WOMEN AND SPORT

SCIENTIFIC REPORT SERIES
ISSUE 2.4 • YEAR 2014

PHYSICAL FITNESS
I. MUSCLE STRENGTH
II. AEROBIC FITNESS: MUSCLE OXYGEN UPTAKE AND HEART RATE

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PUBLISHED BY SISU SPORT BOOKS IN COOPERATION WITH WORLD VILLAGE OF WOMAN SPORTS

PHYSICAL FITNESS

I. MUSCLE STRENGTH

II. AEROBIC FITNESS: MUSCLE OXYGEN UPTAKE AND HEART RATE

Eva Andersson

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SUMMARY

Improved muscle strength and aerobic fitness are of great importance in many sports and are also associated with increased life expectancy and a reduced incidence of a number of diseases. In this chapter, we will discuss some of the factors that influence muscle strength and aerobic fitness, including sex-related factors. The way physical fitness is measured is also important when making comparisons. An increased understanding of the assessment of strength and aerobic fitness may inspire fruitful improvements in practical test and training programs in various sport and health contexts.

Projektledning: SISU Idrottsböcker
Översättning: Leigh Findlay
Formgivning: Catharina Grahn, ProduGrafia
Omslagsfoto: Urszula Striner
ISBN: 978-91-87745-20-1

Take home messages:

- Fitness profiles among athletes of various ages and populations in different health contexts can help decide how muscle groups and physical capacities can be strengthened and trained. However, factors that influence performance outcomes—for example, age, sex, which muscle group is involved, and how measurements are made— must be taken into account.
- We hope that the information presented helps to further develop knowledge for accomplishing objectives such as increased athletic performance and better health.
- In adults, a smaller sex difference occurs in maximal oxygen uptake (VO2 max) when it is expressed relative to body mass (mL·kg-1·min-1), rather than as an absolute value (L·min-1).
- Sex differences in VO2 max are generally greatest among elite athletes, are somewhat less for regular athletes, and are least in a general population of young adults.
- Because an increased VO2 max is related to improved performance in many sports, to longer life and to a reduced incidence of many diseases, the results of the numerous studies presented above can be used to evaluate the performance of athletes in many sports and the health of common populations in various contexts.

I. MUSCLE STRENGTH

Factors such as how, when and in whom strength is measured directly affect test results.

Sex differences in muscle strength among adults

Absolute strength and strength relative to body mass and lean body mass

The maximal strength and/or force produced by normal adult women, in a comparison with that of men, is usually reported as (i) leg muscles about 60–80%, (ii) trunk muscles about 50–70%, and (iii) upper body about 40–65% of men's values, in absolute terms (i.e. not relative to body mass). These measurements are mostly made during maximal static or concentric actions, that is, when the muscle is shortened. Thus, the sex differences in absolute strength are generally reported as smallest in the leg muscles and greatest in the arm muscles. However, when maximal strength is expressed relative to body mass, the difference between the sexes decreases somewhat, and decreases even more when expressed relative to lean body mass (Table -1.1).

Table 1.1. The strength of women compared to that of men in absolute terms, relative to body mass and relative to lean body mass in various strength tests

Test/muscles tested	Absolute strength	Strength relative to body mass (absolute strength ÷ body mass)	Strength relative to lean body mass (absolute strength ÷ lean body mass)
Leg muscles	73–75%	92–96%	106–108%
Elbow flexion & handgrip	49–61%	62–77%	70–88%
Bench press	37–41%	46–52%	53–59%

Note: mean age = 20 years; leg and grip strength were measured with dynamometers; arm and shoulder strength were assessed by the 1 RM (i.e. one repetition maximum) technique using the curl and bench press. Based on data from Wilmore (1974)

In this data, the leg muscle strength of women and men relative to body mass is very similar, and is actually higher in women. Although the difference in upper body strength is somewhat reduced when expressed relative to total and lean body mass in untrained women and men, substantial differences remain. A possible contributing factor to this difference is that women have a higher percentage of their muscle mass in the legs than men do. In addition, the usage patterns of leg and arm muscles appear to favour the leg muscles in women.

In terms of muscle strength in the trunk, the female to male values in the general population are about 65–75% when expressed relative to body mass (in both static and concentric muscle contractions at various ages). The corresponding values for absolute strength in the trunk muscles are somewhat lower (50–70%), which means that the sex differences are higher in absolute terms. Elite female gymnasts have been shown to have a peak dynamic strength (relative to body mass) about 75% that of men. Thus, gymnastics training, which varies in character between the sexes, does not essentially alter the normal strength ratio between men and women in this sport. Other researchers have reported smaller sex differences in trained compared to untrained groups: female to male percentage in knee flexion strength (relative to body mass) was 90% in the trained group and 80% in a sedentary group; and in bench press, corresponding values were 75% and 69%, respectively. These results again show a larger sex difference in upper body strength than in lower body strength. With regard to muscle strength and back health in otherwise normal women and men, reduced strength of trunk extension is associated with low back pain.

Concentric versus eccentric strength

A study showed that the absolute strength of the knee extensor muscles during concentric strength testing was significantly different between adult women and men (female to male percentage: 68–71%). However, this was not the case (83–87%) with eccentric strength testing (i.e. testing an active muscle during lengthening) (Figure 1.1). Also, strength per kilogram body mass did not significantly differ between women and men in either concentric or eccentric measures. In both sexes, the activity of the knee extensor muscles was somewhat higher in maximal concentric tests than in eccentric tests, and was highest at the fastest concentric velocity. Furthermore, the eccentric to concentric strength ratio (in knee extensors, knee flexors and elbow flexors) is significantly higher in women than in men, and this difference is accentuated at higher velocities.

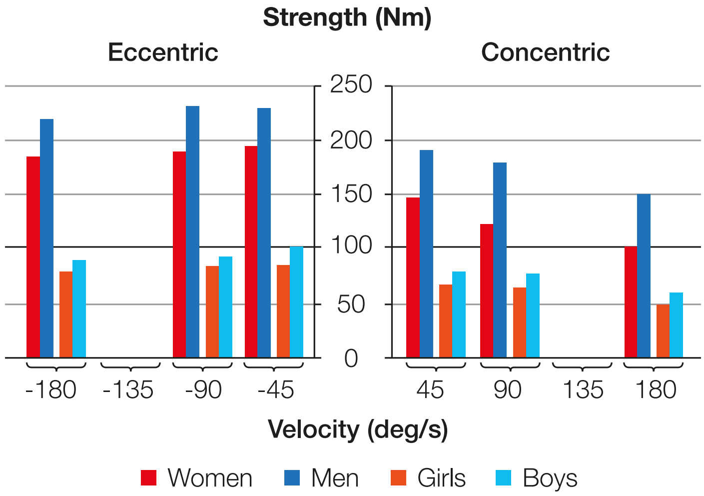

Figure 1.1. Mean strength at three velocities in maximal eccentric (lengthening) and concentric (shortening) knee extensor muscle actions. At each velocity (45, 90 and 180 degrees per second), the four groups of subjects are, from the left, adult women, adult men, pre-pubertal (11 year-old) girls and pre-pubertal (11 year-old) boys. The strength is expressed in Newton metres (Nm). The adult subjects were physical education students (22–35 years). Note that the children never exceeded a strength of 100 Nm (prepared from the data of Seger & Thorstensson, 1994).

Finally, with regard to thigh strength, at velocities approaching those of functional activities, the hamstring to quadriceps strength ratio (i.e. knee flexor to extensor ratio) was significantly lower in women than in men. In female collegiate athletes with particularly low values for these ratios, the incidence of injury to the anterior cruciate ligament in the knee is higher than the incidence in women with higher ratios. Similarly, pubertal and post-pubertal female athletes with low ratios may be at increased risk of injury.

Strength in athlete groups

Women football players (in the three highest divisions) showed significantly higher (about 10%) absolute concentric and eccentric strength in knee extension than did a control group. The difference was even greater for knee flexion (up to about 20%), with the largest difference at the highest concentric velocity. However, the absolute dynamic knee extension and flexion strength in a female control group and a group of cross country skiers were similar. Cross country skiing is an endurance sport, and the study measured instant peak strength, not endurance of the thigh muscles, which could account for the similar strength values. Likewise, the absolute static force of the extremities and the trunk were similar in older female cross country skiers and a reference group (moderately active female physiotherapy students). In contrast, these skiers had significantly greater strength relative to body mass (in the knee extensors and forearm flexors) than the reference group. However, standing trunk extension and trunk flexion strengths were similar.

Of the different types of female athletes tested, only female cyclists and weightlifters had significantly higher knee extensor force—both in absolute terms and relative to body mass—than that of the same reference group. Also, the female weightlifters were the only athlete group with significantly higher absolute strength in all measures (knee extensors, forearm flexors, trunk extensors and trunk flexors) than that of the reference group. Moreover, in the muscle groups tested, female weightlifters frequently, but not always, generated significantly higher forces than those of the other athlete groups. These results demonstrate that the strength profiles of women athletes can vary among sports.

Strength related to muscle cross-sectional area

Several studies have found no significant difference between women and men in various calculations of force or strength measured per unit of anatomical cross-sectional area in the muscles of the upper arm, thigh and lower back. However, a few investigations have found differences in thigh muscle strength: a lower force to cross-sectional area relationship for women than for men. This suggests that sex differences in absolute force or strength are often caused by differences in muscle mass among similarly matched groups (see also below). In certain evaluations, force per cross-sectional area is higher in trained than in untrained individuals of both sexes. Neuromuscular adaptations are one of the factors that possibly explain the increased contraction efficiency of the trained persons. When assessing strength performance, it is important that the antagonist muscles are not activated and that the agonist (co-operating) muscles are appropriately activated.

Women and men may respond to strength training in different ways; therefore, considering training status when assessing sex differences is also important. One study measured the cross-sectional area of an elbow flexor (m. biceps brachii, measured with magnetic resonance imaging) and the muscle strength (static elbow flexion via strain gauge, and in curl exercise via one repetition maximum) before and after 12 weeks of resistance training in 585 healthy individuals of both sexes. The participants had a mean age of 24 years, all were less than 40 years old, had no chronic medical conditions, and had not performed strength training of the arms within the prior 12 months. The relative increase in cross-sectional area was 20% for men and 18% for women—a very small, but significant, sex difference. In contrast, the women's relative increase in strength was higher than the men's increase, both for static elbow strength (22% vs 16%) and in curl exercise (64% vs 40%). These results suggest that the magnitude of the strength increase is influenced by the type of assessment. The researchers suggested that skill acquisition during training and increased experience with the exercises used may have affected the increase in relative strength. Different levels of untrained status between sexes may have also been a contributing factor.

Thus, the force per unit of muscle area can increase as a result of training. In addition to the increased anatomical cross-sectional area, other possible reasons for increased strength are: an even greater increase in the physiological cross-sectional area (i.e. perpendicular to the muscle fibres); changes in the pennation angle of the muscle fibres; changes in the electrical firing patterns in the nerves and the muscles; changes in the relative areas of the rapid, high-force type II muscle fibres and the slow, endurance–sustained-force type I fibres; changes in tendon attachment; or proliferation of connective tissue that can transmit force from intermediate points on the fibres to the tendons (cf. below).

Strength related to size-independent factors

Clearly, as children grow or mature, their strength increases. Both sexes improve their strength and muscle mass almost linearly in the pre-pubertal years. Boys and girls up to the age of 10–12 years show no significant difference in absolute muscular strength. From puberty in girls, the strength curve continues to rise slowly or, in some reports, even plateaus with increasing age. In contrast, boys' improvements in strength accelerate during puberty due to increased levels of the hormone testosterone.

Both adults and children can experience strength gains from resistance training without an increase in muscle bulk. Changes in innervation, muscle architecture and muscle contractile properties can cause these size-independent strength gains. Also, an increase in strength may be observed without any change in muscle cross-sectional area early in a program of strength training. Other researchers reported that this finding can be explained by the fact that a trained person can recruit more motor units for a contraction.[1]

Studies show that one consequence of strength training for adults is that, during a maximal effort, more signals occur in each motor unit. The maximum possible firing rate for each motor unit is generally lower in females than in males, and is especially so in older than in younger adults. Compared to young adults, elderly adults show higher relative increases in the firing frequencies of each motor unit after a period of strength training.

During a strength training program, the initial gain in strength in both sexes is mainly from neural factors. Thereafter, both neural factors and hypertrophy (i.e. muscle enlargement) combine to further increase strength, with hypertrophy becoming the dominant factor after the first 3–5 weeks of training. However, some studies have reported hypertrophy of whole muscle or type I and type II fibres after just 2 weeks.

Effects of strength training

What are the effects if concentric and eccentric strength training are performed separately? Untrained healthy women (mean age 20 years) participated in a heavy resistance training program for 10 weeks, 3 days per week. The average concentric and eccentric knee extensor strength increased by 18% and 13%, respectively, in the group only training with concentric muscle actions. Corresponding increases of 7% and 36% occurred in the eccentrically trained group, and the values for a control group without strength training were 5% and –2%. Thus, in this study, eccentric training is more effective than concentric training for developing eccentric strength, and vice versa. Cross-sectional area measured with magnetic resonance imaging increased significantly more with eccentric (6.6%) than with concentric training (5.0%). Neural activity patterns in the muscles also changed. Therefore,

1 A motor unit consists of one nerve and all the muscle fibres innervated by that nerve.

muscle hypertrophy and neural adaptations apparently contribute to strength increases from both concentric and eccentric training.

In addition to increasing their leg strength, women who perform heavy leg resistance training can increase the size of their type I muscle fibres and, especially, the size of their type II (IIA and IIX) fibres. The proportion of type IIA fibres also increases, while the proportion of type IIX fibres decreases, suggesting that strength training may lead to conversion of one fibre type to another. For example, these findings have been demonstrated in a 20-week training program, twice per week, in both physically active and sedentary young women.

Fitness versus functional performance

Is there any relationship between fitness measurements (such as strength and maximal oxygen uptake) and athletic performance? Among elite female ice hockey players, only off-ice fitness tests related to body mass appear to predict skating performance, including skating speed. This study also showed that skating performance was generally not significantly associated with the fitness variables for knee strength, either in absolute values or relative to lean body mass. Compared to a group of male hockey players (second division), the top female players had values between 62–65% of the absolute strength of the men, and a higher proportion when strength was related to body mass (74–78%). The same trends were seen for maximal oxygen uptake (VO_2 max), which is a measure of aerobic fitness (see Part II below). On the other hand, no sex differences occurred either in strength or VO_2 max when the values were divided by lean body mass. On-ice performance (including skating speed) was significantly lower in women than in men. The authors suggested that the skating performance of female hockey players may be improved by increasing their thigh muscle strength, relative muscle mass and oxygen uptake.

A review of research studies reported that female and male basketball players show a significant positive correlation between static strength and both counter movement jump and static jump. Other results for sprint swimmers of both sexes showed small, but significant, positive correlations between static strength (of the shoulder–arm complex in three positions) and average velocity in a 50-metre sprint. In contrast, others have found that knee extension and flexion tests in women skiers could not discriminate between national-level and college-level players. Likewise, three static upper-body tests specific to volleyball actions could not discriminate between beginners and more experienced players. Thus, it would seem that the size of any association between physiological measurements and athletic performance depends on the tests used and the sports players assessed.

The ability to generate high force at high velocity (i.e. power) is of value for both athletic performance and functional capacity. In healthy untrained women (21–29 years), a comparison was made between various laboratory and field tests intended to evaluate leg power. The study found that maximum power in the double leg press occurred between 56–78% of one repetition maximum. Also, power in the double leg press significantly correlated with maximal strength in one repetition maximum and with field tests for vertical jump, but not with time to run 40 yards or with maximal gait velocity. The authors suggested that strength is a key component for developing power and that the vertical jump is an appropriate field test for evaluating explosive leg power in young women. They recommended that training interventions (including development of power) should be evaluated for their effects on muscle power production. Further, investigations should address the functional importance of developed muscle power in athletic and non-athletic populations of different ages (see also below).

Training that includes various types of jumping and hopping exercises is called plyometric training and is a method of choice to improve vertical jump ability and leg muscle power in athletes and non-athletes of both sexes. Plyometric training has been shown to be better than 12 weeks of weight training in significantly increasing the height of various standardised jumps. In a study of the plantar flexor muscles in men (mean age 22 years), plyometric and weight training similarly increased strength and also muscle activity, but only in the concentric jumping phase. The plyometric training produced less increase in muscle volume (measured by magnetic resonance imaging) than did weight training, and less stiffness in the tendons, but more stiffness in the joints. Leg muscle power is considered a crucial element of daily activities, occupational tasks and general athletic performance, while vertical jump performance is vital for particular movements required in some sports.

Among first division female and male football players (18–23 years), a developed field test (distance in triple-hop on the same dominant limb) significantly correlated with concentric strength in the knee extensor and flexor muscles at various velocities, and with vertical jump height. Therefore, triple-hop distance might be a useful clinical test to predict an athlete's leg strength and power.

Muscle strength, endurance and fatigue

For the common static back endurance test (the Sorensen test), most studies have found significantly longer position-holding times in adult women than in adult men. For this test, the person holds the upper body in a horizontal prone position alongside a bench that supports the legs. Proposed reasons for the sex difference are that women have less weight in the upper body and that their centre of gravity in the trunk is lower than that of men. However, the most compelling hypothesis is that women have a significantly larger cross-sectional area of endurance–sustained-force type I muscle fibres in the back muscles (erector spinae), compared to the area of type II fibres, which are mostly used for rapid, high-force activities. However, the relative *number* of type I, type IIA and type IIX fibres is generally the same in both sexes. A low static endurance of the back muscles can be associated with low back pain in both sexes.

Also, a lower fatigability in the activity signals (frequency and amplitude) in the back muscles has been shown for women than for men when they statically extend the upper body while lying in a prone position with a bench supporting the legs. This resulted from the women having a smaller decrease in the firing frequency of the muscle fibres than did the men, and less variation in the patterns of signal amplitude that represent fatigue. Another interpretation of the physiological sex differences mentioned above is that increased endurance in women's back muscles is beneficial during pregnancy, when the spine is subjected to excessive load for an extended period of time.

Other static endurance tests for the abdominal and the hip flexor muscles have been used to compare muscle endurance in the sexes. In a static hip-flexion sit-up from a supine position (with the trunk elevated to a 60 degree angle and with flexed and supported legs), healthy women and men showed similar performance. However, in a test for static lateral supine position (i.e. supported on the lower arm with the feet side-by side), the men could hold the position longer than the women could. Furthermore, during repetitive concentric contractions for maximal knee extension in untrained young adults, similar fatigue patterns were seen in both sexes in terms of the relative decline of peak strength (Figure 1.2), work, mean power and muscle activity patterns, and of the increasing fatigue experienced. These results demonstrate that comparisons of endurance and fatigue outcomes in men and women vary, depending on the muscle groups examined and the measures used.

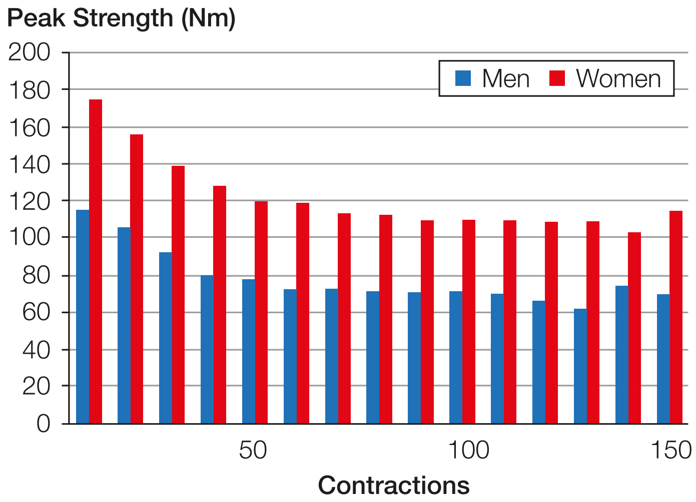

Figure 1.2. Peak strength in relation to the number of contractions in repetitive knee extension in male and female untrained subjects. The mean age of the subjects was 26 years. Strength, expressed in Newton metres (Nm) is shown for every 10th contraction (prepared from the data of Wretling & Henriksson-Larsén, 1987).

Strength and aging

A 65-year-old person can develop 75–80% of the strength produced when younger (20–30 years). From 30 to 80 years of age, strength declines in both sexes to about 70% of former levels in the arm muscles and to 60% of former levels in the leg and back muscles. Thus, elderly people generally maintain comparably higher strength in the upper body. Strength declines with aging in both sexes mainly because the number of motor neurons (i.e. nerves to the muscles that originate in the spinal cord) decreases with age. Consequently, the total muscle mass of older women and men is less than previously. In particular, the size of type II (fast-twitch) fibres decreases more than the size of type I (slow-twitch) fibres. These changes can be reversed to some extent with high-resistance strength training, even in very old individuals.

With aging in both sexes, the decrease in concentric strength is higher than that in eccentric strength. However, old women generally preserve a higher proportion of eccentric strength than men. Among moderately mobility-limited elderly people (over 70 years), improvements in leg power—independent of strength—apparently make a marked contribution to clinically meaningful improvements in various functional assessments, including gait speed. Strength and power in the legs is predictive of performance in the 6-minute walk test. Healthy men and women of the same age perform similarly in this distance test, whether they are old or young. In contrast, a distinct sex difference is present in measurements of maximal oxygen uptake. Knee extensor peak power in old women is increased more by a high-velocity resistance training program than by a traditional low-velocity program, whereas similar increases in strength occur with the two programs.

Furthermore, older subjects can substantially increase their strength, even with a smaller improvement in muscle mass, compared to the increases seen in young adults; however, the improvement in muscle mass is sometimes similar in older and younger adults. Therefore, a lesser hypertrophic response to resistance training should not preclude strength training in elderly people. Elderly adults performing resistance training markedly increase their muscle mass, strength and power; they can also perform daily tasks more easily, and improve their energy expenditure and body composition. Participation in an organised exercise program also promotes participation in spontaneous physical activity.

Body composition: Muscle, fat and body mass

Muscle mass accounts for 25–35% of body mass in non-obese women and 38–45% in men. The difference (men/women) in the proportion of body weight as muscle mass is greater in the upper body (140%) than in the legs (133%), meaning that women have proportionally more muscle mass in the lower than in the upper limbs. Sixteen-year-old female cross country skiers and non-active 16-year-old girls (of similar bodyweight and body mass index) significantly differ in their proportions of body fat (24% vs 34%), fat mass (15 kg vs 20 kg) and lean body mass (45 kg vs 37 kg). However, a greater percentage of bodyweight consists of fat in trained and untrained women compared to that of similarly trained men. For example, one study found that female and male university students (mean age 20 years), had mean weights of 58 kg and 73 kg, and relative fat masses of 25% and 13%, respectively. There also appears to be a much lower correlation between absolute strength and girth size in women than in men.

In healthy females 18–81 years old, the resting metabolic rate and fat-free mass (muscle mass is important in this measure) shows a curvilinear decline with age. The decreases are most marked in women over 50 years. These measures are also generally lower in women than in men. The decline in resting metabolic rate is mainly due to a reduction in fat-free mass, which is primarily related to differences in VO_2 max, age, leisure-time physical activity, and dietary protein intake.

Endurance exercise increases resting metabolic rate in elderly men and women. This increase is mediated by an increase in the activity of the sympathetic nervous system.[2] Several reports suggest that resistance training in older individuals also increases resting metabolic rate and basal sympathetic nervous system activity. Also, the decreased oxidation (i.e. metabolic use) of fat throughout the body seen with advancing age is linked to the age-associated decline in fat-free mass. Therefore, exercise programs that preserve fat-free mass and/or increase aerobic capacity may improve or maintain fat oxidation, and therefore reduce the tendency towards excessive weight gain in elderly people.

Bone mass, strength and muscle mass

Bone mineral density and content

These measurements are generally significantly higher in female athletes from various sports than in non-active female control subjects. Studies also show that strength and weightlifting activities apparently provide a more effective bone-generating stimulus than non-weight-bearing activities. For example, higher bone mineral content was observed in female

2 The sympathetic nervous system is a subdivision of the nervous system that is activated in stressful situations and prepares the body for strenuous physical activity.

runners, cross country skiers, football players, weightlifters, bodybuilders, orienteers, and basketball and volleyball players than in a control group. Female junior tennis players also showed a significantly higher bone mineral content in their playing arm than in their other arm, especially during the adolescent growth spurt. Similarly, female tennis players had higher bone content in both the dominant arm and the spine than did control subjects. However, female athletes in cycling and swimming had similar bone mineral content to that of non-active control women; this was also observed in dancers, rowers and cross country skiers. Sometimes, however, intense endurance training may be associated with loss of menstruation and decreased bone mineral content, especially in the spine in young women (see text by Lindén Hirschberg – From girl to woman).

Exercise in the pre-pubertal years probably favours increased bone density in later years, as shown in a study of active and retired female gymnasts and a control group. Because the benefits appear to be sustained into adulthood, exercise before puberty may reduce fracture risk after menopause. Bodyweight is an independent predictor of bone mineral density in the upper leg in healthy adults of both sexes and of all ages, and in the years beyond menopause in older women.

Muscle strength and bone mineral content and density

The relationship between muscle strength and bone mineral content and density is especially strong in female athletes aged 16–18 years and in non-active older women. The absolute knee extensor and flexor strengths are predictors of bone mineral density in the legs and spine, in both non-active women and cross country skiers (mean age 16 years). Although a generally strong relationship has been shown between thigh strength and bone mineral density in many sites in non-active control groups of women, this is not the case in female volleyball and football players. Thus, muscle strength per se may not be decisively important in increasing bone mass in high-activity female athletes. The relationship between strength and bone mass in athletes also appears to vanish when comparing the relationship in groups of active young athletes and somewhat older athletes.

Muscle-building exercise may increase bone mass in the upper leg in premenopausal women; knee extensor strength independently predicted bone mineral density in the upper leg in women who were still menstruating, but not in postmenopausal females. However, other researchers have found that hip flexor strength (both in absolute values and relative to body mass) independently predicted bone mineral density in the lumbar spine and upper thigh of older postmenopausal women. Older postmenopausal women also showed significant positive correlations between bone mineral density and hip abductor, knee extensor and grip strength in absolute values (but not relative to body mass). Thus, maintenance of strength in those muscle groups with anatomical or functional relationships to the hip and lower back may play a role in preventing or stopping a decrease in bone mass and density (i.e. osteoporosis). Furthermore, a decrease in the width of the deep hip flexor and lumbar muscles (m. psoas) has been demonstrated, beginning about 10 years before radiographic bone loss (osteoporosis) became apparent in females and males aged 55–84 years. A causal relationship between muscle and bone mass was suggested. Thus, muscle atrophy might be related to decreased bone mineral density and the development of osteoporosis.

Flexibility and muscle tendons

Sex differences in generalised body joint laxity have not been found in pre-pubertal children. However, during puberty and post-puberty, females have significantly higher joint mobility than males. Muscle tendons appear to hypertrophy (enlarge) in response to both long-term (years) and short-term (months) loading through physical activity. However, the short-term changes in tendon thickness were relatively small and only occurred at specific regions in the tendon.

Mechanical loading apparently induces changes not only in the overall tendon structure but also in the mechanical properties and the biochemical characteristics of the tendon tissue. Very high loading generally increases tendon stiffness, but the extent of adaptation is highly variable. Furthermore, evidence for a link between changes in the cross-sectional area of the tendons and increased stiffness is conflicting. The tendons adapt to mechanical loading by producing more collagen, a protein that increases tendon stiffness. With aging and disuse, tendon stiffness decreases, although resistance training can reduce the decrease. Healthy young women (mean age 26–27 years) had less stiffness in the tendon of the calf muscle than did similar men. Compared to men, women have also been shown to have a higher electromechanical delay (i.e. the time lag between the onset of muscle activity and tension in the muscle–tendon complex, to which muscle and tendon elasticity contribute).

II. AEROBIC FITNESS: MAXIMAL OXYGEN UPTAKE AND HEART RATE

Maximal oxygen uptake among athletes

Maximal oxygen uptake (VO_2 max) is used as a measure of aerobic fitness. It depends on the heart rate, the stroke volume (i.e. the volume of blood pumped out by the heart per beat) and the difference in oxygen content between the arteries and veins. In particular, endurance training improves the stroke volume and also increases the ability of the muscles to utilise oxygen for producing energy. The mean VO_2 max values and the comparative values for women and men among athletes belonging to some Swedish national teams are presented in Table 1.2. The authors who collected the data suggested that the highest values are naturally found in endurance sports because the maximal motor power produced from aerobic processes (which depends on the VO_2 max) is vital for good performance in these sports.

The comparative female:male percentage values for the athletes are generally higher (69–85%) when VO_2 max is expressed relative to body mass (i.e. per kg of body mass, $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) than in absolute terms ($L{\cdot}min^{-1}$; 53–74%). That is, the sex differences are smaller when VO_2 max is related to weight. Comparative values between women and men were more similar in non-athletes than in athletes, especially for VO_2 max relative to body mass. Some of the highest VO_2 max values (relative to body mass) reported to date are 77 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ and 94 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ for female and male cross country skiers, respectively, a sex difference in the same range as previously described.

Table 1.2. Mean maximal oxygen uptake and the comparative values for elite female and male athletes in a variety of sports

Sport	Women	Men	Comparison (%)[a]	Women	Men	Comparison (%)[a]
	VO_2 max ($L{\cdot}min^{-1}$)			VO_2 max ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)		
Cross country skiing	3.8	5.6	68	63	82	77
Orienteering	3.4	5.4	63	59	77	77
Swimming	3.2	5.0	64	57	67	85
400–800 m run	3.1	5.4	63	56	76	74
Speed skating	3.1	5.8	53	54	78	69
Alpine skiing	3.1	4.2	74	51	68	75
Ice hockey	2.8	4.8	58	45	56	82
Table tennis	2.4	3.8	63	44	59	75
Fencing	2.4	4.2	57	43	59	73
Archery	2.3	–	–	40	–	–
Non-athletes	2.2	3.1	71	39	43	91

Note: VO_2 max = maximal oxygen uptake; values are expressed in absolute terms in litres/minute ($L{\cdot}min^{-1}$) and relative to body weight in millilitres/kilogram/minute ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$). Prepared from the data from Saltin & Åstrand (1967, mean age 24 years), except for data on ice hockey players based on data from Gilenstam et al. (2011, mean age 24 years).
[a] comparative value = (female/male x 100)%.

Maximal oxygen uptake in young adults

In another young adult population, the female:male comparison for relative VO_2 max (mL·kg^{-1}·min^{-1}) was 103%, that is, similar levels between sexes, whereas in absolute terms (L·min^{-1}) the percentage was 79% (Table 1.3). In well-trained physical education students, the female:male percentages for VO_2 max were lower both in relation to body mass (80–83%) and in absolute terms (64–71%), compared to the values of the reference group (Table 1.3). However, the values of both measurements are often higher than those of elite athletes (see above). In summary, among young adults, sex differences in VO_2 max are generally more pronounced among elite athletes, followed by regular athletes, and are least—that is the sexes are more similar—in a general population (see also above).

Table 1.3. Mean maximal oxygen uptake in young women and men and comparative values in various populations

Population (20–33 years)	Women	Men	Comparison (%)[a]	Women	Men	Comparison (%)[a]	Data source
	VO_2 max (L·min^{-1})			VO_2 max (mL·kg^{-1}·min^{-1})			
Well trained	2.9	4.1	71	49	59	83	Åstrand & Ryhming (1954); Åstrand et al. (1997)
Physical education students	2.9	4.5	64	47	59	80	Andersson & Nilsson (2011)
Physical education students	2.7	4.2	64	43	52	83	Andersson et al. (2011)
Healthy people	2.2	4.2	52	40	52	77	Åstrand (1960)
Normal population	2.6	3.3	79	41	40	103	Ekblom et al. (2007)

Note: VO_2 max = maximal oxygen uptake; values are expressed in absolute terms in litres/minute (L·min^{-1}) and relative to body weight in millilitres/kilogram/minute (mL·kg^{-1}·min^{-1}).
[a] comparative value = (female/male x 100)%.

Maximal oxygen uptake in elderly people

At the age of 65 years, the mean absolute VO_2 max value is about 70% that of a 25-year-old individual. However, reports state that 25-year-old women and 65-year-old men have similar average absolute VO_2 max values. The gradual decline in VO_2 max beyond age 20 is related to, at least in part, a reduction in maximal heart rate. However, many older individuals have a higher absolute VO_2 max than do many younger individuals.

In a longitudinal study, VO_2 max was measured three consecutive times in the same individuals: (i) when they were physical education students aged 20–33 years, (ii) 12 years later at 41–54 years, and (iii) when they were 53–66 years old. Over this life span, the average absolute VO_2 max values from the youngest to the oldest age were 2.9, 2.2 and 2.2 L·min^{-1} for the women and 4.1, 3.3 and 3.1 L·min^{-1} for the men. The corresponding relative VO_2 max values for the women were 49, 38 and 38 mL·kg^{-1}·min^{-1} and 59, 46 and 43 mL·kg^{-1}·min^{-1} for the men. The differences were only significant between the two younger age ranges.

Also, healthy elderly people tend to have a higher sex difference for absolute VO_2 max (relative percentage 68–77%) than for relative VO_2 max (72–93%; Table 1.4). In healthy, moderately physically active groups of both sexes, the mean VO_2 max of the older group was 52–55% that of the younger adults, both in absolute and relative terms. Thus, in this comparison of older and younger healthy adults (mean ages 69–70 years and 23–27 years, respectively), the two sexes showed similar relationships.

Table 1.4. Maximal oxygen uptake in various groups of older adults, women and men, and comparative values

Population	Women	Men	Comparison (%)[a]	Women	Men	Comparison (%)[a]	Data source
	VO_2 max (L·min^{-1})			VO_2 max (mL·kg^{-1}·min^{-1})			
Normal adults (60–65 years)	1.7	2.2	77	25	27	93	Ekblom et al. (2007)
Healthy (women 50–65 years; men 50–69 years)	1.9	2.4	76	28	31	88	Åstrand (1960)
Male currently & previously active athletes (60–67 years)		2.7 & 2.6			43 & 37		Saltin & Grimby (1968)
Healthy (mean 69–70 years)	1.5	2.2	68	23	27	85	Andersson et al. (2011)
Healthy females (mean 69 years)	1.7–1.9			23–27			Broman et al. (2006)
Male golf players (mean 75 years)		2.6			32		Broman et al. (2004)
Healthy untrained (age 75 years)	1.1	1.6	69	18	25	72	Shvartz & Reibold (1990)

Note: VO_2 max = maximal oxygen uptake; values are expressed in absolute terms in litres/minute (L·min^{-1}) and relative to body weight in millilitres/kilogram/minute (mL·kg^{-1}·min^{-1}).
[a] comparative value = (female/male x 100)%.

Several investigators have found a VO_2 max below 18.0 mL·kg^{-1}·min^{-1} in elderly people living independently. For persons aged 60 years and older, 12–18 mL·kg^{-1}·min^{-1} represents minimal to suboptimal fitness levels for independent functioning in the community. Values of between 10–18 mL·kg^{-1}·min^{-1} have also been reported for people of both sexes with various cardiopulmonary diseases. These VO_2 max levels are lower than in normal elderly populations (mean age 69–73 years) with values of 17–20 mL·kg^{-1}·min^{-1} for women, 22–24 mL·kg^{-1}·min^{-1} for men, and a sex difference of 77–83%. For further comparisons of various absolute and relative VO_2 max values among young and old adults, see tables 6-2 to 6-5.

Both women and men with higher aerobic fitness have a reduced risk of mortality and cardiovascular disease. Furthermore, a review of the research showed that aerobic *fitness*, rather than assessments of physical activity habits, was more strongly associated with a lower risk of coronary heart disease and other cardiovascular diseases, including stroke. Consequently, maximal oxygen uptake is relevant, not only in various sports but also in several contexts for assessing public health. Hopefully, people interested in physical activity and performance for health reasons will be inspired by the knowledge gained from various athletic contexts. For risk estimations for cardiovascular and other diseases, aerobic fitness and the VO_2 max are of great importance.

Comparison of maximal oxygen uptake in children and adults

The mean absolute VO_2 max values of girls aged 6–12 years are about 10% lower than those of boys (Table 1.5). However, other reports state that girls and boys generally have similar absolute maximal aerobic power (VO_2 max) up to the age of about 10 years, that is, before puberty. Thereafter, the power achieved by females is, on average, 65–75% that achieved by males in absolute terms, and 75–90% in relative terms. When the VO_2 max is expressed per kilogram of fat-free body mass, the values for women and men are very similar, especially when they are well trained. A peak in absolute maximal oxygen uptake generally occurs between 18 and 20 years of age in both sexes. Although the relative VO_2 max differences between healthy women and men beyond puberty are very similar (see percentage values in Table 1.5), the absolute values vary.

Table 1.5. Maximal oxygen uptake in female and male children and in young and old adults, and comparative values

Age (years)	Females	Males	Comparison (%)[a]	Females	Males	Comparison (%)[a]
	VO_2 max ($L \cdot min^{-1}$)			VO_2 max ($mL \cdot kg^{-1} \cdot min^{-1}$)		
6	0.9	1.0	90	42	47	89
9	1.2	1.4	86	44	48	92
12	1.8	2.0	90	43	50	86
15	2.2	3.0	73	42	50	84
18	2.2	3.4	65	42	48	88
30	2.1	3.2	66	43	48	90
40	2.0	3.0	67	44	50	88
50	1.8	2.7	67	41	48	85
60	1.6	2.3	70	28	35	80
75	1.1	1.6	69	18	25	72

Note: VO_2 max = maximal oxygen uptake; values are expressed in absolute terms in litres/minute ($L \cdot min^{-1}$) and relative to body weight in millilitres/kilogram/minute ($mL \cdot kg^{-1} \cdot min^{-1}$); based on data from Shvartz & Reibold (1990).
[a] comparative value = (female/male x 100)%.

Maximal heart rate

In many forms of exercise, heart rate (HR) increases in a linear fashion as exercise intensity increases. There are exceptions, which are probably more frequent among untrained individuals. HR at a given VO_2 is higher with arm exercise than with leg exercise. The maximal heart rate (HR max) during exercise generally varies by about 10 beats either side of the average. The HR max declines with age, but the size of the decline varies widely between individuals. Table 1.6 shows the mean HR max for various groups of individuals and ages; the values are derived from a number of investigations. Children of both sexes and, especially, elite female athletes and well-trained women and men have a high mean HR max. Healthy, physically active elderly people have shown mean HR max of 161 for women and 167 for men (mean ages 69 and 70 years, respectively). These values are higher than the expected values calculated from the commonly used equation HR max = 220 – age (in years).

Table 1.6. Maximal heart rate among various groups and ages of males and females

Group	Female HR max (beats/min)	Male HR max (beats/min)	Data source
Normal girls and boys (5–18 years)	200–220		Åstrand et al. (2003)
Top female athletes in various sports (23 years[a])	195 (185–204)		Saltin & Åstrand (1967)
Top male athletes in various sports (26 years[a])		187 (169–205)	Saltin & Åstrand (1967)
Well trained (20–33 years)	199	195	Åstrand (1960)
Healthy (20–33 years)	187	186	Åstrand (1960)
Physical education students (F 23 years[a], M 27 years[a])	185	188	Andersson et al. (2011)
Physical education students (F 22 years[a], M 26 years[a])	196	190	Åstrand et al. (1997)
Same physical education students (F 55 years[a], M 59 years[a])	177	175	Åstrand et al. (1997)
Former male athletes (60–67 years)		170	Saltin & Grimby (1968)
Healthy elderly (F 69 years[a], M 70 years[a])	161	167	Andersson et al. (2011)

Note: HR max = maximal heart rate; F = female; M = male
[a] = mean age

SELECTED REFERENCES: MUSCLE STRENGTH

Andersson, E., Swärd, L., & Thorstensson, A. (1988). Trunk muscle strength in athletes. *Medicine and Science in Sports and Exercise, 20*(6), 587–593.

Astrand, P.-O., Rodahl, K., Dahl, H. A., & Stromme, S. B. (2003). *Textbook of work physiology. Physiological bases of exercise* (4th ed.) (pp. 266–269). Champaign, IL: Human Kinetics.

Gilenstam, K. M., Thorsen, K., & Henriksson-Larsén, K. B. (2011). Physiological correlates of skating performance in women's and men's ice hockey. *Journal of Strength and Conditioning Research, 25*(8), 2133–2142.

Grimby, G., & Saltin, B. (1983). The ageing muscle. *Clinical Physiology, 3*(3), 209–218.

Heinonen, A., Oja, P., Kannus, P., Sievänen, H., Mänttäri, A., & Vuori, I. (1993). Bone mineral density of female athletes in different sports. *Bone and Mineral, 23*(1), 1–14.

Higbie, E. J., Cureton, K. J., Warren, G. L., 3rd, & Prior, B. M. (1996). Effects of concentric and eccentric training on muscle strength, cross-sectional area, and neural activation. *Journal of Applied Physiology, 81*(5), 2173–2181.

Hubal, M.J., Gordish-Dressman H., Thompson, P. D., Price, T. B., Hoffman, E. P., Angelopoulos, T. J., … & Clarkson, P. M. (2005). Variability in muscle size and strength gain after unilateral resistance training. *Medicine and Science in Sports and Exercise, 37*(6), 964–972.

Pettersson, U., Alfredson H., Nordström P., Henriksson-Larsén K., & Lorentzon, R. (2000). Bone mass in female cross-country skiers: Relationship between muscle strength and different BMD sites. *Calcified Tissue International, 67*(3), 199–206.

Schantz, P., Randall-Fox, E., Hutchison, W., Tydén, A., & Åstrand, P. O. (1983). Muscle fibre type distribution, muscle cross-sectional area and maximal voluntary strength in humans. *Acta Physiolica Scandinavica, 117*(2), 219–226.

Seger, J. Y., & Thorstensson, A. (1994). Muscle strength and myoelectric activity in pre-pubertal and adult males and females. *European Journal of Applied Physiology, 69*(1), 81–87.

Thomas, M., Fiatarone, M. A., & Fielding, R. A. (1996). Leg power in young women: Relationship to body composition, strength, and function. *Medicine and Science in Sports and Exercise, 28*(10), 1321–1326.

Wilmore, J. H. (1974) Alterations in strength, body composition and anthropometric measurements consequent to a 10-week weight training program. *Medicine and Science in Sports and Exercise, 6*(2), 133–138.

Wilson, G. J., & Murphy, A. J. (1996). The use of isometric tests of muscular function in athletic assessment. *Sports Medicine, 22*(1), 19–37.

Wretling, M.-L., & Henriksson-Larsén, K. (1998). Mechanical output and electromyographic parameters in males and females during fatiguing knee extensions. *International Journal of Sports Medicine, 19*(6), 401–407.

SELECTED REFERENCES: MAXIMAL OXYGEN UPTAKE & HEART RATE

Andersson, E. A., & Nilsson, J. (2011). Can a six-minute shuttle walk test predict maximal oxygen uptake? *Gazzetta Medica Italiana, 170*, 163–170.

Andersson, E., Lundahl, G., Wecke, L., Lindblom, I., & Nilsson, J. (2011). Maximal aerobic power versus performance in two aerobic endurance tests among young and old adults. *Gerontology, 57*(6), 502–512.

Astrand, P.-O., & Ryhming, I. (1954). A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. *Journal of Applied Physiology, 7*(2), 18–21.

Astrand, I. (1960). Aerobic work capacity in men and women with special reference to age. *Acta Physiolica Scandinavica, 49*(suppl. 169), 1–92.

Astrand, P.-O., Bergh, U., & Kilbom, Å. (1997). A 33-year follow-up of peak oxygen uptake and related variables of former physical education students. *Journal of Applied Physiology, 82*(6), 1844–1852.

Astrand, P.-O., Rodahl, K., Dahl, H. A., & Stromme, S. B. (2003). *Textbook of work physiology. Physiological bases of exercise* (4th ed.) (pp. 167–168, 262–265). Champaign, IL: Human Kinetics.

Blair, S. N., Kohl, H. W., 3rd, Paffenbarger, R. S., Jr, Clark, D. G., Cooper, K. H., & Gibbons, L. W. (1989). Physical fitness and all-cause mortality. A prospective study of healthy men and women. *Journal of the American Medical Association, 262*(17), 2395–2401.

Broman, G., Johnsson, L., & Kaijser, L. (2004). Golf: A high intensity interval activity for elderly men. *Aging, Clinical and Experimental Research, 16*(5), 375–381.

Broman, G., Quintana, M., Lindberg, T., Jansson, E., & Kaijser, L. (2006). High intensity deep water training can improve aerobic power in elderly women. *European Journal of Applied Physiology, 98*(2), 117–123.

Ekblom, B., Engström, L.-M., & Ekblom, Ö. (2007). Secular trends of physical fitness in Swedish adults. *Scandinavian Journal of Medicine & Science in Sports, 17*(3), 267–273.

Saltin, B., & Åstrand, P.-O. (1967). Maximal oxygen uptake in athletes. *Journal of Applied Physiology 23*(3), 353–358.

Saltin, B., & Grimby, G. (1968). Physiological analysis of middle-aged and old former athletes. *Circulation, 38*(6), 1104–1115.

Shvartz, E., & Reibold, R. C. (1990). Aerobic fitness norms for males and females aged 6 to 75 years: A review. *Aviation, Space, and Environmental Medicine, 61*(1), 3–11.

Williams, P. T. (2001). Physical fitness and activity as separate heart disease risk factors: A metaanalysis. *Medicine and Science in Sports and Exercise, 33*(5), 754–761.