 to 0.47.[54] Despite the low to moderate nature of these correlation coefficients, the delay in motor and sensory nerve conduction in the PNS is thought to be the major reason for the 35 to 40% increase in falls seen among persons aged 60 years and over.[55]

The senses of sight, hearing and taste are also affected by advancing age. Common visual diseases include cataracts, macular degeneration, glaucoma and diabetic retinopathy. Hearing and vestibular function diminish with age, with approximately 90% of nursing home residents and 30% of the noninstitutionalised having a significant hearing impairment.[53] The loss in vestibular function, because of loss of hair in the crista ampullaris or inside the semicircular canals of the inner ear, leads to a loss in balance and may also contribute to the high rate of falls among elderly people.[5]

2.2 Biomechanical Factors

There is a decrease in the size of individual muscles with aging, particularly beyond 60 years of age.[30] Muscle strength and mass decline 30 to 50% between the ages of 30 to 80 years, with the loss of muscle mass accounting for most of the observed loss of strength.[56,57] The loss of muscle tissue is due to a decrease in number of muscle fibres and atrophy of type II muscle fibres.[30,56,58] A 26% reduction in the size of type II fibres from age 20 to 80 years is seen as being responsible for a large proportion of the age-related loss of muscle mass.[58,59] This reduction is not uniform, with longitudinal research[57] indicating that there are negligible differences in muscle fibre composition between 69 and 76 years of age, followed by a significant reduction in the proportion of type II fibres from 76 to 80 years of age. The most important factor in muscle atrophy in elderly individuals is the reduction in the number of type II fibres and not the size of the fibre area. Muscle fibre reduction commences around 25 years of age, with the total fibre number decreasing by 39% by the age of 80 years.[57,58,60,61] Muscle mass loss is subordinate to age-related denervation of the type II fibres which removes the trophic effect on the fibres, leading to atrophy. Type I muscle fibre collaterals expand to some of the denervated type II fibres in an attempt to lessen fibre loss. This leads to an increase in type I motor neuron units at the expense of type II fibres resulting in smaller and weaker muscles.[38,57]

With age there is a decrease in muscle strength that seems to parallel the reduction in muscle mass, even though the force generating capacity of contractile material is unaltered.[4,30] Skeletal muscle is considered the most responsive in terms of adaptation to changes in chronic patterns of use.[31] Therefore, reduced skeletal muscle strength is marked in the elderly. For example, handgrip strength is reduced by 25 to 30% between the age of 30 and 70 years.[28]

The rate of decline of muscle mass and muscle strength is relatively slow from 20 to 50 years of age, but is marked between 50 and 60 years,[30] and is greater in females.[25] Older females show 25 to 54% lower peak power and torque.[62] By the age of 65 years, males have experienced a strength loss of approximately 20%.[63]

With aging, the process of resorption and redeposition of bone is slowed which, together with an age-related decrease in total body calcium, weakens bone.[30] After the age of 40 years, bone mass decreases with increasing age.[33,64] The initial rate of corticol bone loss approximates 0.3 to 0.5% per year. This loss is accelerated in postmenopausal females to a rate of 2 to 3% per year for the first year or two and then slows exponentially.[30] Females over 35 years of age lose bone mass at a rate of approximately 1% per year, while trabecular bone loss over adult life is at a higher rate (1.2% per year) than that of corticol bone.[65] Bone involution poses a serious health risk, particularly for aging females.[25] Thus, an important goal for the elderly is to maintain and/or slow down the rate of bone loss.[4,64]

Irregular shape, tighter meshing and decreased linear pull in collagen tissue leads to decreased flexibility with aging. The combination of collagen changes and reduced water content results in a decrease in vertebral disc size and a more inflexible spine.[66] Degenerative changes in the elastin component of connective tissue can also lead to a loss of mobility and stability in the joints.[53]

Decreased range of motion (ROM) of joints and increased joint stiffness occur with aging.[67] There is a significant relationship between the ability to move around in one's environment and ROM in knee flexion, the ability to bend down and hip flexion ROM, and the ability to undertake activities requiring the use of hands and arms and ROM of the upper extremities.[1] The ROM of lower extremity joints in elderly adults has been shown to decline in a range from negligible to 57% when compared with younger population norms.[68] In healthy females, various ROMs of the lumbar spine decline by 25 to 50% from 20 to 80 years of age.[69] However, between 65 and 80 years of age there are no significant differences in the ROM of a range of 28 joints.[70]

2.3 Mobility Impairment

Functional dependence is one of the most serious health problems encountered by elderly people.[23,27,67] Reduced muscular strength and muscle mass are associated with increased frailty, an increased risk of falls and eventual inability to perform ADL tasks other than walking which are essential for self care.[2,46,70,71] Consequently, physical mobility is an important goal for elderly people.[25,27,72]

Of noninstitutionalised individuals aged 65 years and over in the US, 12.9% have been found to have difficulty with at least one ADL. Difficulty with walking affects 7.7% and difficulty with bed and chair transfers affects 5.9%. The rate of difficulty increases progressively after the age of 65 years, rising sharply in the 80s to reach 34.5% in non-institutionalised people aged over 85 years. Females have higher rates of ADL limitation than males at all ages.[73] Several factors affect the mobility of an individual, and the most important of these are balance and gait.[74,75]

2.4 Balance

Standing postural sway is more pronounced in elderly individuals[75-77] than in those aged 16 to 59 years who are able to accurately control random changes in the centre of gravity. Those aged from 6 to 14 years and 60 to 80 years have great difficulty in controlling such shifts. This is particularly noticeable in the aged in stressful situations such as in leaning forward.[78]

Balance times for those less than 30 years of age is some 22 seconds, whereas those over 70 years can balance for no more than 13 seconds.[79] Young adults exhibit sway excursions but compensatory responses return the centre of mass to normal before balance is lost. Fifty percent of older adults are sufficiently destabilised to require assistance in balancing. However, on repeated trials older adults show similar adaptational abilities to young adults.[80]

Cutaneous and proprioceptive sensation thresholds, particularly in the lower extremities, increase with age from a mean of 2.5mμ in young adults (aged under 45 years) to 19mμ in aging adults (aged 65 to 95 years), reducing the perception of vibration at the ankle joint.[81,82] Since the ankle joint is a major source of receptors controlling posture, this loss would be expected to decrease balance control considerably and act as a primary contributor to gait dysfunction in elderly people.[80]

2.5 Gait

A slowing of gait, caused mainly by a prolongation of the stance and double support phases of the gait cycle, is commonly reported in elderly individuals.[80] The prolongation of the stance phase is believed to be a strategy designed to obtain increased postural stability at the cost of a reduction in kinetic efficiency.[83]

Males over 67 years of age spend a significantly longer time in the stance phase and a significantly shorter time in the swing phase than younger males.[84] After age 62 the rate of decline in speed of walking increases from 2.5 and 4.5% in males and females, respectively, to 16 and 12% per decade.[85] Changes in gait speed range from 143 to 160 cm/s in younger adults compared with 118 to 145 cm/s in older adults.[86,87] The evidence for increased stride width is equivocal.[84,88]

Stride length is significantly impaired in elderly people.[89,90] Stride length ranges from 151 to 170cm in younger populations to 135 to 153cm in older populations.[91] Decreased step and stride length and ambulatory velocity are apparent in elderly male nursing home residents[34] and elderly females.[26] The gait of hospitalised fallers differs from other elderly, showing a large variability in step length, a wide range of stepping frequency, a narrow stride width, short step length and slow speed.[83] While the natural walking velocity of the elderly is significantly reduced, this reduction is not due to a decrease in cadence but rather to a reduction in stride length.[92,93] In contrast, absolute temporal characteristics of gait do not appear to differ with age. Stride time values do not vary between young and old adults.[84,87,91]

Males change their speed of walking by altering their step length only, whereas females alter step length and frequency as they age.[85] In healthy elderly adults aged 60 to 75 years, females have a shorter stride length (117.4cm) and gait cycle duration (1.13 seconds) than males. Percentage stance time (62.0%), stance time (0.70 seconds) and velocity (104.1 cm/s) are also different.[94] Increased peak hip flexion in the elderly may be an unconscious precaution against tripping or an attempt to maintain stride length.[91] Increased ankle dorsiflexion and decreased ankle plantar flexion are also common in elderly individuals.[84,91]

2.6 Falls

Impairment of gait and balance may diminish an individual's ability to cope with environmental hazards, leading to falls.[95] The incidence of falls is known to increase with age,[9,96] there being a 35 to 40% increase in falls in people over 60 years of age.[97] The figure is higher for females.[5] In the US, falling is the leading cause of fatal injury in people over the age of 70 years.[98,99] Death rates from falls per 100 000 persons in 1984 were 1.5 for those aged younger than 65 years, and 147.0 for those 85 years of age or over.[1] Of those aged over 65 years, 20% experience a serious fall each year[25,95] and 30% experience a fall of some magnitude.[100] Serious injuries, such as hip and other bone fractures, result in 10 to 15% of falls.[74,101] Thirty two percent of institutionalised people aged 75 years plus fall at least once and of these 24% sustain serious injuries and more than 5% experience fractures.[74,102] Among elderly people, falls account for 87% of all fractures.[1]

Risk factors associated with falls include dementia, visual impairment, neurological and musculoskeletal disabilities, postural hypotension, medication, fear of falling and environmental hazards.[74,95,100] However, muscle weakness, impaired gait and diminished balance are the most significant risk factors for falling.[8,34,71,75,93] Some aspects of locomotion (ie. initiation of walking, turning, stopping) are implicated in almost all falls.[92] The risk of falling increases linearly with the number of abnormalities possessed.[103] Many of the risk factors for falling also contribute to immobility and functional decline.[64,98,100] As well as decreased physical function, the fear of falling adds to decreased mobility and increased functional dependence, possibly as an attempt to prevent future falls.[100,101,104,105]

3. Exercise-Related Effects

Vertebrate tissues and organs develop an adaptive increase in functional capacity in response to increased use, which runs counter to the changes that occur with age. On the other hand, lack of activity results in a decrease in cardiovascular conditioning, exercise capacity, disuse atrophy and, in some cases, loss of cells.[106] The following outlines the effects of exercise on the physiological, biomechanical and mobility characteristics of elderly individuals.

3.1 Physiological Factors

There is strong evidence that the decline in exercise capacity often observed in the elderly is neither inevitable nor, once developed, permanent. Exercise provides several physiological benefits for elderly participants.[6,23,29]

Endurance exercise of 6 months duration lowers blood pressure in 70- to 79-year-old males and females with mild to moderate high blood pressure compared with no exercise and resistance training. Resistance training leads to an increase in heart rate and decrease in stroke volume at rest after training, and endurance training leads to a decrease in heart rate.[70] Regular endurance exercise reduces systolic blood pressure by 5 to 10mm Hg in non-hypertensive individuals[107] and lowers resting heart rate and the risk of cardiovascular events.[108] Regular activity limits lower-extremity oedema resulting from an increase in lymphatic and venous return. Lower extremity exercise can improve capillary flow and increase collateral circulation, leading to improved overall systemic circulation.[107]

Exercise can also reduce the incidence of hypertension, hyperlipidemia, obesity, type 2 diabetes mellitus, impaired glucose tolerance and stroke.[4,70] The long term benefits of endurance exercise include reduced mortality risk from coronary heart disease (CHD), improved weight control, lower blood pressure, increased aerobic fitness, improved cholesterol levels and prolonged life expectancy up to 2 years.[25,108,109]

Healthy males in their 50s who exercise vigorously on a regular basis have a $\dot{V}O_{2max}$ 20 to 30% higher than young, sedentary males. Middle-aged and old masters athletes who train in endurance events have a $\dot{V}O_{2max}$ 50% or more above that of ex-athletes of the same age who have stopped training.[106] Masters athletes exhibit fitness levels comparable to individuals who are 30 to 50 years younger and demonstrate reduced heart rate, reduced lactate production and reduced perceived exertion at a given VO_2.[4,25]

Highly active elderly females have up to 67% greater aerobic power than sedentary individuals their own age. Physical activity has a profound influence on the immune system with fit, healthy, relatively lean elderly females retaining superior natural killer cell and T cell function.[52] Active elderly people also demonstrate an elevated immune response and a reduced risk of cancer.[25]

Major determining factors for CHD are body composition and distribution of adipose tissue. It is well documented that exercise, with a controlled diet, is effective in reducing fat levels.[13] Changes in fat free mass vary from –8% to +30% after 8 weeks of endurance exercise in males and females aged 86 to 96 years of age.[110] High levels of endurance exercise are associated with a reduced accumulation of adipose tissue.[111] The greatest benefits occur in the truncal region, the area of greatest concern for health disorders including hypertension and artherosclerosis.[47]

3.2 Biomechanical Factors

Exercise may have the potential to slow the age related deterioration in structure and function of skeletal muscles and the skeletal system, including bones, tendons and ligaments.[8,106,112] The trainability of skeletal muscle appears unaffected by age,[4,56,37] and strength loss is modifiable in the oldest members of the population.[113,114] Strength training of varied duration and intensity has been shown to increase strength by 174 to 180%,[110] 28 to 115%[114,115] and 107 to 226%[116] in males and females 60 to 90+ years. Muscle mass has also been shown to increase by 11.4 to 15%.[110,116] A return to a sedentary lifestyle leads to a 32% loss in muscle strength and decreased muscle mass.[110]

Along with decreasing muscle mass, osteoporosis is a problem amongst older adults, in particular amongst females. Moderate exercise can retard the progress of this disease[64,117] with more active individuals experiencing fewer fractures than those who are sedentary.[5] While regular physical activity does contribute to bone health in elderly individuals, bone mass is reduced in the absence of normal menstrual function.[30] However, bone disturbances associated with amenorrhoea are less severe in the active compared with inactive individuals.[33] Active individuals are also more flexible than the inactive,[118,119] particularly in relation to ROM of the hip, spine, ankle and knee.[32,67,99]

3.3 Mobility Impairment

Lack of exercise is an independent predictor of mobility decline, and mobility decline is related to increased risk of falling.[105] Exercise training programmes enhance the functional independence of elderly people through increased mobility.[17,25,56,110] Resistance training increases muscular strength and muscle mass, resulting in improved gait characteristics and enhanced ADL performance.[110,114,120] Elderly exercisers also possess better motor control and coordination than their sedentary counterparts.[26]

3.4 Balance

Older females who exercise demonstrate less postural sway than sedentary females.[121] The more active the individual, the less the degree of postural sway.[32] Older females who have participated in vigorous activity for periods ranging from 6 weeks to 10 years or more possess better balance than inactive females of the same age.[122] Strength and balance training have been shown to be effective in improving balance.[123-127] However, other studies have failed to demonstrate any significant effects of exercise on balance in the elderly.[7,34,99,112,128] Balance control is a very complex behaviour and the beneficial effects of exercise interventions may be a function of individual postural control deficits and the type of exercise intervention adopted.[129]

3.5 Gait

Calf strength, step-score, hours spent in active leisure and height are positively related to walking speed in the elderly, while age, the presence of leg pain and the presence of a health problem are negatively related to walking speed. Age is not a significant factor when calf strength or step-score have been accounted for and active leisure hours correlate significantly with step-score. Therefore, exercise training aimed at strengthening leg muscles and encouraging walking might be worthwhile in improving walking speed in elderly individuals.[125,130]

Strength training and aerobic exercise have been shown to significantly improve left-sided stride length, left gait velocity and average stride length and velocity in elderly males.[34] However, exercise does not influence speed of walking in elderly individuals except at a very slow pace. Also, exercise-related improvement in hip extension ROM and trunk flexor muscle performance does not correspond with improvements in gait economy, and there are no significant differences in gait characteristics and ankle joint flexibility between low and high energy groups of elderly volunteers.[131,132] While long term (5 years) exercise has been shown to improve hip flexion and hip rotation in women aged 50 to 71 years,[67] a shorter period (1 year) of low intensity exercise failed to demonstrate significant differences in gait measures between exercisers and nonexercisers amongst community dwelling older women.[112] Similarly, 8 weeks of resistance training has been shown to have no effect on locomotor stability, preferred gait velocity and step time in community dwelling older adults.[133] However, when gait training is combined with a strength training protocol, gait measures are significantly improved beyond improvements achieved by strength training alone.[125] Limited literature exists concerning the effects of exercise and physical fitness on gait in elderly people. Considering the importance of gait to the mobility of an individual, and the importance of mobility to elderly people, further research is warranted.

3.6 Falls

Falls, especially noninjury falls, are preventable.[8,95] Adjustments in medication, behavioural instructions and exercise programmes reduce the risk of falling,[71,100,128,129] as well as the need for medical attention following a fall.[112] However, while there is evidence that endurance, strength, and balance training promote mobility and reduce fall risk, exercise intervention effects differ according to the exercise protocol, the type of exercise and the postural control characteristics of the older adults under investigation.[8,129,134] The identification of individuals at risk of falling is an important issue.[129]

4. Acute Exercise

The majority of recent research on the physiology, biomechanics and mobility of elderly individuals has been derived from research on the effects of habitual or long term exercise programmes (6 weeks or more). Little is known of the effect of acute or short term exercise bouts on these parameters. Short term benefits of exercise include significant and same-day improvement in flexibility, elevated alertness and cognitive function, stress reduction and better sleep. Acute exercise may lead to significant interactions of biochemical and physiological mechanisms that may lead to enhanced psychological perceptions of increased coping and relaxation.[25] Gait economy has also been shown to significantly improve after a single bout of stretching.[135]

5. Conclusions

Physiological changes in elderly individuals include reduced stature, decreased cardiovascular function, increased risk and occurrence of cardiovascular disease, elevated blood pressure, reduced aerobic function, decreased fat free body mass, increased levels of adipose tissue, decreased immune function, decreased maximal lung capacity and maximal ventilation, diminished senses, cortical atrophy and decreased neurotransmitter levels. Biomechanical changes include decreased muscle size and strength, a slowing of the resorption and redeposition of bone and tightened ligaments and tendons leading to reduction in joint ROM and flexibility. Changes in mobility include reduced muscle strength and impairment of balance and gait leading to an increased risk of falling. Gait changes include slowing of gait and a decrease in stride length.

The reported benefits of exercise to elderly individuals focus primarily on physiological and musculoskeletal factors. Exercise is known to slow the decline in several factors mentioned above and, in some cases, to reverse the aging process. Exercise can aid in cardiovascular function, maintaining healthy blood pressure, developing aerobic function, decreasing immunocompetence, developing the strength and size of muscle and bone, and increasing flexibility and joint ROM. Research on the effect of exercise on the mobility (balance and gait) of elderly individuals has been more limited. Mobility is central to the issue of independence in elderly people and, while research indicates that exercise may be beneficial, more investigations are necessary.

References

1. Schultz AB. Mobility impairment in the elderly: challenges for biomechanics research. J Biomech 1992; 25: 519-28
2. Martin PE, Grabiner MD. Aging, exercise, and the predisposition to falling. J Appl Biomech 1999; 15: 52-5
3. Australian Bureau of Statistics and Social Policy Directorate. Older people in New South Wales: a profile. Sydney: Australian Government Publishing Service, 1995
4. Åstrand P-O. Why exercise? Med Sci Sports Exerc 1992: 24: 153-62
5. Rimmer JH. Fitness and rehabilitation programs for special populations. Madison (WI): Brown & Benchmark, 1994
6. Campanelli LC. Mobility changes in older adults: implications for practitioners. J Aging Phys Act 1996; 4: 105-18
7. Judge JO, Lindsey C, Underwood M, et al. Balance improvements in older women: effects of exercise training. Phys Ther 1993; 73: 254-62
8. Buchner DM. Preserving mobility in older adults. West J Med 1997; 167: 258-64
9. Hayes WC, Myers ER, Robinovitch SN, et al. Etiology and prevention of age-related hip fractures. Bone 1996; 18: 77-86S
10. Department of the Environment, Sport and Territories. Active and inactive Australians: assessing and understanding levels of physical activity. Canberra: Australian Government Publishing Service, 1995
11. Ostrow A, Dzewaltowski D. 'Older adults' perceptions of physical activity participation based on age-role and sex-role appropriateness. Res Q Exerc Sport 1986; 57: 67-169
12. Prohaska TR, Leventhal EA, Leventhal H, et al. Health practices and illness cognition in young, middle-aged and elderly adults. J Gerontol 1985; 40: 569-78
13. Barry HC, Rich BSE, Carlson RT. How exercise can benefit older patients: a practical approach. Physician Sports Med 1993; 21: 124-41
14. Ostrow A, Jones D, Spiker D. Age role expectations and sex role expectations for selected sport activities. Res Q Exerc Sport 1981; 52: 216-27
15. National Health and Medical Research Council. Exercise and the older person: series on clinical management problems in the elderly. No. 2. Canberra: Australian Government Publishing Service, 1994
16. Shephard RJ. The scientific basis of exercise prescribing for the very old. Physician Sports Med 1990; 11: 91-101
17. Seeman TE, Berkman LF, Charpentier PA, et al. Behavioural and psychosocial predictors of physical performance: Macarthur studies of successful aging. J Gerontol 1995; 50: M177-83
18. Strawbridge WJ, Cohen RD, Shema SJ, et al. Successful aging: predictors and associated activities. Am J Epidemiol 1996; 144: 135-41
19. Sandvik L, Erikssen J, Thaulow E, et al. Physical fitness as a predictor of mortality among healthy, middle-aged Norwegian men. N Engl J Med 1998; 338: 533-7
20. Vita AJ, Terry RB, Hubert HB, et al. Aging, health risks, and cumulative disability. N Engl J Med 1998; 338: 1035-41
21. Chodzko-Zajko WJ. Physical fitness, cognitive performance, and aging. Med Sci Sports Exerc 1991; 23: 868-72
22. Rogers RL, Meyer JS, Mortel KF. After reaching retirement age physical activity sustains cerebral perfusion and cognition. J Am Geriatr Soc 1991; 38: 123-8
23. La Croix AZ, Newton KM, Leveille SG, et al. Healthy aging: a women's issue. West J Med 1997; 167; 220-32
24. Buckwalter JA. Decreased mobility in the elderly: the exercise antidote. Physician Sports Med 1997; 25: 126-8, 130-3
25. O'Brien SJ, Vertinsky PA. Elderly women, exercise and healthy aging. J Women Aging 1990; 2: 41-65
26. Leiper CI, Craik RL. Relationships between physical activity and temporal distance characteristics of walking in elderly women. Phys Ther 1991; 71: 791-803
27. Ho SC, Woo J, Yuen YK, et al. Predictors of mobility decline: the Hong Kong old-old study. J Gerontol 1997; 52: M356-62
28. Smith EL, Gilligan C. Physical activity prescription for the older adult. Physician Sports Med 1983; 11: 91-101
29. Van Camp SP, Boyer JL. Cardiovascular aspects of aging (1). Physician Sports Med 1989; 17: 120-30
30. Wilmore JH. The aging of bone and muscle. Clin Sports Med 1991; 10: 231-44
31. Booth FW, Gollnick PD. Effect of disuse on the structure and function of skeletal muscle. Med Sci Sports Exerc 1983; 15: 415-20
32. Voorrips LE, Lemmink KAPM, Van Heuvelen MJG, et al. The physical condition of elderly women differing in habitual physical activity. Med Sci Sports Exerc 1993; 25: 1152-7
33. Schoutens A, Laurent E, Poortmans JR. Effects of inactivity and exercise on bone. Sports Med 1989; 7: 71-81
34. Sauvage, LR, Myklebust BM, Crow-Pan J, et al. A clinical trial of strengthening and aerobic exercise to improve gait and balance in elderly male nursing home residents. Am J Phys Med Rehab 1992; 71: 333-42
35. Kelly PL, Kroemer KHE. Anthropometry of the elderly: status and recommendations. Hum Factors 1990; 32: 571-95
36. Stoudt H. The anthropometry of the elderly. Hum Factors 1981; 23: 29-37
37. Spidurso WW. Physical dimensions of aging. Champaign (IL): Human Kinetics, 1995
38. Kirkendall DT, Garrett WE. The effects of aging and training on skeletal muscle. Am J Sports Med 1998; 26: 598-602
39. Williams M. Human development and aging. In: Roitman JL, editor. ACSM resource manual for guidelines for exercise testing and prescription. 3rd ed. Baltimore (MD): Williams & Wilkins, 1998: 501-6
40. Marin J. Age-related changes in vascular responses: a review. Mech Ageing Dev 1995; 79: 71-114
41. Susic D. Hypertension, aging, and atherosclerosis: the endothelial interface. Med Clin North Am 1997; 81: 12-31
42. Bortz WM. Disuse and aging. JAMA 1982; 248: 1203-8
43. Blocker WP. Maintaining functional independence by mobilizing the aged. Geriatrics 1992; 47: 42-56
44. Martin PE, Morgan DW. Biomechanical considerations for economical walking and running. Med Sci Sports Exerc 1992; 24: 467-73

45. Åstrand P-O. Exercise physiology and its role in disease prevention and in rehabilitation. Arch Phys Med Rehabil 1987; 68: 305-9
46. Posner JD, McCully KK, Landsberg LA, et al. Physical determinants of independence in mature women. Arch Phys Med Rehabil 1995; 76: 373-80
47. Depres JP, Moorjani S, Lupien PJ, et al. Regional distribution of body fat, plasma lipoproteins and cardiovascular disease. Artherosclerosis 1990; 10: 497-511
48. Scott B, Going DP, Lohman TG, et al. Aging, body composition and physical activity: a review. J Aging Phys Act 1994; 2: 38-66
49. Frontera WR, Hughes VA, Lutz KJ, et al. A cross-sectional study of muscle strength and mass in 45 to 78-year-old men and women. J Appl Physiol 1991; 71: 644-50
50. Schoeller DA. Changes in total body water with age. Am J Clin Nutr 1989; 50: 1176-81
51. Enzu G, Gasparo M, Biondetti PR, et al. Subcutaneous and visceral fat distribution according to sex, age, and overweight, evaluated by computed tomography. Am J Clin Nutr 1986; 44: 739-46
52. Nieman DC, Henson DA, Gusewitch G, et al. Physical activity and immune function in elderly women. Med Sci Sports Exerc 1993; 25: 823-31
53. Berman R, Haxby JV, Pomerantz RS. Physiology of aging, part 1: normal changes. Patient Care 1988; 22: 20-36
54. Salthouse TA. Speed of behaviour and its implications for cognition. In: Birren JE, Schaie KW, editors. Handbook of the psychology of aging. New York (NY): Van Nostrand, 1985: 400-26
55. Vandervoort A, Hill K, Sandrin M, et al. Mobility impairment and falling in the elderly. Physiother Can 1990; 42: 99-107
56. Frischknecht R. Effect of training on muscle strength and motor function in the elderly. Rep Nutr Dev 1998; 38: 167-74
57. Aniansson A, Grimby G, Hedberg M. Compensatory muscle fiber hypertrophy in elderly men. J Appl Physiol 1992; 73: 812-6
58. Lexell J, Taylor CC, Sjostrom M. What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. J Neurol Sci 1988; 84: 275-94
59. Lexell J, Downham D. What is the effect of ageing on type 2 muscle fibres? J Neurol Sci 1992; 107: 250-1
60. Lexell J, Downham D, Sjostram M. Distribution of different fibre types in human skeletal muscles: fibre type arrangement in m. vastus lateralis from three groups of healthy men between 15 and 83 years. J Neurol Sci 1998; 72: 211-22
61. Lexell J, Henriksson-Larsen K, Winblad B, et al. Distribution of different fibre types in human skeletal muscles: effects of aging studied in whole muscle cross sections. Muscle Nerve 1983; 6: 588-95
62. Vandervoort A, Kramer JF, Wharram ER. Eccentric knee strength of elderly females. J Gerontol 1990; 45: 125-8
63. Larsson L, Grimby G, Karlsson J. Muscle strength and speed of movement in relation to age and muscle morphology. J Appl Physiol 1979; 6: 451-6
64. Silver JJ, Einhorn TA. Osteoporosis and aging: current update. Clin Orthop Relat Res 1995; 316: 10-20
65. Riggs BL, Wahner HW, Melton LJ. Rates of bone loss in the axial and appendicular skeletons of women: evidence of substantial vertebral bone loss prior to menopause. J Clin Invest 1986; 77: 1487-91
66. Lewis CB. Musculoskeletal changes with age. Clin Manage Phys Ther 1984; 4: 12-5
67. Misner JE, Massey BH, Bemben M, et al. Long-term effects of exercise on the range of motion of aging women. J Orthop Sport Phys Ther 1992; 16: 37-42
68. Walker JM, Sue D, Miles-Elkousy N, et al. Active mobility of the extremities in older subjects. Phys Ther 1984; 64: 919-23
69. Einkauf D, Gohdes ML, Jensen GM, et al. Changes in spinal mobility with increasing age in women. Phys Ther 1987; 67: 370-5
70. Cononie CG, Graves JE, Pollock ML, et al. Effect of exercise training on blood pressure in 70-to-79-yr-old men and women. Med Sci Sports Exerc 1991; 23: 505-11
71. Schwender KI, Mikesky AE, Holt WS, et al. Differences in muscle endurance and recovery between fallers and nonfallers and between young and older women. J Gerontol 1997; 52: M155-60
72. Davies MJ, Dalsky GP. Economy of mobility in older adults. J Orthop Sports Phys Ther 1997; 26: 69-72
73. Schultz AB. Mobility impairment in the elderly: challenges for biomechanics research. J Biomech 1990; 25: 519-28
74. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med 1988; 319: 1701-7
75. Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. J Gerontol 1994; 49: M72-84
76. Era P, Heikkinen E. Postural sway during standing and unexpected disturbance of balance in random samples of men of different ages. J Gerontol 1985; 40: 287-95
77. Sheldon JH. The effect of age on the control of sway. Gerontol Clin 1963; 5: 129-38
78. Hasselkus BR, Shambes GM. Aging and postural sway in women. J Gerontol 1975; 30: 661-7
79. Bohannon RW, Larkin PA, Cook AC, et al. Decrease in timed balance test score with aging. Phys Ther 1984; 64: 1067-70
80. Woollacott MH. Gait and postural control in the aging adult. In: Bles W, Brandt TH, editors. Disorders of posture and gait. Amsterdam: Elsevier, 1986: 325-36
81. Birren JE. Vibratory sensitivity in the aged. J Gerontol 1974; 2: 267-8
82. Brocklehurst JC, Robertson D, James-Groom P. Clinical correlates of sway in old age-sensory modalities. Age Ageing 1982; 11: 1-10
83. Guimaraes RM, Isaacs B. Characteristics of the gait in old people who fall. Int Rehabil Med 1980; 2: 177-80
84. Murray MP, Kory RC, Clarkson BH. Walking patterns in healthy old men. J Gerontol 1969; 24: 169-78
85. Himann JE, Cunningham DA, Rechnitzer PA, et al. Age-related changes in speed of walking. Med Sci Sports Exerc 1988; 20: 161-6
86. Hageman PA, Blanke DJ. Comparison of gait of young women and elderly women. Phys Ther 1986; 66: 1382-7
87. Murray MP, Kory RC, Sepic SB. Walking patterns of normal women. Arch Phys Med Rehabil 1970; 50: 140-6
88. Heitmenn DK, Gossman MR, Shaddeau SA, et al. Balance performance and step width in noninstitutionalized, elderly, female fallers and nonfallers. Phys Ther 1989; 69: 923/43-931/51
89. Wolfson L, Whipple R, Amerman P, et al. Gait assessment in the elderly: a gait abnormality rating scale and its relation to falls. J Gerontol 1990; 45: M12-9
90. Visser H. Gait and balance in senile dementia of Alzheimer's type. Age Ageing 1983; 12: 296-301
91. Ostrosky KM, VanSwearingen JM, Burdett RG, et al. A comparison of gait in young and old subjects. Phys Ther 1994; 74: 637-44
92. Winter DA, Patla AE, Frank JS, et al. Biomechanical walking pattern changes in the fit and healthy elderly. Phys Ther 1990; 70: 340-7

93. Baumann JU. Gait changes in elderly people [in German]. Orthopade 1994; 23: 6-9
94. Myklebust BM, Myklebust J, Prieto T, et al. Changes in kinematic gait parameters in healthy aging subjects. In: Woollacott MH, Horak F, editors. Posture and gait: control mechanisms. Proceedings of the XIth International Symposium of the Society for Postural and Gait Research; 1992 May 24-27; Portland (OR). Portland (OR): University of Oregon Books, 1992: 295-7
95. Hornbrook MC, Stevens VJ, Wingfield DJ, et al. Preventing falls among community dwelling older persons: results from a randomized trial. Gerontologist 1994; 34: 16-23
96. Quail GC. An approach to the assessment of falls in the elderly. Aust Fam Physician 1994; 23: 873, 876-82
97. Overstall PW, Exton-Smith AN, Imms FJ, et al. Falls in the elderly related to postural imbalance. BMJ 1977; 1: 261-4
98. Jensen RK, Fletcher P. Body segment moments of inertia of the elderly. J Appl Biomech 1993; 9: 287-305
99. Mills EM. The effect of low-intensity aerobic exercise on muscle strength, flexibility, and balance among sedentary elderly persons. Nurs Res 1994; 43: 207-11
100. Tinetti ME, Baker DI, McAvay G, et al. A multifactorial intervention to reduce the risk of falling among elderly people living in the community. N Engl J Med 1994; 331: 821-7
101. Tinetti ME, Williams CS. The effect of falls and fall injuries on functioning in community-dwelling older persons. J Gerontol 1998; 53A: M112-9
102. Tinetti ME, Speechley M. Prevention of falls among the elderly. N Engl J Med 1989; 320: 1055-9
103. Tinetti ME. Performance-oriented assessment of mobility problems in elderly patients. J Am Geriatr Soc 1986; 34: 119-26
104. Maki BE. Gait changes in older adults: predictors of falls or indicators of fear? J Am Gerontol Soc 1997; 45: 313-20
105. Snow CM. Exercise effects on falls in frail elderly: focus on strength. J Appl Biomech 1999; 15: 84-91
106. Holloszy JO. Exercise, health, and aging: a need for more information. Med Sci Sports Exerc 1983; 15: 1-5
107. Ettinger WH, Evans WJ, Weindruch R, et al. Exercise for the elderly. Patient Care 1989; 23: 165-91
108. Limacher MC. Aging and cardiac function: influence of exercise. South Med J 1994; 87: S13-6
109. Heyden S, Fodor GJ. Does regular exercise prolong life expectancy? Sports Med 1988; 6: 63-71
110. Fiatarone MA, Marks EC, Ryan ND, et al. High-intensity strength training in nonagenarians: effects on skeletal muscle. JAMA 1990; 263: 3029-34
111. Kohrt WM, Malley MT, Dalsky W, et al. Body composition of healthy sedentary and trained, young and older men and women. Med Sci Sports Exerc 1992; 24: 832-7
112. MacRae PG, Feltner ME, Reinsch S. A 1-year exercise program for older women: effects on falls, injuries, and physical performance. J Aging Phys Act 1994; 2: 127-42
113. Chandler JM. Understanding the relationships between strength and mobility in frail older persons: a review of the literature. Top Geriatr Rehab 1996; 11: 20-37
114. Fiatarone MA, O'Neill EF, Ryan ND, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. N Engl J Med 1994; 330: 1769-75
115. Charette SL, McEvoy L, Pyka G, et al. Muscle hypertrophy response to resistance training in older women. J Appl Physiol 1991; 70: 1912-6
116. Frontera WR, Meredith CN, O'Reilly KP, et al. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. J Appl Physiol 1988; 64: 1038-44
117. Schilke JM. Slowing the aging process with physical activity. J Gerontol Nurs 1991; 17: 4-8
118. Germain NW, Blair SN. Variability of shoulder flexion with age, activity and sex. Am Correct Ther J 1983; 37: 156-60
119. Frekany G, Leslie D. Effects of an exercise program on selected flexibility measurements of senior citizens. Gerontology 1975; 15: 182-3
120. Chandler JM, Duncan PW, Kochersberger G, et al. Is lower extremity strength gain associated with improvements in physical performance and disability in frail, community dwelling elders? Arch Phys Med Rehabil 1998; 79: 24-30
121. Lord SR, Caplan GA, Ward JA. Balance, reaction time, and muscle strength in exercising and nonexercising older women: a pilot study. Arch Phys Med Rehabil 1993; 74: 837-9
122. Rikli R, Busch S. Motor performance of women as a function of age and physical activity level. J Gerontol 1986; 41: 645-9
123. Wolf SL, Barnhart HX, Ellison GL, et al. The effect of Tai Chi Quan and computerized balance training on postural stability in older subjects. Phys Ther 1997; 77: 371-81
124. Seidler RD, Martin PE. The effects of short term balance training on the postural control of older adults. Gait Post 1997; 6: 224-36
125. Verfaillie DF, Nichols JF, Turkel E, et al. Effects of resistance, balance, and gait training on reduction of risk factors leading to falls in elders. J Aging Phys Act 1997; 5: 213-28
126. Nichols JF, Hitzelberger LM, Sherman JG, et al. Effects of resistance training on muscular strength and functional abilities of community dwelling older adults. J Aging Phys Act 1995; 3: 238-50
127. Campbell AJ, Robertson MC, Gardner MM, et al. Randomized controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. BMJ 1997; 315: 1065-9
128. Buchner DM, Cress ME, de Lateur BJ, et al. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. J Gerontol 1997; 52: M218-24
129. Shupert CL, Horak FB. Adaptation of postural control in normal and pathologic aging: implications for fall prevention programs. J Appl Biomech 1999; 13: 64-74
130. Bendall MJ, Bassey EJ, Pearson MB. Factors affecting walking speed of elderly people. Age Ageing 1989; 18: 327-32
131. Godges JJ, MacRae PG, Engelke KA. Effects of exercise on hip range of motion, trunk muscle performance, and gait economy. Phys Ther 1993; 73: 57-66
132. Ronsky JL, Nigg BM, Fisher V. Correlation between physical activity and the gait characteristics and ankle joint flexibility of the elderly. Clin Biomech 1995; 10: 41-9
133. Berg WP, Lapp BA. The effect of a practical resistance training intervention on mobility in independent, community-dwelling older adults. J Aging Phys Act 1998; 6: 18-35
134. Owings TM, Pavol MJ, Foley KT, et al. Exercise: is it a solution to falls by older adults? J Appl Biomech 1999; 15: 56-63
135. Godges JJ, MacRae H, Longdon C, et al. The effects of two stretching procedures on hip range of motion and gait economy. J Orthop Sport Phys Ther 1989; 10: 350-7

Correspondence and reprints: Dr *Warwick L. Spinks*, Human Movement Studies, University of Technology, Sydney, PO Box 222, Lindfield, NSW 2070, Australia.
E-mail: Warwick.Spinks@uts.edu.au