

**MUSCLE HYPERTROPHY AND SERUM HORMONE
CONCENTRATIONS DURING COMBINED STRENGTH AND
ENDURANCE TRAINING VS. STRENGTH OR ENDURANCE
TRAINING ONLY IN MIDDLE AGED AND OLDER WOMEN**

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ABSTRACT

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Purpose: The purpose of this investigation was to compare the effects of strength training only (2 x week), endurance training only (2 x week), and combined training (2 + 2 x week) on muscle hypertrophy and serum hormone concentrations in middle-aged and older women during 21 weeks of training.

Methods: 96 healthy, moderately active middle-aged and older women were assigned to three training groups and a control group; 1) Strength training only (S, $n = 27$) 2 x week, program included dynamic exercises that activate a large amount of muscle bulk and increase energy metabolism. 2) Endurance training only (E, $n = 26$) 2 x week was performed by bicycle ergometer, heart rate levels of endurance training were determined by aerobic performance tests and monitored during training. 3) Combined strength and endurance training (SE, $n = 25$), performed both E and S sessions. 4) Control group (C, $n = 18$) was instructed to maintain their habitual physical activities which were monitored by training diaries. Lean mass (LM) of the legs and arms was measured by dual-energy x-ray absorptiometry (DEXA) and muscle thickness of several muscles by ultrasound at weeks 0, 10, and 21. Serum basal hormone concentrations of several anabolic hormones were measured at weeks -1, 0, 10, and 21.

Results: The S and SE groups showed significant increases in LM in both arms and legs (S 1.6%, 1.4%, SE 2.1%, 4.0% respectively). All training groups showed significant increases ($p < 0.05$, $p < 0.001$) in LM legs, but only the S and SE groups showed increases in arms LM. S and SE groups showed the largest increases in muscle thickness in all muscles measured, with the SE group having the largest gains in the legs (vastus lateralis + vastus intermedius) 11.5%, biceps femoris long 8.3%) while the S group had the largest increases in arms (triceps brachii 10.0%, biceps brachii 7.1%). All training groups exhibited significant increases in serum testosterone ($p < 0.05$, $p < 0.001$).

Conclusion: Combined strength and endurance training by cycling may be more effective than strength training alone for increasing muscle hypertrophy whether being measured by DEXA or ultrasound in middle aged and older women.

Keywords: hypertrophy, strength training, serum hormones, DEXA, ultrasound, aging

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1. INTRODUCTION

It seems inevitable that a decline in the physiological capacity of humans will occur as a consequence of the biological aging process. The deterioration in functional capacity can decrease the ability to perform common activities of daily living in the older population (*Rhodes et al. 1999*).

Normal biological aging is associated with declines in the functional capacity of the neuromuscular and neuroendocrine systems, resulting in decreases in maximal strength and muscle power output (*Izquierdo et al 2001*). Prior research has demonstrated that resistance training in women can augment strength, physical performance, fat free mass, and muscle fiber hypertrophy (*Chilibeck et al. 1996, 1998, Kraemer et al. 1998, Wang et al. 1993*). Muscle power has been shown to be positively associated with the ability in older adults to perform activities of daily life such as walking, rising from a chair, and climbing stairs (*Bean et al. 2003, 2002*) and that muscle power may even be a stronger predictor of functional dependency than muscle strength (*Bean et al. 2003, 2002, Suzuki et al. 2001*).

Estrogens and their effect on reproductive health and chronic diseases have been the overwhelming focus of hormone studies in women (*Fauser et al. 1997*). In contrast there is relatively little information about the role of androgens in women's health. Evidence indicates that declining muscle mass with age is associated with declining levels of circulating hormones (*Baumgartner et al. 1999, Lamberts et al. 1997*). With aging blood concentrations of circulating anabolic hormones and growth factors, e.g., testosterone, growth hormone (GH), and insulin like growth factor I (IGF I), are diminished, especially in women, suggesting that the decreasing basal level of blood testosterone in aging women over the years may lead to decreasing anabolic effects on muscles associated possibly with muscle atrophy and decreased strength (*Häkkinen et al. 1993*). A decrease in the concentrations of these hormones may be linked to losses in both muscle mass and muscle strength.

Muscular hypertrophy is an increase in muscle mass and cross sectional area (*Vermeulen et al. 1999, Russell et al. 2000*), which is caused by an increase in the size of individual muscle fibers. Muscles are able to adapt to hypertrophy by increasing the

size and amount of contractile proteins, which comprise the myofibrils within each muscle fiber, leading to an increase in the size of the individual muscle fibers and their consequent force production (*Russell et al. 2000*). Growth factors are specific proteins, such as hormones and cytokines, which are involved in muscle hypertrophy (*Pedersen et al. 1997*). An increase in lean muscle mass is a favourable and desired effect of exercise training programs and contributes to an enhanced level of fitness and health (*Bradley et al. 2000*).

The purpose of this investigation was to compare the effects of strength training only (2 x week), endurance training only (2 x week), and combined training (2 + 2 x week) on muscle hypertrophy and serum hormone concentrations in middle-aged and older women during 21 weeks of training.

2. AGING AND MUSCLE ATROPHY

A predictable accompaniment to natural aging beyond the fourth to fifth decade of life is a steady reduction in the force generating capacity, or strength, of the skeletal muscles (*Bosco et al. 1994, Izquierdo et al. 1999*). With increasing age, especially at the onset of the sixth decade, a steeper decline in maximal strength begins in both genders (*Viitasalo et al. 1985, Frontera et al. 1991, Häkkinen & Häkkinen 1991, Narici et al. 1991*). Age associated loss in muscle strength occur predominately as a consequence of reductions in muscle cross sectional area (*Frontera et al. 2000, Izquierdo et al. 2001*). Age related decline in strength may also be due to decreased maximal voluntary activation of the agonist muscle or changes in degree of agonist antagonist co-activation (*Häkkinen et al. 1998, Kamen et al. 1995, Winegard et al. 1996*).

The process of biological aging also includes a reduced capability for protein synthesis, leading to a decline in muscle mass (*Häkkinen et al. 1994*). Aging is associated with a reduction in total muscle mass and an increase in intramuscular fat and connective tissue (*Brose et al. 2003*). These changes are correlated with reduced strength, type II fiber area (*Grimbly et al 1982, Larsson et al. 1979*) and number (*Lexell et al. 1988*), motor unit number (*Doherty et al. 1993*) and circulating anabolic hormones (*Birkenhager et al. 1994, Morley et al. 1997, Zadik 1985*).

The loss of muscle strength in the proximal muscles of the lower extremities seems to be greater than that of the upper extremities, presumably due to a decreasing use of lower compared with upper limb muscles in older groups (*Frontera et al. 1991*). Muscular performance may vary between the upper and lower extremity muscles in relation to differences in age related declines in the quantity and or intensity of daily physical activities throughout the life span (*Enoka et al. 1992, Häkkinen 1994, Izquierdo et al. 1999, Lynch et al. 1999*). These negative characteristics occur due to sarcopenia.

Sarcopenia is the loss of muscle mass with advanced age and is associated with dysfunction, poor health status, and the loss of muscle strength and power in older adults (*Rantanen et al. 1999, 1999 b*). Muscle power accounts for a greater amount of the variance in physical performance than strength in older adults (*Bean et al. 2002,*

Foldvari et al. 2000) and deteriorates at a faster rate than strength with advanced age (*Bassey et al. 1992, Metter et al. 1997, Skelton et al. 2003*). Previous cross sectional data suggest that this decline in peak muscle power with age is associated with muscle structure and function, tendon characteristics, and sarcopenia in specific muscle groups (*Runge et al. 2004*). Age related changes in the neuromuscular system may play a role in the onset of sarcopenia. With age the number of spinal cord motor neurons and functioning motor units decline (*Hurley et al. 2000, Roubenoff et al. 2001*).

2.1 Fiber Size/Types and Changes Due to Aging

The decline in muscle mass is thought to be mediated by a reduction in the size and or number of individual muscle fibers, especially of fast twitch fibers (*Lexell et al. 1988*). The difference between the two fiber types (type I slow twitch, type II fast twitch) can be distinguished by metabolism, contractile velocity, neuromuscular differences, glycogen stores, capillary density of the muscle, and the actual response to hypertrophy (*Robergs et al. 1997*).

Preferential atrophy of type II muscle fibers (*Häkkinen et al. 1998, Singh et al. 1999*) which possess a twofold to fourfold greater contraction velocity than do type I muscle fibers (*Faulkner et al 1986, Krivickas et al 2001*), may partially explain the discrepancy between losses in strength and power with age. Age related decreases in strength and power result from a reduction in muscle mass. Neither endurance nor resistance training alone appears to counteract the age associated atrophy of type II fibers (*Coggan et al. 1992, Proctor et al. 1995, Always et al. 1996*)

3. AGING AND HORMONAL CHANGES

Aging is associated with alterations in hormone balance, especially with decreased androgen levels (*Vermulen et al. 1972, Chakravati et al. 1976, Hammond et al. 1978, Häkkinen & Pakarinen 1993*). Suggestion that basal concentrations of blood testosterone may be of great importance, a low level of testosterone may be a limiting factor in older women, for both strength development and overall training induced muscle hypertrophy. The decrease in strength seems to be explained to a great extent by the reduction in muscle mass, perhaps related to changes in hormone balance and decline in the intensity of daily physical activities (*Häkkinen et al 1998*). Table 1 summarises age and gender differences in circulating anabolic hormones and their primary binding proteins.

| | Young Women | Young Men | Older Women | Older Men |
|-----------------------------|-------------|------------|-------------|------------|
| n | 11 | 11 | 9 | 11 |
| IGF-I,* ng/ml | 326±33 | 385±43 | 170±20 | 170±21 |
| IGFBP-3, ng/ml | 4,480±187 | 4,461±299 | 4,532±191 | 4,076±134 |
| IGFBP-1,† ng/ml | 55.3±12.4 | 23.3±6.3 | 73.9±17.0 | 54.3±13.9 |
| Total testosterone,†† ng/dl | 22.5±4.0 | 597.9±49.1 | 32.3±11.5 | 460.0±28.6 |
| SHBG,† nM | 183±26 | 65±9 | 152±21 | 98±5 |
| Free testosterone,*†† pM | 4.7±0.8 | 316.6±28.3 | 6.2±2.9 | 156.6±10.4 |
| Androstenedione, ng/ml | 2.1±0.3 | 2.5±0.2 | 1.1±0.2 | 1.8±0.1 |

Values are means ± SE; n, no. of subjects. IGF I insulin like growth factor I, IGFBP, IGF binding protein, SHBG, sex hormone binding globulin. *Main age effect, $P \leq .05$. Age x gender interaction, $P \leq .05$ ($P = 0.069$ for SHBG).

It has been shown that in those older women who have demonstrated very low basal testosterone levels, the individual gains in maximal strength during the strength training period may be minor compared with those with higher testosterone concentrations (*Häkkinen et al. 2000*). The same study showed that the gains in the cross sectional areas (CSA) of the trained muscles were minor in those with lower testosterone levels. In premenopausal women, testosterone is produced in the ovaries and adrenals, while in postmenopausal women testosterone is produced by the adrenals and the peripheral conversion of androstenedione in adipose tissue (*Sowers et al. 2000*).

According to *Bunt et al. (1986)* higher fitness levels are associated with greater GH response to exercise. Although these higher levels of fitness may increase the GH

response, it has been previously shown that exercise induced increases in GH do not result in short term increases in IGF I concentrations (*Kraemer R. et al. 1992*). There is evidence that GH and IGF I facilitate anabolic functions of bone formation and protein synthesis in muscle (*Bellantoni et al. 1996*). Circulating GH and IGF I concentrations have been shown to decline with age in women of reproductive age and postmenopausal women (*Wilshire et al. 1995*).

4 TRAINING INDUCED HYPERTROPHY/CHANGES IN MUSCLE FIBERS

The large initial increases in maximal strength observed during the initial weeks of strength training can be attributed largely to the increased motor unit activation of the trained agonist muscles (*Moritani et al. 1980, Sale DG, 1991, Häkkinen et al. 1998, 1999, 2000*). Strength training induced increases in the magnitude of EMG could result from the increased number of active motor units and or increase in their firing frequency (*Sale, 1991*). Training induced hypertrophy in older men and women seems to take place in both fast and slow twitch muscle fibers.

The basic requirements for training induced hypertrophy and strength development in both older men and women are that the overall training intensity should be high enough and the duration of the training period long enough (*Charette et al. 1991, Fiatarone et al. 1990, Frontera et al. 1988, Häkkinen & Häkinen 1995, Häkkinen et al. 1996, Keen et al. 1994, Roman et al. 1993, Winegard et al. 1996*). Marked gains in strength (*Hunter et al. 1995*) myofiber cross sectional area (*Hepple et al. 1994, Taaffe et al. 1997*), whole muscle area (*Hurley et al. 1995*), rates of muscle protein synthesis (*Yarasheski et al. 1999*) and functional abilities (*Fiatarone et al. 1990*) have been noted after progressive programs varying in duration from 8-52 weeks.

Age related decreases in strength and power result from a reduction in muscle mass. In a study by *Chilibeck et al (1998)* the arms of women underwent greater hypertrophy than did their legs and trunk. One hypothesis from these findings could be that with resistance training, women may alter their relative muscle mass distribution so that a greater proportion exists in their upper body. Similar studies to *Chilibeck et al (1998)* done previously have shown that arm muscles responded considerably to the overload imposed by resistance exercise (*Chilibeck et al. 1996, Cureton et al. 1995*). In contrast to the results in the arms, small gains were observed in leg lean mass, despite significant strength gains.

It is known that the subcutaneous fat of the arm area is morphologically different compared with other areas, and this fact may contribute to a proclivity of the arm area

to store and mobilize fat. A cross sectional study of 100 women aged 18-87 (*Madsen et al. 1997*) reported that the regional percentage of fat was greatest in the arm area.

A poor correlation between strength gain and lean mass has been demonstrated in women (*Cureton et al. 1988, Chilibeck et al. 1998*). Thus the larger increases in strength with little gain in lean mass indicate that this effect is primarily due to neural adaptation rather than muscle hypertrophy (*Häkkinen et al. 2001*).

4.1 Cross Sectional Area (CSA)

Physiological muscle CSA is defined as the magnitude of muscle fiber area perpendicular to the longitudinal axis of individual muscle fibers multiplied by the cosine of the angle of pennation (*Wickiewicz et al. 1983, Powell et al. 1984*). In a study by *Häkkinen et al (2001)* strength training performed over a 21 week period twice a week showed strength gains were accompanied by significant increases in the voluntary neural activation of the trained agonist muscles accompanied by significant enlargements in muscle fiber areas of types I, IIa, and IIb as well as in the total CSA of the trained extensor muscles (Figure 1, table 2).

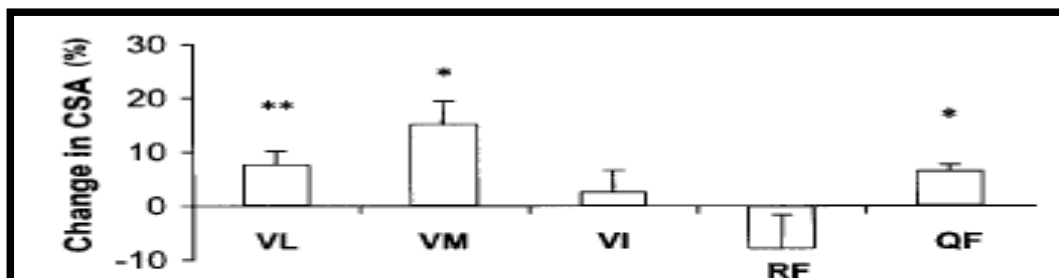


Figure 1. Changes of the CSA's of the individual muscles of the VL, VM, VI, and RF and the total QF muscle group at the length of the site (the lower third portion of the thigh) of the muscle biopsy of (the VL muscle) in older women after the 21 wk strength training period (* $P < .05$, ** $P < .01$). (*Häkkinen et al. 2001*)

Table 2. Fiber areas of the vastus lateralis muscle before and after a 21 wk strength training period in older women. (*Häkkinen et al. 2001*)

| | Pre | Post |
|---------------------------|-----------------|------------------|
| Type I, μm^2 | 4,131 \pm 980 | 4,878 \pm 778* |
| Type IIa, μm^2 | 3,051 \pm 902 | 3,899 \pm 946† |
| Type IIb, μm^2 | 2,183 \pm 820 | 3,014 \pm 839† |

Values are means \pm SD, n = 10 subjects. Significant difference pre to post-training (* $P < .05$, † $P < .001$).

Tracy et al. (1999) showed that strength training induced muscle hypertrophy was greatest in the region of the largest CSA and that the increase in the CSA became progressively smaller toward the proximal and distal regions of the QF. Average enlargements in the total muscle CSA may be as large as 10% during a 3 month heavy resistance strength training period in both middle aged and older men and women (*Häkkinen & Häkkinen 1995*).

Häkkinen and associates (Häkkinen et al. 2001) found substantial gains in myofiber size in older women following a strength power training program performed 2 days per week, suggesting that older women may benefit from reduced frequency periodized resistance training and a combination of heavier and lighter loads.

4.2 Training Induced Changes to Muscle Types

Type 1 fibers have been shown to hypertrophy considerably due to progressive overload (*Kraemer et al. 1996, Häkkinen et al. 2001*), but do not change percentage wise due to resistance training programs (*Frontera et al. 1988, Kraemer et al. 1995, Lexell et al. 1995*). There is an increase in type I fiber area not only with resistance exercise, but also to some degree with aerobic exercise (*Carter et al. 2001*). *Hikida et al. (2000)*, and *Häkkinen et al. (1998)*, have reported increases in type IIa and type IIb muscle fiber areas following resistance exercise in older men.

Strength training also reduces mitochondrial density and decreases the activity of oxidative enzymes, which can impede endurance capacity, but has minimal effect on capillary density or the conversion from fast (type II) to slow twitch (type I) fiber types (*Nelson et al. 1990, Sale et al. 1990*). In contrast, endurance training usually induces little or no muscle hypertrophy, but increases the mitochondrial content, citric acid enzymes, oxidative capacity, and the possibility of muscle fiber conversion from fast to slow twitch (*Åstrand et al. 1986*). Skeletal muscles of older people of both genders seem to retain the capacity to undergo training induced hypertrophy provided that the volume, intensity, and the duration of the training period are sufficient (*Charette et al. 1991, Fiatarone et al. 1990, Frontera et al. 1988, Häkkinen et al. 1993, 1998, Pyka et al., 1994*).

According to *Roubenoff et al. (2001)*, and *Roth et al. (2000)*, a properly designed resistance training program may increase motor neuron firing rates, improve muscle fiber recruitment, and create a more efficient motor unit. Partial reversal of age associated sarcopenia with progressive resistance training has been demonstrated in several investigations (*Hikida et al. 2000*, *Häkkinen et al. 2001*).

5. COMBINED STRENGTH AND ENDURANCE TRAINING

Strength training causes muscle fiber hypertrophy (*MacDougall et al. 1980*) associated with an increase in the amount of contractile protein (*MacDougall et al. 1982*), which contributes to an increase in maximal contraction force. In contrast endurance training usually causes little or no muscle fiber hypertrophy (*Andersen et al. 1977, Denis et al. 1986*). Endurance training has been associated with a loss of strength (*Costill et al. 1967*) and decreased muscle fiber size (*Klausen et al. 1981*), changes obviously antagonistic to strength development. The pattern of muscle adaptation to resistance training usually involves an initial neural adaptation followed by a gradual increase in myofibrillar proteins leading to muscular hypertrophy (*Häkkinen et al. 1998, Mikesky et al. 1991*)

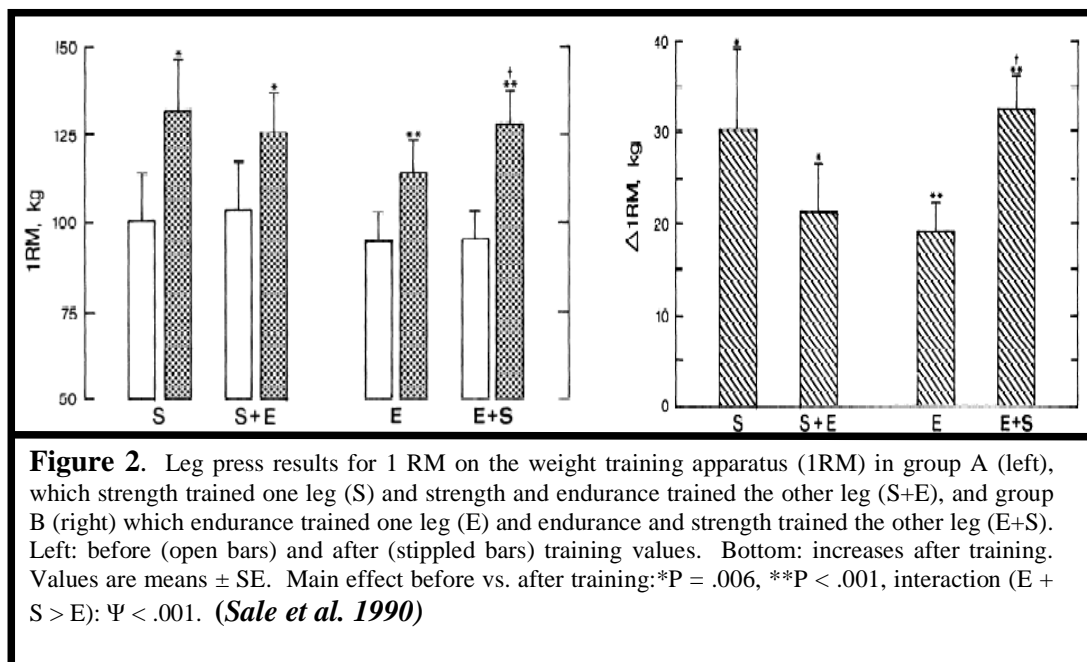
In a study by Ferketich and colleagues (*1998*) 21 women aged 60-75 underwent training 3 times a week for duration of 12 weeks. The subjects were separated into endurance, combined and control groups. Subjects in the combined groups used resistance equipment to train the knee extensors. The workload for resistance training was based on an initial assessment of 10 repetitions maximum (10 RM), with 80% of that value used for training, 3 times weekly. The results showed the 10 RM load increased by 111% ($P < 0.05$) in the combined group. This was greater than the 43% increase in 10 RM loads that occurred in the endurance only group. The 10 RM extension load in the control group did not change over the duration of the study *Ferketich (1998)* concluded that in older women, resistance training combined with endurance training improves strength and fatigue resistance to sub maximal exercise to a greater extent than endurance training alone.

In previously untrained subjects, a combination of moderate to high intensity and volume endurance and strength training impeded strength development but did not increase maximal aerobic power or short term endurance (*Dudley et al. 1985*).

It has been suggested that a lack of change in the size of skeletal muscles may be an underlying reason for the depressed gains in maximal strength observed after concurrent strength and endurance training (*Bell et al. 1991, Kraemer et al. 1995*). Theoretically, training induced muscle adaptations are divergent and can even be antagonistic to

improvements in strength or endurance during combined training (Nelson *et al.* 1990, Bishop *et al.* 1999).

The interference between endurance and strength training can be possibly be explained by the following reasons: (a) the inability of muscle to adapt optimally to two different stimuli because of simultaneous requests from different energy pathways during the same session (Bell *et al.* 2000, McCarthy *et al.* 1995) (b) muscle tiredness resulting from the preceding training (Craig *et al.* 1991, Hennessy *et al.* 1994), (c) the type, nature, and specific mode of strength and aerobic training (Häkkinen *et al.* 1985), as well as the physical fitness and age of the athletes (Paavolainen *et al.* 1999, Millet *et al.* 2002, McCarthy *et al.* 1995), (d) the volume, frequency, and intensity of training may also influence the degree of incompatibility observed (Bishop *et al.* 1999, McCarthy *et al.* 1995), (e) finally, the sequencing order—that is, the order in which endurance and strength training are carried out (Figure 2)—may also have an effect on the training induced adaptations (Sale *et al.* 1990).

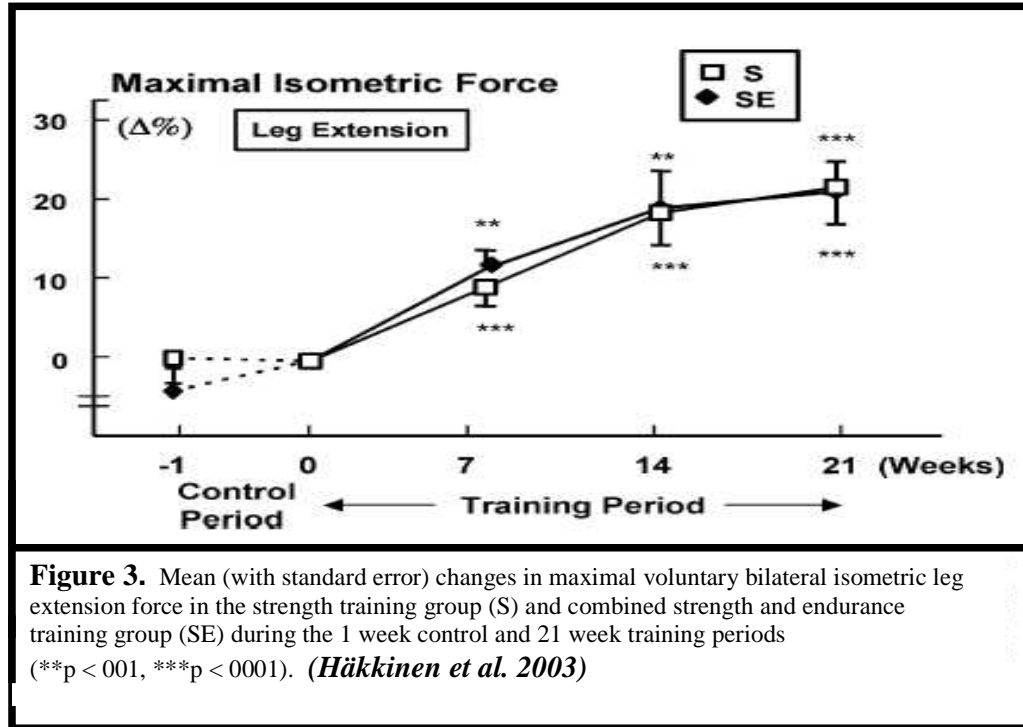


Traditional heavy resistance training utilizing high loads performed with slow movement velocities leads to improved maximal strength with only minor changes in explosive characteristics of the trained muscles in both middle aged and older subjects

(Frontera *et al.*, 1988). Relatively few studies have been specifically designed to increase muscle power in older adults. Most studies use traditional high intensity, slow velocity resistance training protocols for the purpose of increasing strength, which may yield disproportionately lower power gains (Jozi *et al.* 1999, Skelton *et al.* 1995), thus warranting more specific training strategies to improve muscle power in older adults.

Endurance training induces a shift in fiber type composition, at least temporarily, promoting transformation of fast twitch to slow twitch fibers (Saltin *et al.* 1983). Endurance training by cycling may be more likely to increase strength (Moroz *et al.* 1987, Rosler *et al.* 1986), and muscle size (Anderson *et al.* 1977, Terrados *et al.* 1986) than running.

In a study by Sang-Kab *et al.* (2003) obese female subjects between the ages of 40-45, were separated into 3 groups: aerobic training, strength training and control. After the 24 week study the results showed the subcutaneous fat and visceral fat levels were decreased in the combined training group more than in the aerobics training group. Also, the lean body mass (LBM) was significantly increased only in the combined training group.



In a study by *Häkkinen et al. (2003)* during a 21 week training period significant increases of 22% and 21% were recorded in the strength and concurrent groups respectively in the bilateral isometric leg press (Figure 3). The mean relative increases recorded for strength and concurrent groups did not differ significantly.

5.1 Training Protocols

Only a few studies have reported whether strength training should precede or follow endurance training when both are performed in the same session (*Collins et al. 1993, Gravelle et al. 2000*). The study by *Gravelle et al. (2000)* found that the 1 RM leg press increased for all women training concurrently or for strength only (Table 3). This training adaptation occurred regardless of the order in which the combined training was performed.

Table 3. Changes in 1 repetition (1RM) leg press association with lift row (LR, n = 6), row lift (RL, n = 7), and lift only (LO, n = 6) training programs (values are mean \pm SE). (*Gravelle et al. 2000*)

| | | | |
|--------------------------------------|--------------------|---------------------|---------------------|
| 1RM leg press (kg) | | | |
| Pretest | 148.0 \pm 14.0*† | 175.0 \pm 15.0*†‡ | 184.0 \pm 15.0*†‡ |
| Midtest | 124.0 \pm 11.0 | 141.0 \pm 10.0‡ | 159.0 \pm 19.0‡§ |
| Posttest | 134.0 \pm 6.0 | 148.0 \pm 4.0‡ | 167.0 \pm 4.0‡§ |
| Change in 1RM leg press (%) | | | |
| Pretest–midtest | 19.5 \pm 3.2‡ | 7.1 \pm 4.4*† | 26.6 \pm 7.9‡ |
| Midtest–posttest | 14.6 \pm 3.9‡ | 12.8 \pm 1.9§ | 27.4 \pm 5.9‡ |
| Pretest–posttest | 11.3 \pm 2.8‡ | 14.6 \pm 3.6§ | 25.9 \pm 6.7‡ |
| * Different from group RL (p<.05). | | | |
| ‡ Different from group LO (p<.05) | | | |
| † Different from pretraining (p<.05) | | | |
| § Different from midtraining (p<.05) | | | |

The physiological stimuli directed to skeletal muscle as a result of strength training and endurance training is divergent in nature. Under concurrent training conditions, there would be a limited change in skeletal muscle cross sectional area (*Bell et al. 1991*) and or a reduced hypertrophy of individual muscle fibers (*Kraemer et al. 1995, Bell et al. 2000*). More specifically, *Kraemer et al. (1995)* demonstrated that combined training muted the hypertrophy of type I fibers. However, concurrent training may not impair adaptations in strength, muscle hypertrophy, and neural activations induced by strength training only over a short term period (*McCarthy et al. 2002*).

According to *Häkkinen et al. (2003)* the frequency of strength training in previously untrained adults can be as low as twice a week when the loading intensity of training is sufficient and increased progressively (i.e. periodized) throughout the training period to increase strength. In the same study by *Häkkinen et al (2003)* strength gains of the lower extremities took place gradually throughout the 21 week training period showing clearly that the strength development was not influenced adversely by the simultaneous endurance training, as some others have found (e.g. *Kraemer et al. 1995, McCarthy et al. 1995, 2002*). Therefore, the present data do not support the concept of the universal nature of the “interference effect” that has been described by *Hickson (1980)* in strength development when strength training is performed concurrently with endurance training. The primary findings of the previously mentioned study by *Häkkinen* were that concurrent strength and endurance training resulted in large gains in maximal strength

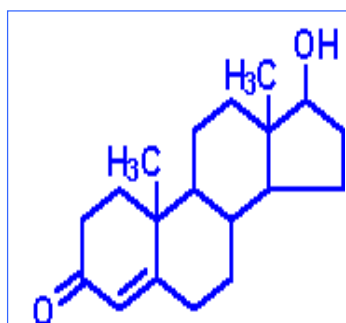
accompanied with significant enlargements in CSA of the QF and in the sizes of individual muscle fibers.

The interference effect may also hold true when the overall volume and or frequency of training is higher over a longer period of time, so that simultaneous training for both strength and endurance may be associated with large strength gains during the initial weeks of training but with only limited strength development during the later months of training (*Häkkinen et al. 2003*). Training frequency and the intensity of each program may influence the level of interference. The physiological basis for this may be linked to an interaction between an elevated catabolic hormonal state leading to a reduced change in skeletal muscle CSA (*Kraemer et al. 1995, Bell et al. 2000*).

6. HORMONES

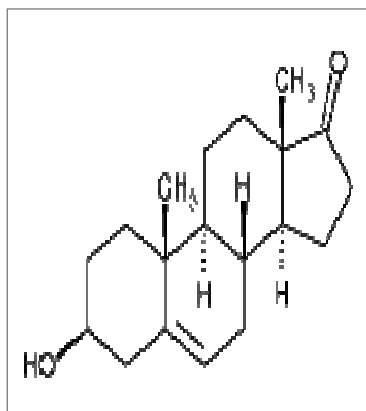
Hormones are chemicals which organs secrete to initiate or regulate the activity of an organ or group of cells in another part of the body. It should be noted that hormone function is decidedly affected by nutritional status, and lifestyle factors such as stress, sleep, and general health (*Hernandez et al. 2003*).

6.1 Testosterone



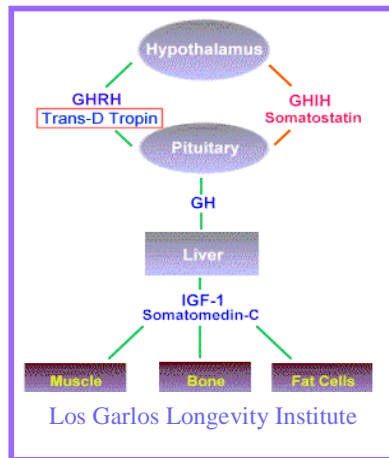
Testosterone is an androgen, or the male sex hormone. According to *Sowers et al. (2000)* testosterone is the most important circulating and naturally occurring androgen in both men and women. The primary physiological roles of androgens are to promote the growth and development of male organs and characteristics. Testosterone affects the nervous system, skeletal muscle, bone marrow, skin, hair and the sex organs (*Spangenburg et al. 2002*). Testosterone increases protein synthesis, which induces muscle hypertrophy (*Vermeulen et al. 1999*). Limited evidence suggesting endogenous testosterone levels are related to the magnitude of periodized resistance training (PRT) induced hypertrophy in older women (*Häkkinen et al. 2001*) and strength gain in women. Low levels of testosterone may therefore impede PRT induced hypertrophy and strength gain (*Bamman et al. 2003*).

6.2 Dehydroepiandrosterone



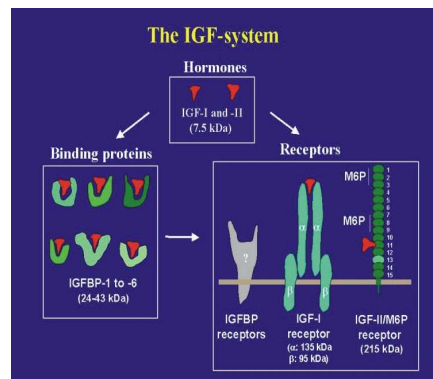
Dehydroepiandrosterone (DHEAS) is a natural steroid hormone produced from cholesterol by the adrenal glands found atop of the kidneys in the human body. DHEAS is also produced in the gonads, adipose tissue and the brain. DHEAS is structurally similar to, and is a precursor of, androstenedione, testosterone and estrogen. It is the most abundant hormone in the human body. DHEAS treatment has previously been shown to increase serum IGF I in older men and women (*Morales et al. 1998*), and declining levels of both DHEAS and IGF I correlate with lower levels of muscle power in older women (*Kostka et al. 2000*).

6.3 Growth Hormone



Growth hormone (GH) is a peptide hormone that stimulates IGF in skeletal muscle, promoting satellite cell activation, proliferation and differentiation (Frisch 1999). However, the observed hypertrophic effects from the additional administration of GH, investigated in GH treated groups doing resistance exercise, may be less credited with contractile protein increase and more attributable to fluid retention and accumulation of connective tissue. It has been suggested that the decline in bone mineral density and muscle mass is associated with reduced GH release (Xu *et al.* 1996).

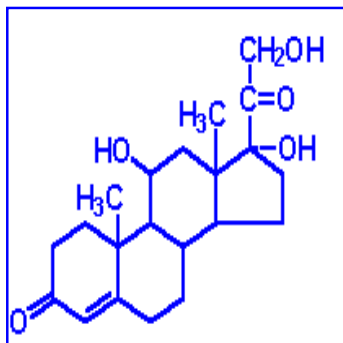
6.4 Insulin Growth Factor I



IGF is a hormone that is secreted by skeletal muscle. It regulates metabolism and stimulates protein synthesis (Hernandez *et al.* 2003). In response to progressive overload resistance exercise, IGF I levels are substantially elevated, resulting in skeletal muscle hypertrophy (Fiatarone *et al.* 1999). IGF plays an essential role in the formation and maintenance of skeletal muscle (Fernandez *et al.* 2002).

Overloading of skeletal muscle produces hypertrophy and is associated with increases in IGF I mRNA and peptide level (Adams *et al.* 1996). IGF binding proteins are multifunctional proteins that transport IGF in circulation, localize IGF in specific cell types, and alter binding characteristics of IGF to receptors (Hwa *et al.* 1999). Serum IGF I is positively related to rates of muscle protein synthesis and has been measured extensively in recent studies of sarcopenia (Proctor *et al.* 1998). IGF I is known to decline with age and is related to the decline in lean mass in cross sectional studies across a wide age spectrum (Lamberts *et al.* 1997, Baumgartner *et al.* 1999).

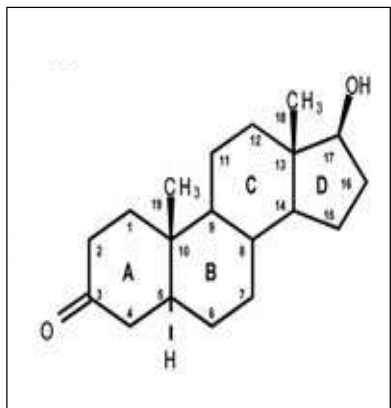
6.5 Cortisol



Cortisol is a steroid hormone which is produced in the adrenal cortex of the kidney. It is a stress hormone, which stimulates gluconeogenesis, which is the formation of glucose from sources other than glucose, such as amino acids and free fatty acids. Cortisol also inhibits the use of glucose by most body cells. This can initiate protein catabolism, thus freeing amino

acids to make different proteins, which may be necessary and critical in times of stress. In terms of hypertrophy, an increase in cortisol is related to an increased rate of protein catabolism. Cortisol breaks down muscle proteins, inhibiting skeletal muscle hypertrophy (*Spangenburg et al. 2002*).

6.6 Sex Hormone Binding Globulin



Sex hormone binding globulin (SHBG) is a glycoprotein possessing high affinity binding for 17 beta-hydroxysteroid hormones such as testosterone and oestradiol. It is synthesized in the liver, plasma concentrations being regulated by, amongst other things, androgen/oestrogen balance, thyroid hormones, insulin and dietary factors, it is involved in transport of sex steroids in plasma and its concentration is a major factor regulating their distribution between the protein-bound

and free states (*Grishkovskaya et al. 2000*).

7. SERUM HORMONES AND STRENGTH TRAINING

Human muscle metabolism is under homeostatic hormonal control, and strength training related changes in resting anabolic environment have been thought to play an important role in protein accretion, increased neurotransmitter synthesis, and strength development (*Gray et al. 1991, Kraemer et al. 1999*) attenuating the known sarcopenia and loss of strength with aging (*Kraemer et al. 1998, 1999, Häkkinen et al. 1994, 2000*).

According to Izquierdo (*Izquierdo et al. 2001*) subjects with lower levels of anabolic hormones may be able to produce minor strength gains vs. those with higher levels, especially during the last 8 weeks of the training period when the overall intensity and volume of the training were greatly increased. This may suggest that a low level of the anabolic hormone testosterone may be a limiting factor in strength development during prolonged strength and or power training in both middle aged and older people of both genders. Table 5 below shows the serum hormone concentrations the study by *Izquierdo*.

| Table 5. Serum hormone concentrations in middle aged (M46) and elderly (M64) men during the control period (weeks -4 to 0) and after the 16 wk strength training (weeks 0 to 16) | | | | |
|---|---------|---------|---------|---------|
| | Week -1 | Week 0 | Week 8 | Week 16 |
| M46 | | | | |
| Total testosterone, nmol/l | 19.1±8 | 18.6±5 | 18.5±5 | 19.4±6 |
| Free testosterone, pmol/l | 63.5±12 | 63.4±15 | 63±13 | 67±13 |
| Cortisol, nmol/l | 578±128 | 564±156 | 551±176 | 538±137 |
| M64 | | | | |
| Total testosterone, nmol/l | 17.4±4 | 18.8±5 | 19±6 | 17.8±5 |
| Free testosterone, pmol/l | 52.8±13 | 53±13 | 54±15 | 50.3±14 |
| Cortisol, nmol/l | 541±128 | 552±118 | 611±84 | 517±90* |
| Values are means ± SD. *Significantly different (P<0.05) from corresponding value at week 8. (<i>Izquierdo et al. 2001</i>) | | | | |

In a investigation by *Häkkinen et al. (2001)* no significant training induced changes occurred in the basal concentrations of serum anabolic and catabolic hormones in men, but the mean level of individual serum testosterone correlated significantly with the gains recorded in the CSA of the trained muscles, and a systematic acute exercise induced increase of GH was observed only after the 21 week strength training period. In the same study no changes were observed during the 21 week strength training

period in serum testosterone, free testosterone, DHEAS, GH, IGF I, or cortisol, nor in the testosterone SHBG ratios (Table 6). These results are similar to previous studies (Nicklas *et al.* 1995, Häkkinen *et al.* 1995, 2000, Kraemer *et al.* 1998).

Table 6. Serum total and free testosterone, GH, DHEAS, IGF I, cortisol and SHBG basal concentrations in older women during the 4 wk control period (week -4 to week 0) and the course of the 21-wk strength training period (weeks 0, 7, 14, and 21).

| | Weeks | | | | |
|---------------------------|-----------|-----------|-----------|-----------|-----------|
| | -4 | 0 | 7 | 14 | 21 |
| Testosterone, nmol/l | 1.8±1.2 | 1.9±0.9 | 1.6±0.6 | 1.1±0.5 | 1.5±0.7 |
| Free testosterone, pmol/l | 4.9±2.0 | 4.8±1.9 | 4.2±2.2 | 3.4±0.7 | 4.3±2.6 |
| GH, µg/l | 0.9±0.7 | 2.4±2.5 | 1.6±3.3 | 2.3±3.6 | 2.2±3.7 |
| DHEAS, µmol/l | 2.4±1.1 | 2.3±1.3 | 2.4±1.0 | 2.1±1.2 | 2.3±1.0 |
| IGF-I, nmol/l | 18.4±8.8 | 17.7±8.9 | 18.8±9.9 | 17.3±6.3 | 17.4±5.8 |
| Cortisol, µmol/l | 0.57±0.20 | 0.49±0.17 | 0.36±0.10 | 0.47±0.13 | 0.47±0.10 |

Values are means ± SD, n=10 subjects, GH, growth hormone, DHEAS, dehydroepiandrosterone sulfate, IGF I, insulin like growth factor I, SHBG, sex hormone binding globuline. (Häkkinen *et al.* 2001)

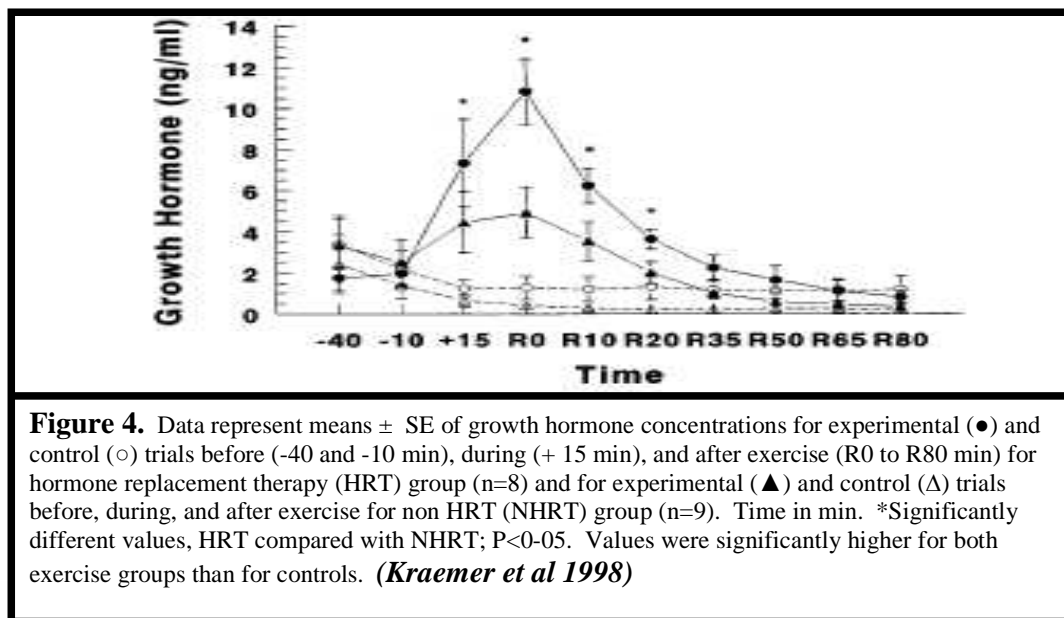
Similar results were found in a study by Figueroa *et al.* (2003) after a 12 month resistance and weight bearing aerobic exercise training program. There were no significant changes from baseline to 12 months in total levels of estrone, estradiol, GH, IGF 1, androstnoedione, and cortisol. Evidence indicates that declining muscle mass with age is associated with declining levels of circulating hormones (Baumgartner *et al.* 1999, Lamberts *et al.* 1997), including testosterone, IGF I, and DHEAS. It has been suggested that the decline in bone mineral density and muscle mass is associated with reduced GH release (Xu *et al.* 1996).

7.1 Menopause/Hormone Replacement Therapy

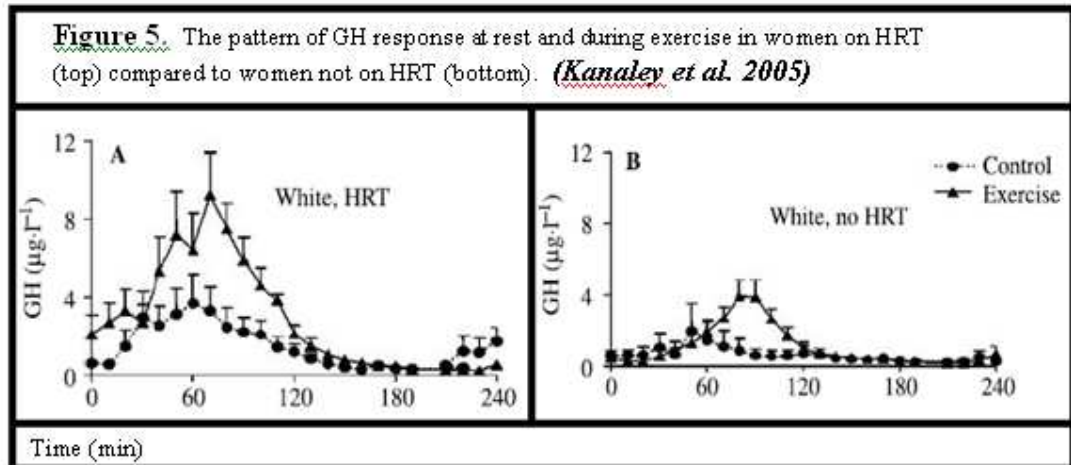
Aging is associated with several changes in hormonal levels, including a decrease in the concentrations of growth hormone (GH), testosterone, and insulin-like growth factor (IGF-1). A decrease in the concentrations of these hormones may be linked to the development of sarcopenia. GH and IGF-1 play a dominant role in the regulation of protein metabolism; GH and testosterone are required for protein maintenance; and IGF-1 levels are positively correlated with muscle protein synthesis rates, specifically myofibrillar protein (actin and myosin filaments) and myosin heavy chain synthesis (part of the myosin containing cross-bridges) (Waters *et al.* 2000). A sustained decrease in these hormones is linked to a decrease in muscle mass and an increase in body fat.

Although these hormones are involved in protein metabolism and maintenance, there is conflicting evidence whether hormone replacement is effective in maintaining or gaining muscle mass (*Roubenoff 2001*).

Total body and regional lean soft tissue mass can be increased and fat mass can be decreased with a combination of resistance and weight bearing aerobic exercise in postmenopausal women. Moreover these changes in body composition are not influenced by prolonged hormone replacement therapy (HRT) or by changes in total serum levels of GH, IGF I, and cortisol according to *Figuroa et al. (2003)*.



Exercise elevates growth hormone and prolactin blood concentrations in premenopausal women. Postmenopausal women taking hormone replacement therapy (Figure 4) maintain higher estrogen levels that could affect GH and PRL (*Kraemer et al. 1998*). A study by *Kanaley et al. (2005)* compared the GH response in women taking HRT to those without HRT at rest and during exercise (Figure 5).



The results revealed that the mean GH concentration was higher in the women on HRT both at rest and in response to exercise. With the increasing estrogen levels also comes a decreased testosterone level. *Sowers et al. (2000)* showed that in those women who used HRT had significantly lower testosterone concentrations in those who did not use HRT (Table 7).

Table 7. Mean total testosterone concentrations (pg/ml) associated with selected reproductive characteristics, from serum collected at three consecutive annual examinations. (*Sowers et al*)

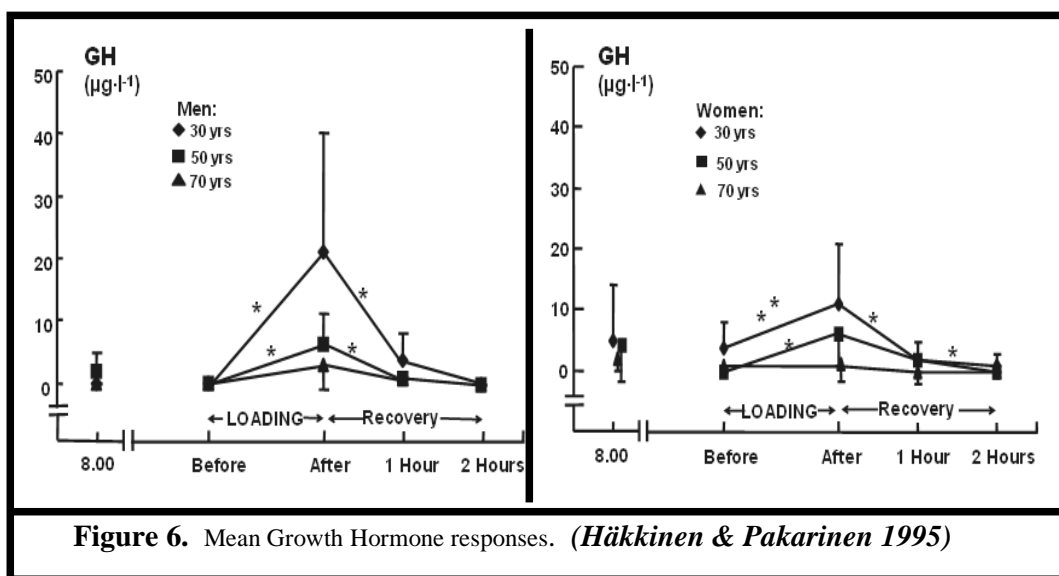
| | 1992–1993 | | 1993–1994 | | 1994–1995 | |
|-----------------------------|-----------|-----|-----------|-----|-----------|-----|
| | Mean | SD* | Mean | SD | Mean | SD |
| Hormone replacement therapy | | | | | | |
| Current users | 163 | 6.8 | 177 | 7.7 | 171 | 6.2 |
| Nonusers | 214 | 2.3 | 213 | 2.3 | 227 | 2.6 |

*SD Standard Deviation.

Figuroa et al. (2003) found that exercise training significantly increased total body and regional lean soft tissue mass and decreased leg fat mass and % body fat independent of HRT use. The same study found no significant exercise and HRT interactions for the changes in body composition. It should be recognized that HRT therapy is usually initiated due to postmenopausal symptoms, and HRT is very effective in eliminating such symptoms and increasing quality of life (*Strickler R. 2003, Warren M. 2004*). HRT also decreases the risk of bone fractures (*Barrett Connor et al. 2003*).

7.2 Gender Differences

The gender difference in GH release patterns may be caused by increased GH-releasing hormone (GHRH) responsiveness or by reduced somatostatin inhibitory tone in women (Veldhuis 1995). Häkkinen & Pakarinen (1995) compared the GH response in loading and recovery in both men and women (Figure 6) in three different groups; 30, 50, and 70 years of age. The primary results indicate that the response of GH concentrations to the same relative heavy resistance work load is greatly lowered with increasing age both in men and women, while acute responses in testosterone levels are minor.



Aerobic exercise is a powerful physiological stimulus of GH release (Kanalay *et al.* 1997, Lassarre *et al.* 1974) According to Giustina *et al.* (1998) and Van den Berg *et al.* (1996) GH release at rest is greater in young women than in comparably aged men. Wideman *et al.* (1999) showed that maximal GH concentrations during exercise were greater in men. However, the relative increase in GH concentration observed for men was significantly greater than the increase observed for women (Figures 7, 8). They also found that serum GH (secretion rate) was not affected by estradiol, total or free testosterone, or IGF I (Table 9). Total and free testosterone concentrations were greater in men than in women. There was no difference in the concentration of total or free testosterone during the rest compared with the aerobic exercise admissions. Serum estradiol and IGF I concentrations were similar in men and women.

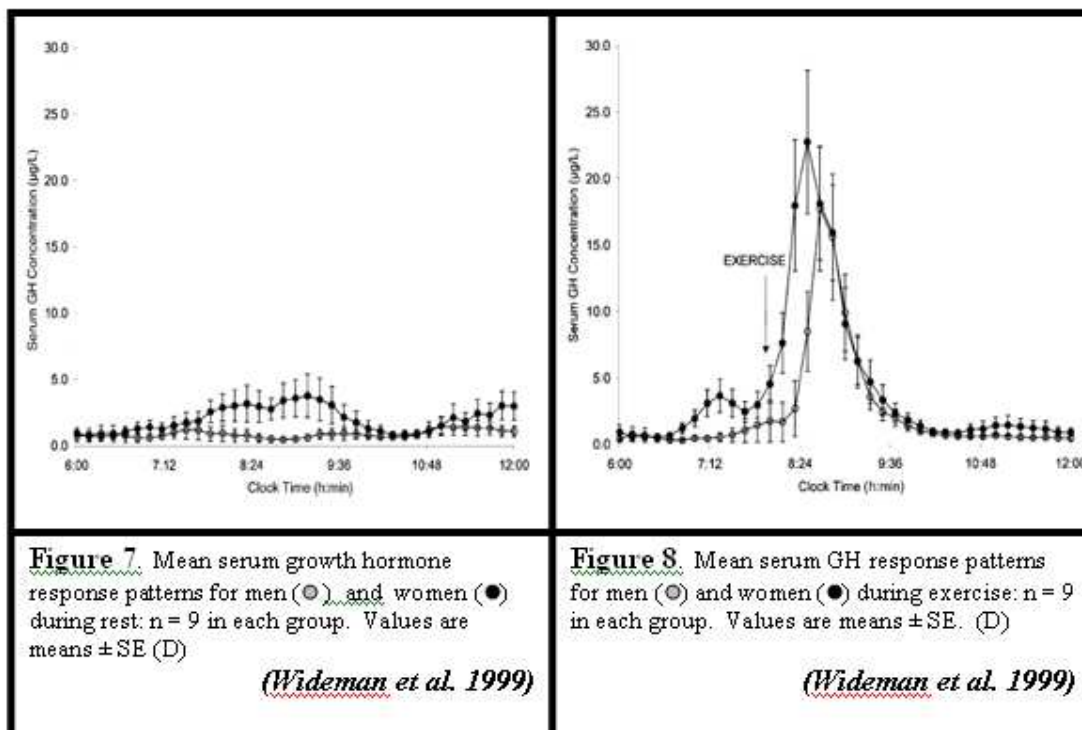


Table 9. Gender comparisons of serum concentrations of sex steroids and IGF I

(Wideman et al. 1999)

| | Rest | Exercise | Rest | Exercise |
|-----------------------------|------------|------------|------------|------------|
| Total testosterone, nmol/l* | 26 ± 1.4 | 24 ± 2.0 | 1.1 ± 0.1 | 1.0 ± 0.1 |
| Free testosterone, pmol/l* | 88 ± 8.0 | 92 ± 10.2 | 9.0 ± 3.9 | 4.0 ± 0.5 |
| Estradiol, pmol/l | 132 ± 10.9 | 143 ± 16.5 | 110 ± 25.7 | 99 ± 15.4 |
| IGF-I, µg/l | 338 ± 18.0 | 319 ± 19.0 | 328 ± 32.0 | 327 ± 22.0 |

Values are means ± SE: n = 9 for men and n = 9 for women: IGF I insulin like growth factor I. *Values for men are significantly greater than those for women. $P < 0.05$.

8. METHODS

8.1 Subjects

Subjects composed of 96 volunteers who were healthy, moderately active women between the ages of 40-65. Subjects had no previous experience with systematic strength or endurance training during the previous year before the study. The participants were randomized according to age and BMI into four groups: strength n=27, endurance n=26, combined n=25, and control n=18. All subjects gave written informed consent and were fully informed about the possible risks and requirements of the study. The study was approved by the Ethics Committee of Jyväskylä Central Hospital. Table 10 shows the subjects' physical characteristics pre and post training.

8.2 Experimental Design

The total duration of the study was 22 weeks. The experimental design included one week control period and 21 weeks of physical training separated into three sub-training periods with measurements taken at -1, 0, 10.5, and 21 weeks (minus, pre, mid, post). The training programs composed of exercises that activated a large amount of muscle bulk and increased energy metabolism. The program consisted of periodised training so that the intensity and amount of training was progressively increased throughout the six-month training period. During this training period all groups including the controls were instructed to maintain their habitual physical activities. This was monitored by the training diaries.

The strength and endurance groups trained twice a week, with the combined training group participating in both strength and endurance training sessions for a total of four sessions a week. All training sessions were supervised.

8.3 Training Protocols

The strength training program was divided into three sub-training periods;

- 1) to improve muscle strength and endurance and to reduce total fat, 15-30 repetitions per set with a load of 30-60% 1RM (months 1-2).
- 2) to produce muscle hypertrophy to further increase the total muscle mass/fat ratio, 6-12 repetitions per set with a load of 60-80% 1RM (months 3-4).
- 3) to optimise gains in maximal strength of trained

muscles, 5-8 x 70-85 % 1RM (months 5-6). The training protocols to increase muscle mass were used primarily during months 3-4 so that the loads increased progressively up to 60-80 % of the maximum with 6-12 reps per set. To optimise strength development primarily during months 5-6, higher loads of 70-85 % (5-8 reps per set) were used. The exercises implemented in the strength training protocol were: leg press, lying hamstring curl, knee extensions, bench press, standing/seated biceps curl, triceps pressdown, abdominal crunches, lower back extensions, thigh abduction/adduction, lat pull downs, seated calf raises, lower back hyperextensions. The overall intensity and amount of training increased progressively throughout the 6-month training period following a so-called periodized training program.

Endurance training program by bicycle ergometer was similarly divided into three different loading phases;

- 1) 30 min two times a week under the level of aerobic threshold. These sessions included also a few 10 min sessions above the aerobic threshold to accustom to higher intensity (months 1-2).
- 2) 45 min divided into four loading intervals: 15 min under the aerobic threshold, 10 min between the aerobic-anaerobic thresholds, 5 min above the anaerobic threshold and 15 min under the aerobic threshold. This phase also had 60 min training sessions under the level of their aerobic threshold.
- 3) 30 min under the aerobic threshold, 2 x 10 min between the aerobic-anaerobic thresholds, and 2 x 5 min above the anaerobic threshold. Every other training session included 90 min cycling under the aerobic threshold (months 5-6).

Combined training group performed both strength and endurance training as described above.

8.4 Muscle Thickness by Ultrasound

The distance between the subcutaneous adipose tissue-muscle interface and intramuscular interface was defined as muscle thickness. The same investigator made all measurements. Muscle thickness was measured from right upper (triceps brachii and biceps brachii) and lower limb (vastus lateralis, vastus intermedius and biceps femoris) using ultrasonography (model SSD-2000, Aloka, Tokyo).

Biceps brachii (BB). The muscle thickness of the right upper limb flexor was measured at a point 30 % distal to the processus coracoideus on a line from the processus to the aponeurosis of biceps brachii (*Seniam 1999*). The muscle thickness was measured in the same condition as triceps brachii (TB). The muscle thickness was determined as the distance between adipose tissue and the deep fascia.

Vastus lateralis (VL) and vastus intermedius (VI). The muscle thickness of the lower limb extensors were measured from the right leg. The thickness was measured at the midway point between the anterior spina iliaca superior and the lateral side of patella (*Seniam 1999*). The measurement point and the muscle thickness measurement were conducted while the subject was lying relaxed on her back. A soft support was utilized under the knee and the heel of the subject was in contact with a vertical support. The muscle thickness was determined as the distances from the adipose tissue – muscle interchange to the aponeurosis between the VL and VI for vastus lateralis and as the distance from the VL – VI aponeurosis to the muscle – bone interchange in case of vastus intermedius muscle. Total thickness (VL+VI) was calculated as the sum of the thicknesses.

Biceps femoris (BF). The thickness of the lower limb flexor muscle was measured at the midway point on a line connecting the ischial tuberosity to proximal head of fibula (*Seniam 1999*). The measurement point was determined while the subject was lying prone with a soft support under the ankles. The muscle thickness was determined as the distance between the adipose tissue – muscle interface and the deep aponeurosis.

The measurement sites were chosen in accordance with *Abe et al. (2000)*.

As all of the measurements, the ultrasonographic measurements were conducted at the same time of day in each measurement. The subjects were asked to refrain from strenuous physical activities two days prior to the ultrasonographic measurement. The scanning head was coated with water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. In the measurements a generous amount of gel was applied to the ultrasound probe to ensure high quality imaging. The probe was held perpendicular to the skin while applying minimal pressure. The measurement was repeated 2 to 4 times and the goal was to get two measurements within two

millimetres of each other. The result was taken as the average of the two most closely matched measurements.

After the first measurement the measurement sites were tattooed on the skin to ensure that the same site was used in the ensuing measurements. The same person conducted the muscle thickness measurements each time. In this study the difference in muscle thickness between the weeks -1 and 0 was 0.5 (2.8) % (ns.) in the upper extremity extensor and 0,1 (3,1) % (ns.) in the flexor. The corresponding value in lower extremity extensor was (VL+VI) 0,5 (5,0) % (ns.) and 1,1 (7,6) % (ns.) in the flexor.

8.5 Lean Body Mass by Dual X-Ray Absorptiometry

Whole body and regional body composition were estimated by DEXA (LUNAR, GE Healthcare) located at the Jyväskylä Central Hospital. The system software (enCORE 2005, version 9.30) provides the mass of lean soft tissue, fat, and bone mineral for the whole body and specific regions (trunk and both arms and legs). Appendages were isolated from the trunk and head by using DEXA regional computer-generated default lines with manual adjustments (*Kim et al. 2002*). The same investigator made all the measurements and also all manual adjustments.

8.6 Percentage of Body Fat

Subcutaneous fat: The fat percentage was estimated by measuring skin-fold thickness at four different sites according to *Durnin and Womersley (1974)*. The average of three measurements was used in calculations. The same investigator made all the measurements.

8.7 Serum Hormones

Resting blood samples were drawn at weeks -1 (1 week prior to the beginning of training) 0, 10, and 21 (minus, pre, mid and post respectively) during the training period. All subjects were instructed not to eat anything 12 hours prior to the blood sample. The subjects reported to the laboratory and were sitting quietly for 15-20 minutes before the sample was taken. The samples were composed of 7 ml blood of which contained 4 ml serum. All samples were taken from the antecubital vein to determine concentrations of testosterone, DHEAS, growth hormone, insulin growth

factor, cortisol, and SHBG. The sensitivity of the testosterone assay was 0.5 nmol/L, and the intra-assay coefficient variation was 5.7%. The sensitivity of the DHEAS assay was 0.08 μ mol/L, and the intra-assay coefficient of variation was 6.2%. The sensitivity of the growth hormone assay was 0.026 mIU/L, and the intra-assay coefficient of variation was 1.9%. The sensitivity of the insulin growth factor I assay was 20ng/mL, and the intra-assay coefficient of variation was 2.3%. The sensitivity of the cortisol assay was 5.5 nmol/L, and the intra-assay coefficient of variation was 4.8%. The sensitivity of the SHBG assay was 0.2 nmol/L, and the intra-assay coefficient of variation was 4.8%. Samples were taken between the hours of 8 and 10 am to reduce the effects of diurnal variation in hormonal concentrations. All samples were taken by the same laboratory technician, stored at -80°C, and analyzed 1-4 weeks after the final samples were taken. The blood samples were analyzed in the same assay for each hormone by the Immulite 1000 Analyzer (DPC Diagnostics Corporation, Los Angeles, USA), according to the instructions of the manufacturer.

8.8 Statistical Analysis

SPSS version 14.0 for Windows was used for statistical analyses (SPSS, Inc., Chicago, IL). Statistical comparisons during the control period (weeks -1 to 0) was performed by paired t-test. The training related effects were assessed using a two-way analysis of variance (ANOVA) with repeated measures (groups x time). An LSD post-hoc was used when appropriate to locate the pairwise differences between the means. Selected relative changes were analysed via one-way ANOVA. Differences within groups were analyzed by t-test. Statistical difference was assessed at the level of $p < 0.05$.

9. RESULTS

9.1 Physical characteristics

There were no significant differences between groups in any physical characteristics variable at minus, pre, mid, or post measurement. Below table 10 shows a significant difference ($p < 0.05$) was found in BMI from pre to post measurement in the E group. Significant difference ($p < 0.05$) was also found in fat % in S and SE groups between pre and post measurements.

| | | Age | Height | Weight | | BMI | | Fat % | |
|--|------|------|--------|--------|------|------|-------|-------|-------|
| | | | | Pre | Post | Pre | Post | Pre | Post |
| Endurance (E) (<i>N</i> = 26) | Mean | 51,8 | 162,8 | 66,9 | 66,1 | 25,1 | 24,9* | 34,0 | 34,0 |
| | SD | 7,21 | 6,70 | 9,68 | 9,61 | 2,67 | 2,61 | 2,76 | 2,64 |
| Strength (S) (<i>N</i> = 27) | Mean | 52,2 | 163,9 | 65,2 | 64,9 | 24,2 | 24,1 | 33,2 | 32,6* |
| | SD | 8,21 | 7,02 | 9,44 | 9,31 | 2,99 | 2,82 | 3,95 | 3,71 |
| Combined (SE) (<i>N</i> = 25) | Mean | 50,6 | 163,1 | 66,7 | 66,3 | 25,1 | 24,9 | 33,7 | 33,1* |
| | SD | 6,99 | 6,07 | 9,22 | 9,13 | 3,07 | 2,81 | 3,69 | 3,18 |
| Control (C) (<i>N</i> = 18) | Mean | 51,4 | 166,7 | 67,0 | 66,6 | 24,1 | 24,0 | 34,1 | 33,7 |
| | SD | 7,81 | 6,40 | 7,57 | 7,72 | 2,38 | 2,43 | 3,98 | 4,09 |

* $p < 0.05$ significant difference within group from pre to post measurement

9.2 Hypertrophy

9.2.1 Muscle Thickness by Ultrasound

Biceps brachii had significant changes in the S and SE groups (figure 9). The S group showed significance ($p < 0.001$) from pre-mid, pre-post, mid-post. The SE group had significance ($p < 0.001$) from pre-mid, pre-post, mid-post. Biceps brachii relative changes between groups all shown in figure 10. S group had significant pre-mid values from E ($p < 0.001$), SE ($p < 0.05$) with corresponding values 7.0 and 2.3%. The S group had significant pre-post values from E, C, ($p < 0.001$), and SE ($p < 0.01$) with values 9.9, 9.0, and 3.4% respectively. The SE group had significance from E, and C groups ($p < 0.001$). The SE pre-mid values from the E group were 4.6%. The SE groups pre-post values from the E and C groups were 6.5 and 5.6% respectively.

Triceps brachii showed significant within group changes in S, E, and SE (figure 11). The S group had significant changes from pre-mid, pre-post ($p<0.001$), and mid-post ($p<0.01$). The E group had significant changes from pre-post ($p<0.05$), and mid-post ($p<0.01$). The SE group had significant changes from pre-mid, pre-post ($p<0.001$), and mid-post ($p<0.05$). Triceps brachii relative changes between groups all shown in figure 12. S group had significant changes in the pre-mid measurement ($p<0.05$) from E with a value of 2.9%, and also the C group but at the $p<0.1$ level (2.3 %). The S group had significant changes in the pre-post measurement from E ($p<0.01$), and C ($p<0.001$) groups with corresponding values of 4.1 and 6.2 %. The SE group had significant differences from C group ($p<0.01$) in the pre-post measurement with a value of 4.3%.

Biceps femoris long exhibited significant changes in S, E and SE groups (figure 13). The S group had significance from pre-mid, pre-post ($p<0.001$) and mid-post ($p<0.05$). The E group had significance from pre-mid and pre-post ($p<0.001$). The SE group had significance from pre-mid, pre-post ($p<0.001$) and mid-post ($p<0.01$). Biceps femoris long relative changes all can be seen in figure 14. The S group had significant changes from pre-post ($p<0.01$) from C group with a value of 3.9%, and also from SE group but with $p<0.01$ and value 1.9%. The SE group had significance from the pre-mid measurement with group E ($p<0.01$) with a value of 3.4%. SE group had significance from pre-post measurements with E ($p<0.01$) and C groups ($p<0.001$) with corresponding values 4.4 and 6.1%.

Vastus lateralis + intermedius had significant changes in S, E, and SE groups (figure 15). The S group had significance from pre-mid, pre-post ($p<0.001$), and mid-post ($p<0.05$). The E group had significance from pre-mid, pre-post ($p<0.001$), and also mid-post ($p<0.05$). The SE group had significance from pre-mid, pre-post ($p<0.001$). Vastus lateralis + intermedius relative changes all can be seen in figure 16. S group had significance from mid-post with C group ($p<0.05$) with a value of 4.1%. The SE group had significance from pre-mid with S, and E ($p<0.01$). The SE group had significance from pre-post with S ($p<0.05$), E ($p<0.01$) and C ($p<0.001$) groups.

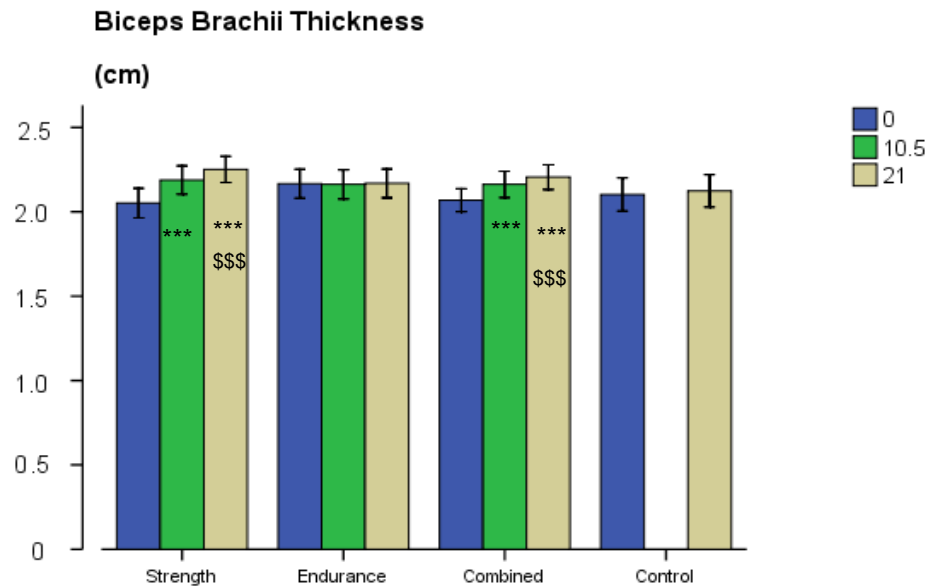


FIGURE 9. Mean (+/- 2 SE) biceps brachii muscle thickness. *** significant from pre (p<0.001). \$\$\$ significant from mid (p<0.001).

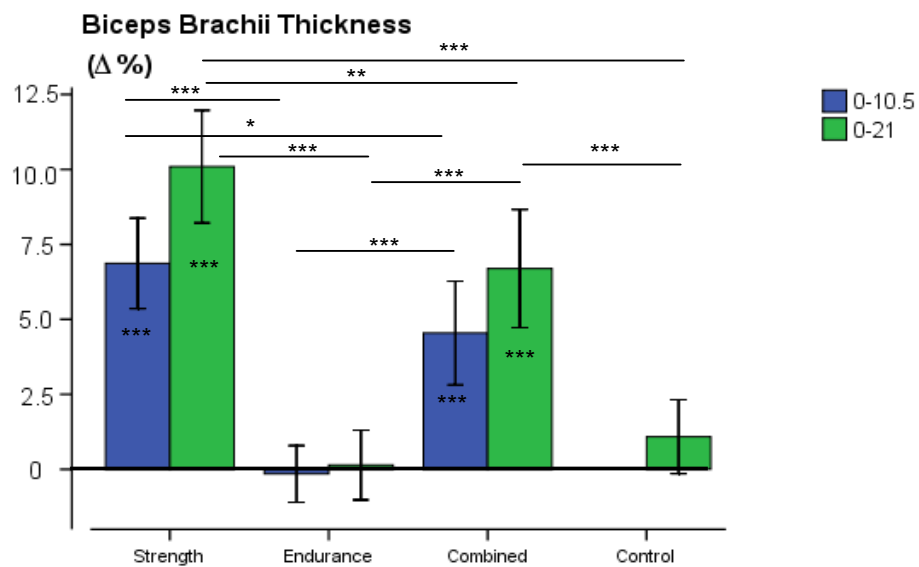


FIGURE 10. Mean (+/- 2 SE) relative changes in biceps brachii muscle thickness. * significance p<0.05, **p<0.01, ***p<0.001.

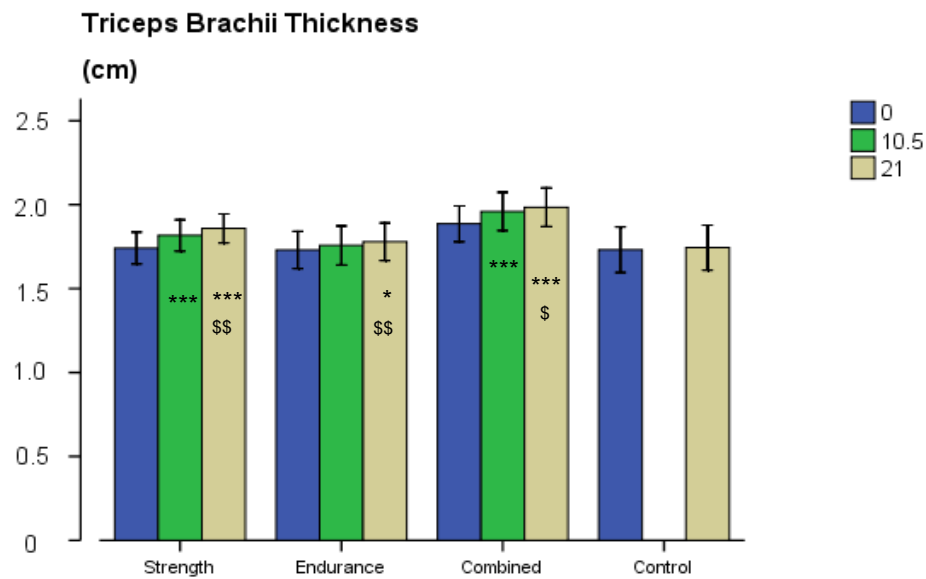


FIGURE 11. Mean (+/- 2 SE) triceps brachii muscle thickness. * significant from pre ($p < 0.05$), *** significant from pre ($p < 0.001$). \$ significant from mid ($p < 0.05$), \$\$ significant from mid ($p < 0.01$).

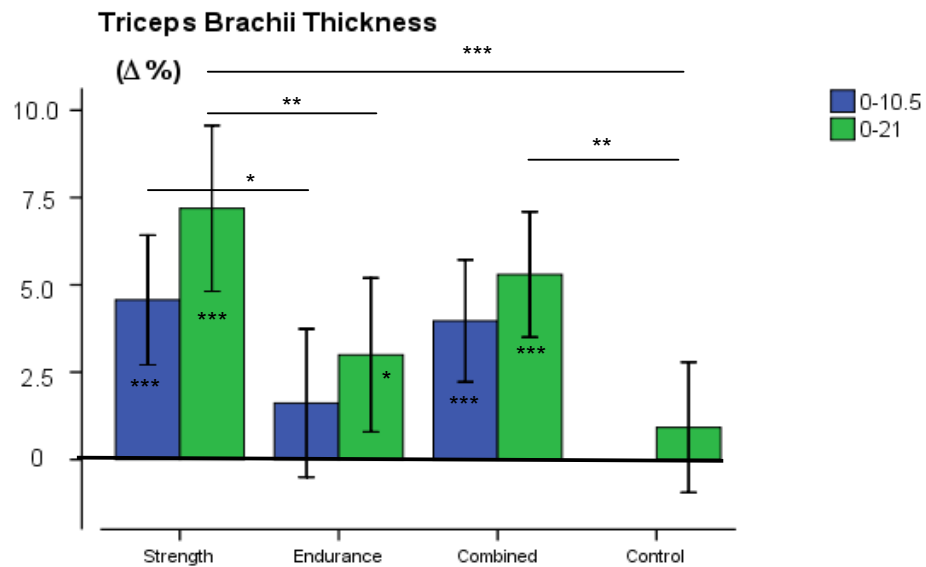


FIGURE 12. Mean (+/- 2 SE) relative changes in triceps brachii muscle thickness. * significance $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

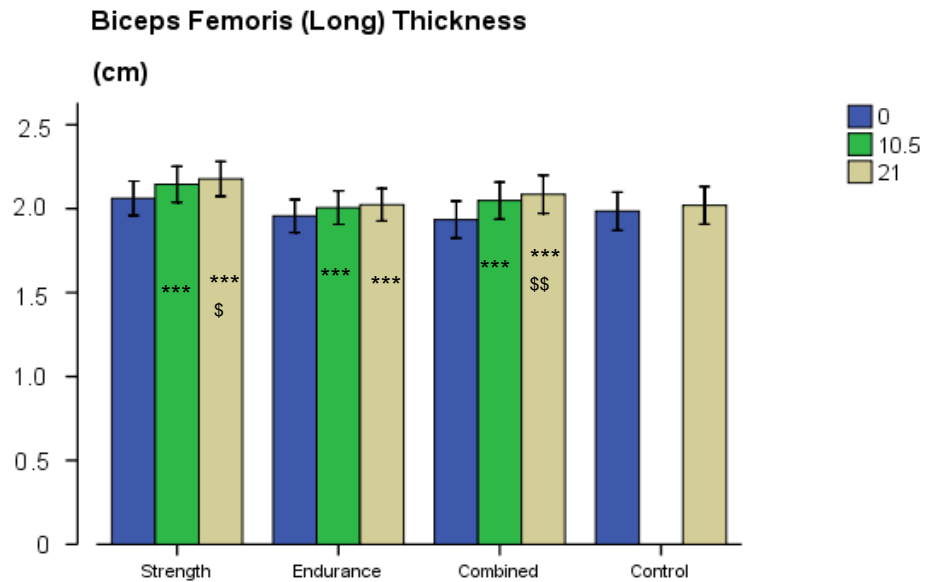


FIGURE 13. Mean (\pm 2 SE) biceps femoris muscle thickness. *** significant from pre ($p < 0.001$). \$ significant from mid ($p < 0.05$), \$\$ significant from mid ($p < 0.01$).

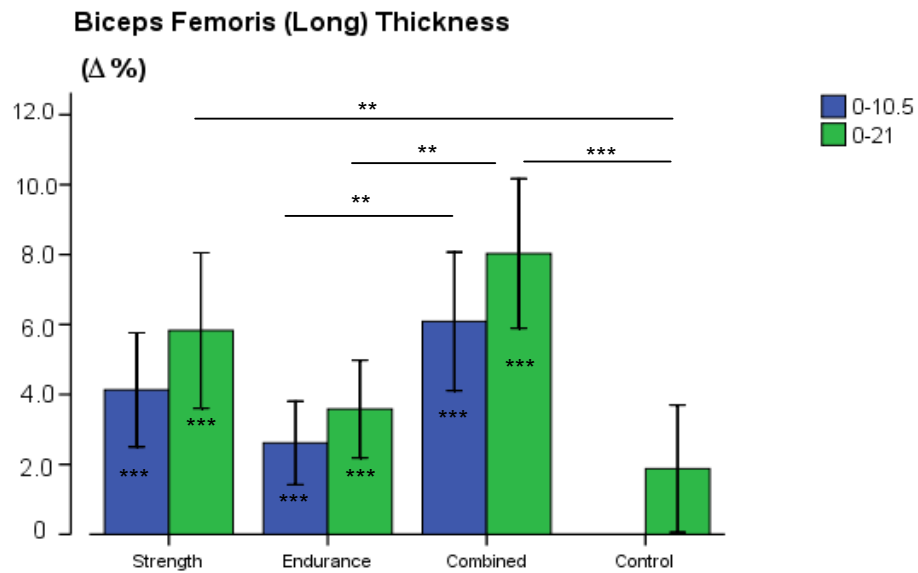


FIGURE 14. Mean (\pm 2 SE) relative changes in biceps femoris muscle thickness. * significance $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

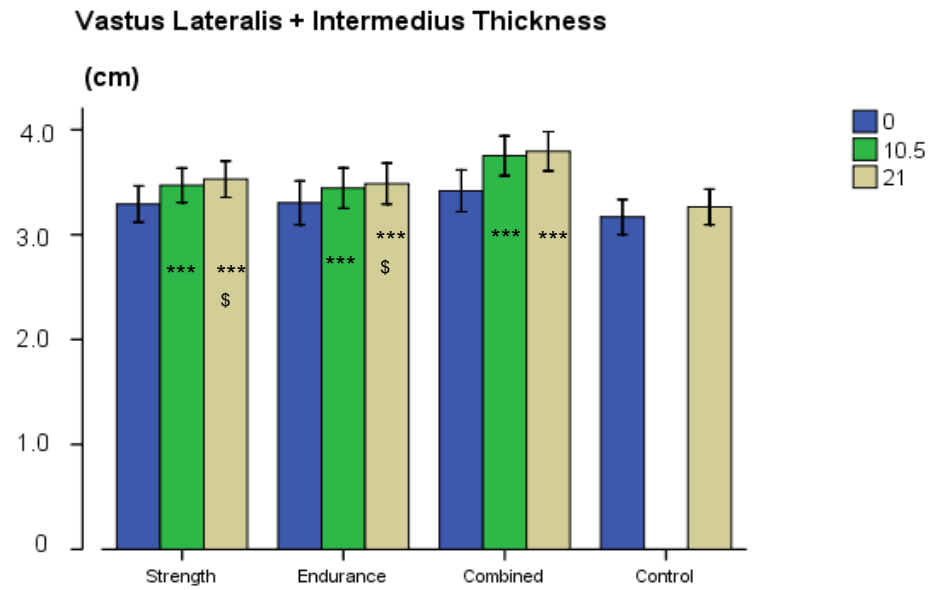


FIGURE 15. Mean (+/- 2 SE) vastus lateralis + intermedius muscle thickness.
 *** significant from pre (p<0.001). \$ significant from mid (p<0.05).

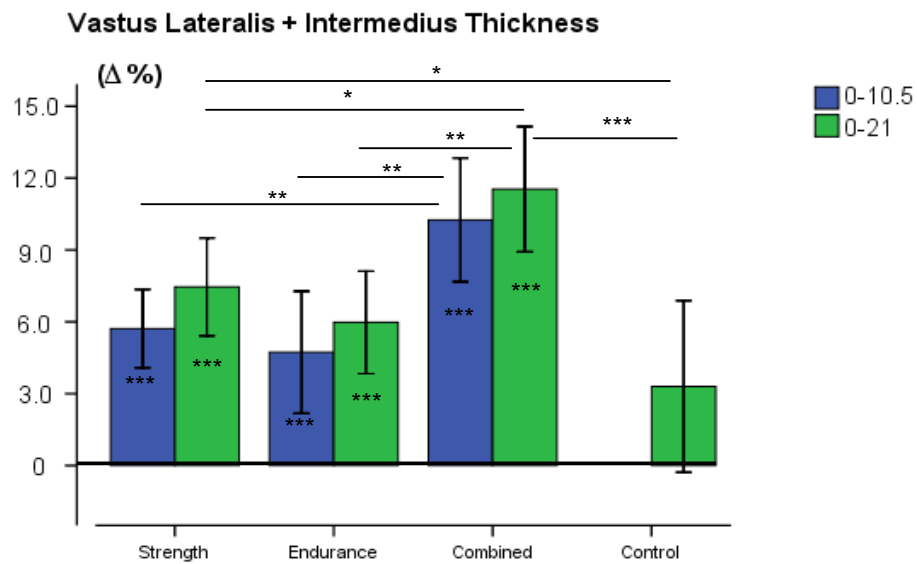


FIGURE 16. Mean (+/- 2 SE) vastus lateralis + intermedius muscle thickness.
 * significance p<0.05, **p<0.01, ***p<0.001.

9.2.2 Lean Body Mass by Dual X-Ray Absortometry

Lean mass of the arms increased significantly in S and SE ($p < 0.05$), while E and C showed significant ($p < 0.05$) decreases (figure 17). The SE group also exhibited significant differences ($p < 0.001$) from groups E and C (3.6 and 3.7% respectively).

Lean mass of the legs increased significantly (figure 19) in S ($p < 0.05$), E ($p < 0.01$), and SE ($p < 0.001$). Groups S ($p < 0.05$), E ($p < 0.01$), and SE ($p < 0.001$) all exhibited significant relative increases (1.4, 1.8, and 4.0% respectively, figure 20). The SE group had significant increases compared to S, C, ($p < .01$), and E ($p < .05$) groups.

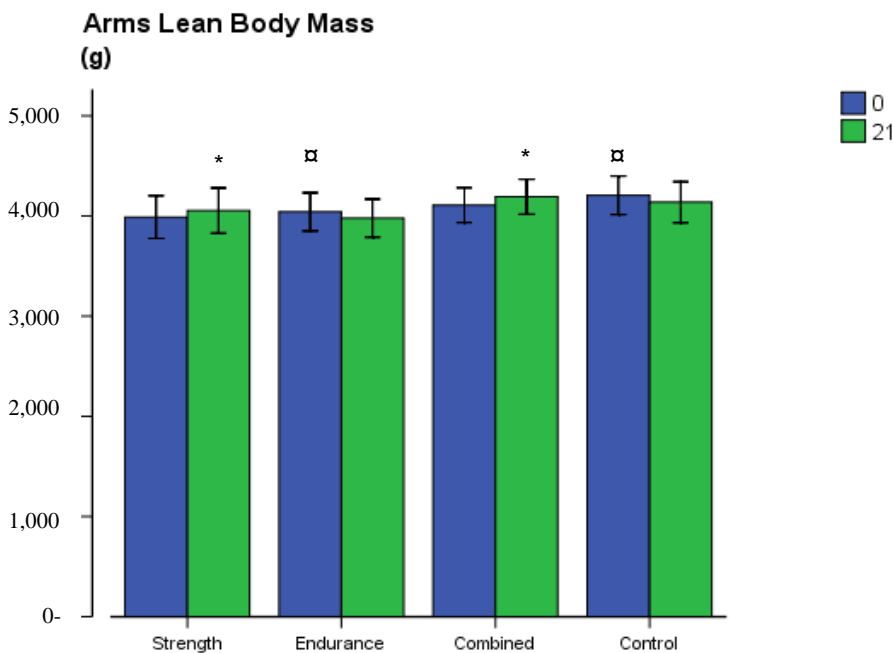


FIGURE 17. Mean (\pm 2 SE) arms lean body mass. * significant from pre ($p < 0.05$).
 α significant from post ($p < 0.05$).

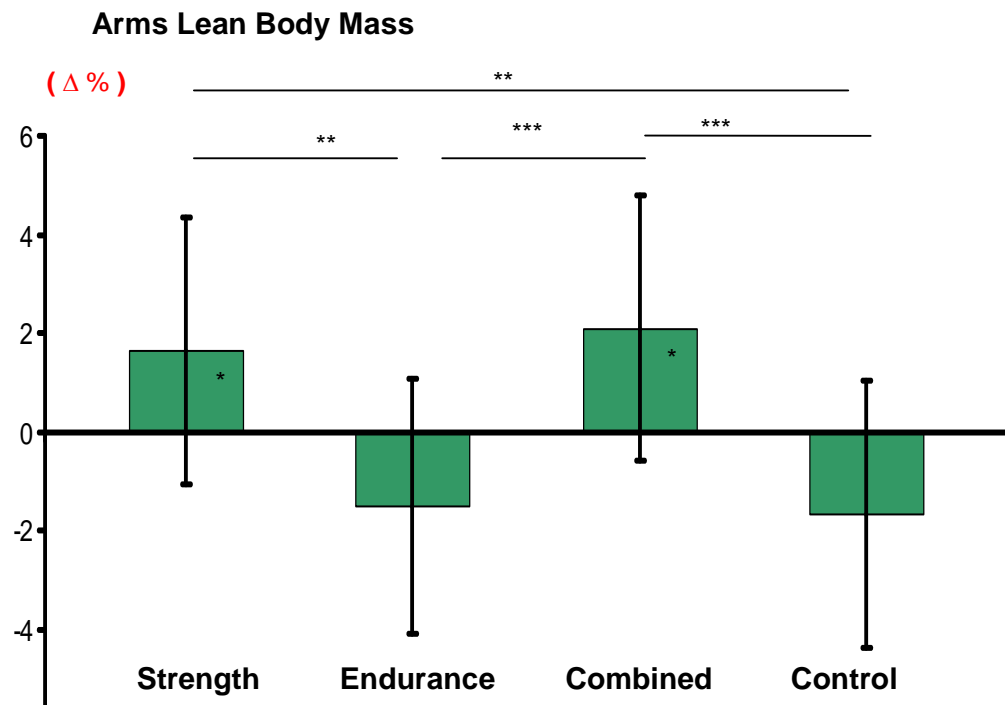


FIGURE 18. Mean (\pm 2 SE) relative changes in arms lean body mass. * significance $p < 0.05$, ** significance $p < 0.01$ ***significance $p < 0.001$.

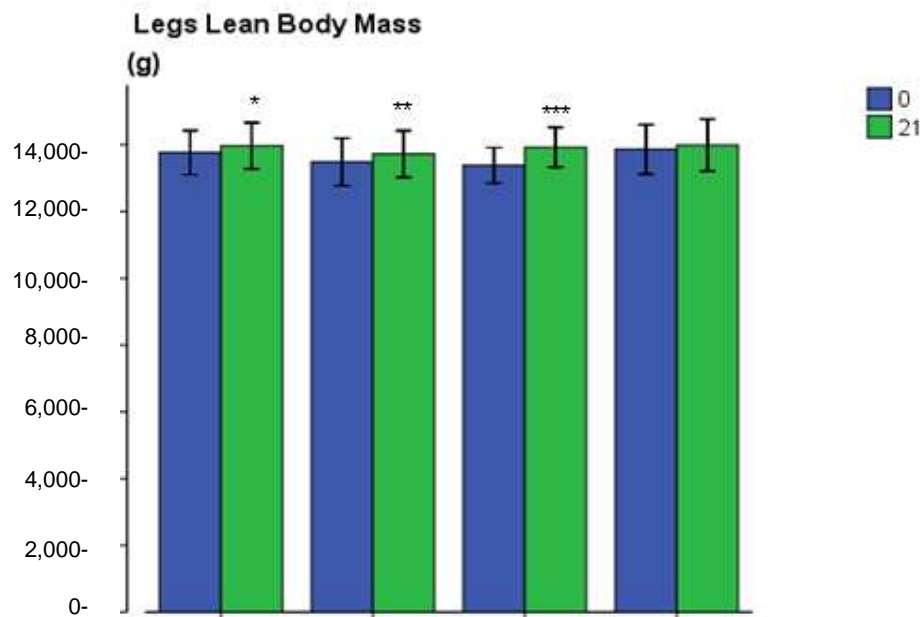


FIGURE 19. Mean (\pm 2 SE) relative changes in legs lean body mass. * significant from pre ($p < 0.05$), **significant from pre ($p < 0.01$), ***significant from pre ($p < 0.001$), significant from post ($p < 0.05$).

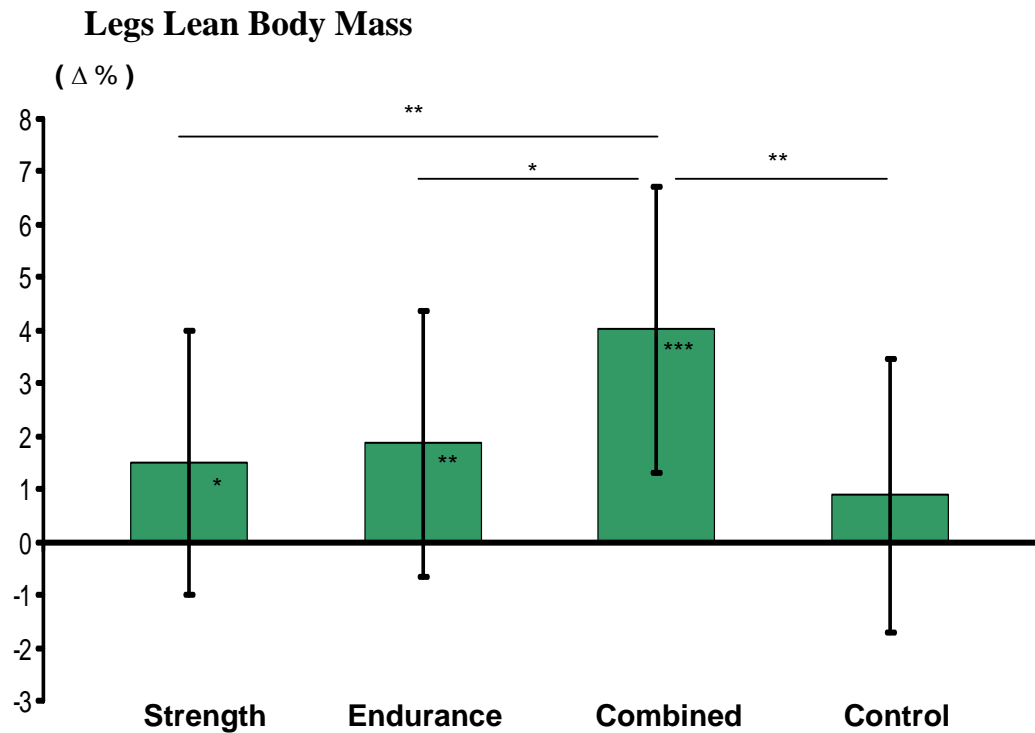


FIGURE 20. Mean (\pm 2 SE) relative changes in legs lean body mass. * significance $p < 0.05$, ** significance $p < 0.01$, ***significance $p < 0.001$.

9.3 Hormonal Changes

Within group changes were found in testosterone, DHEAS, IGF I and cortisol. No significant differences between groups were found in reference to DHEAS, growth hormone, insulin growth factor I, cortisol, and SHBG. All training groups had significant differences in serum testosterone compared to control group.

Serum testosterone increased significantly during training in S, E and SE (figure 21). S group had increases ($p < 0.05$) from weeks minus-21 and 0-21. In E serum testosterone increased significantly also from mid to post measurement. The SE group showed significant increase during the control measurements ($p < 0.05$), and 0-21 ($p < 0.001$) and from 10.5-21 ($p < 0.05$). In reference to between group's significant changes, all training groups showed significant relative changes in comparison to the C group (figure 22). Groups S, and E had significant ($p < 0.05$) relative increases compared to C group, while SE showed significant increase ($p < 0.01$) to C group.

Serum DHEAS did not change during training in training groups (figure 23). Growth hormone had no significant changes within any group during the 21 week training program (figure 24).

IGF I had within group significant changes in E and SE groups (figure 25). E group showed a difference ($p<0.05$) from week minus-0. The SE group had significant differences ($p<0.05$) during the control period (week minus-0), and weeks 0-21, and at the $p<0.01$ level weeks 10.5-21. IGF I had no significant changes over the course of the 21 week training program between any groups (figure 26).

Serum cortisol showed significant increases in all training groups (figure 27). The S group increased serum cortisol from both minus-post ($p<0.01$) and mid-post ($p<0.05$). The E group had significance from minus to post ($p<0.01$), pre-post ($p<0.001$), pre-mid ($p<0.05$) and mid-post ($p<0.01$). The SE group had significant values from minus-pre ($p<0.01$), minus-post ($p<0.01$), pre-mid ($p<0.05$), pre-post ($p<0.001$), and mid-post ($p<0.01$). SHBG had no significant within group changes over the course of the 21 week training program (figure 28).

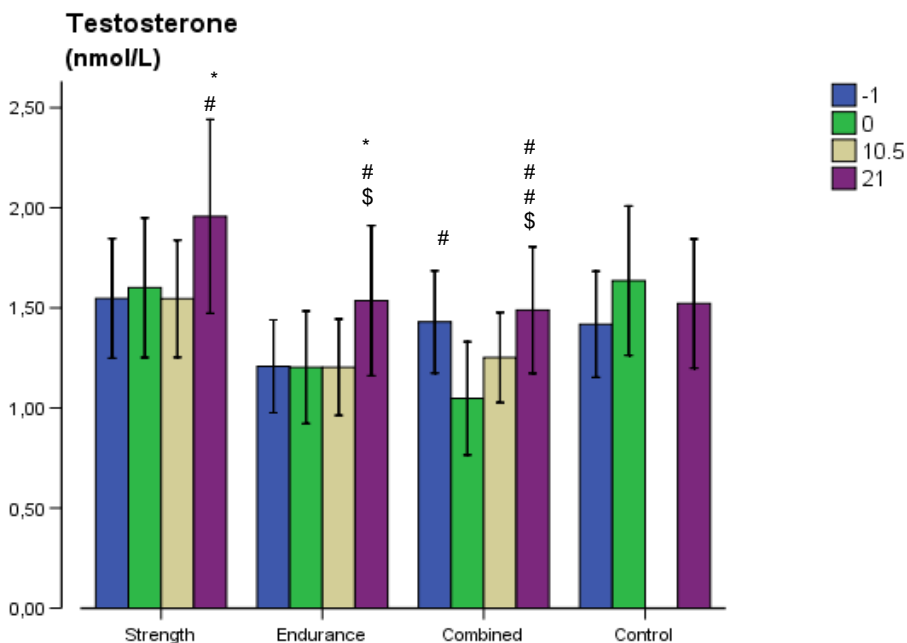


FIGURE 21. Mean (+/- 2 SE) serum testosterone concentrations. * significant from minus ($p<0.05$), # significant from pre ($p<0.05$), ### significant from pre ($p<0.001$), \$ significant from mid ($p<0.05$).

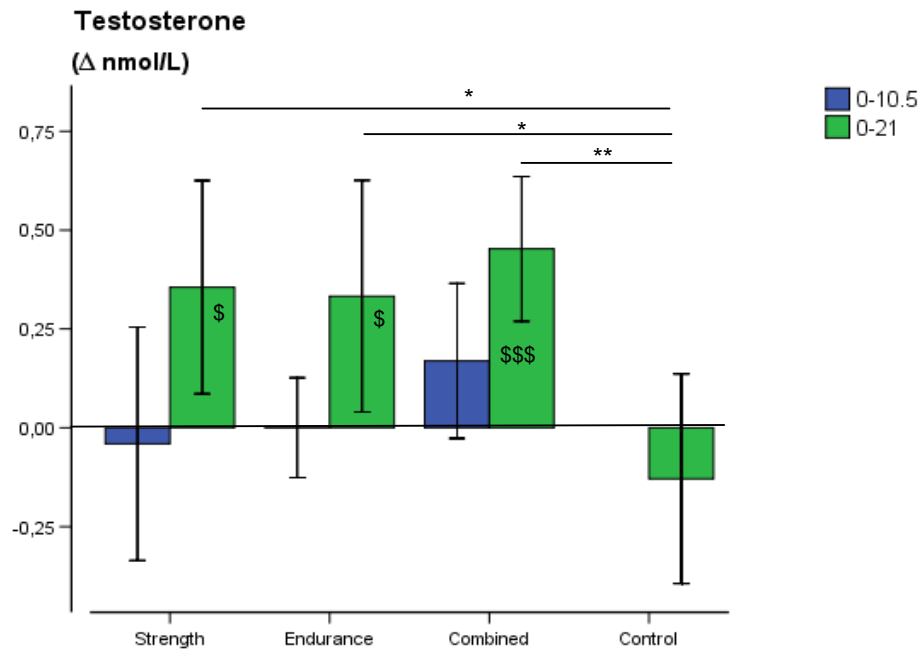


FIGURE 22. Mean (\pm 2 SE) serum testosterone relative changes. * significant from control ($p < 0.05$), ** significant from control ($p < 0.01$). \$ significant from pre-mid ($p < 0.05$).

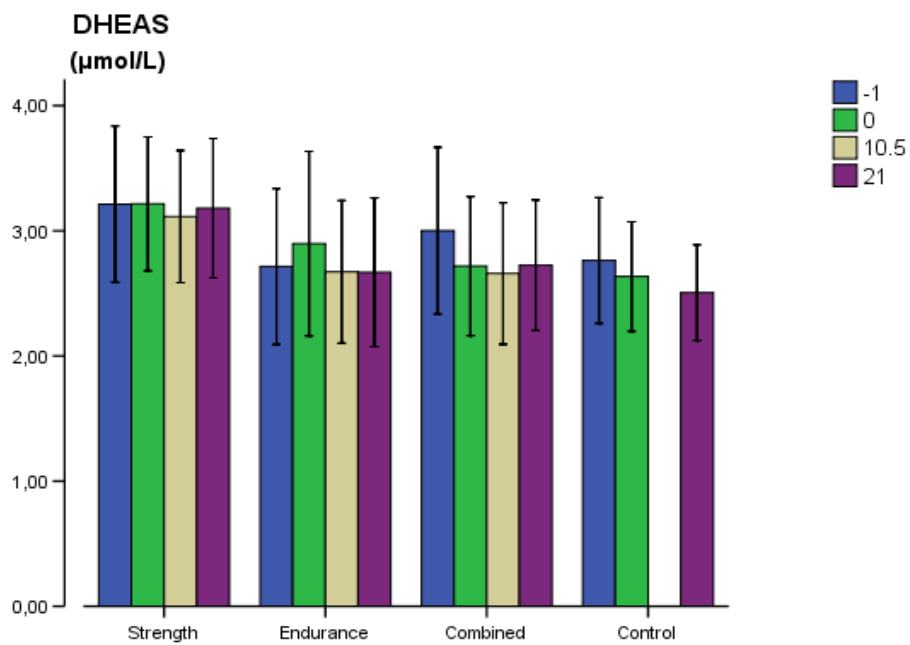


FIGURE 23. Mean (\pm 2 SE) serum DHEAS concentrations. □ significant from post ($p < 0.05$).

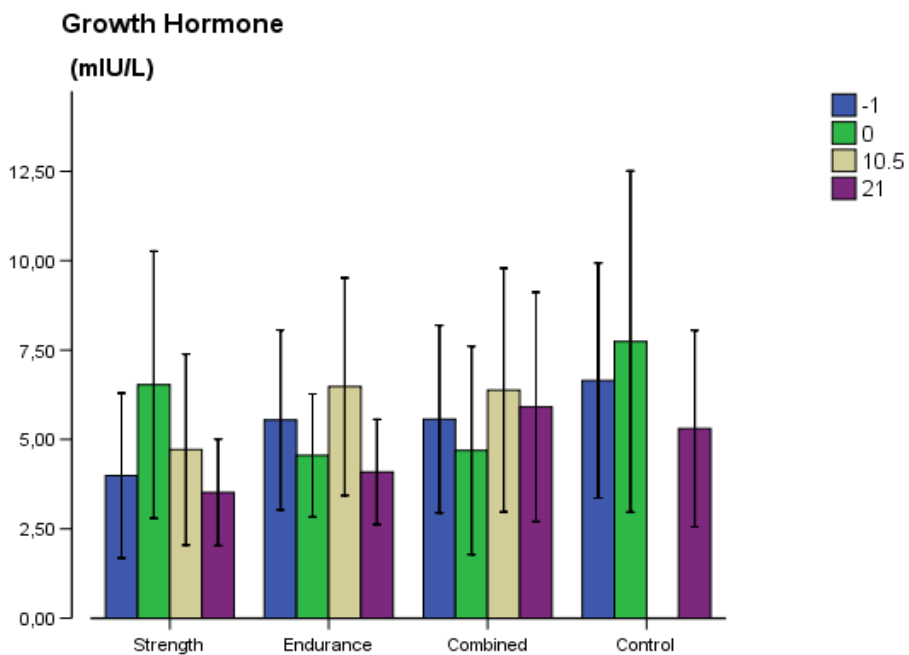


FIGURE 24. Mean (\pm 2 SE) serum growth hormone concentrations.

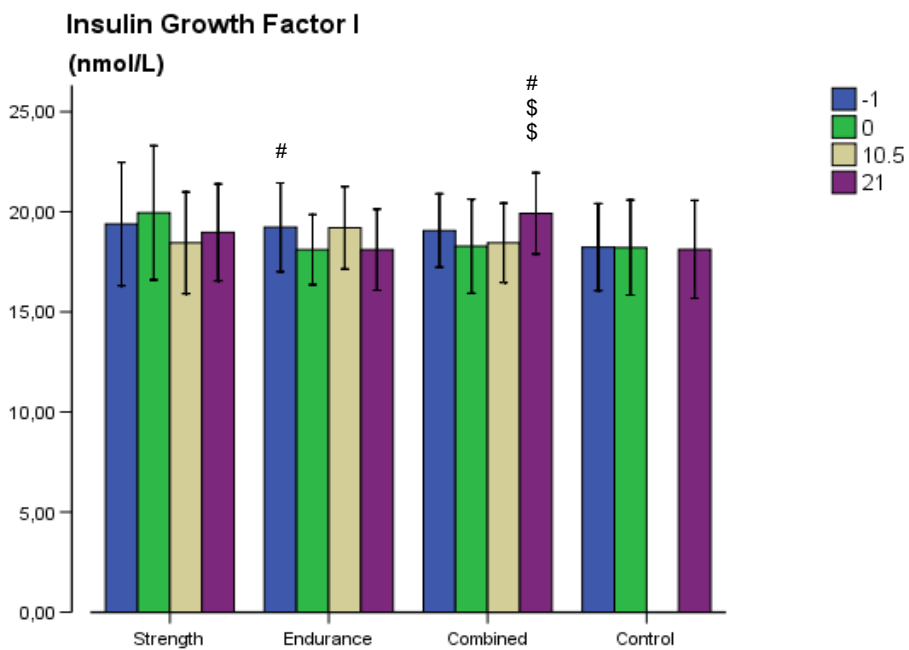


FIGURE 25. Mean (\pm 2 SE) serum insulin growth factor I concentrations.
 # significant from pre ($p < 0.05$), \$\$ significant from mid ($p < 0.01$).

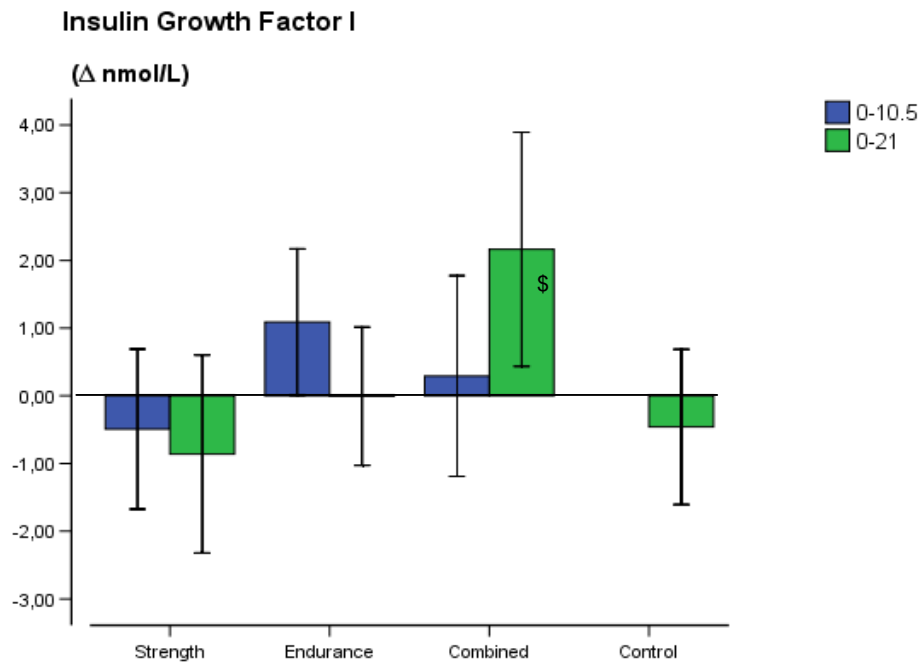


FIGURE 26. Mean (\pm 2 SE) serum insulin growth factor I relative changes. \$ significant from pre-mid ($p < 0.05$).

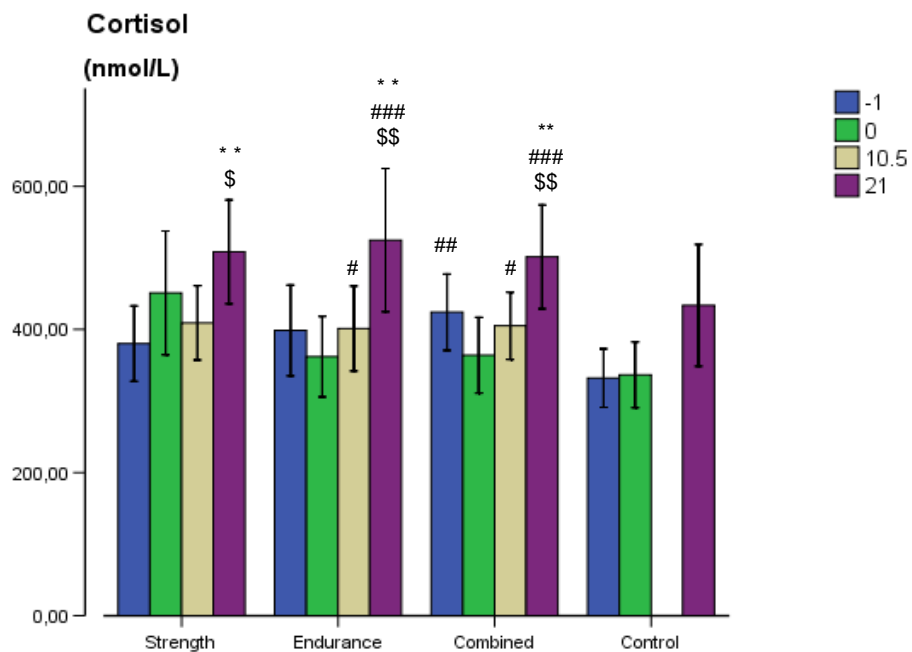


FIGURE 27. Mean (\pm 2 SE) serum cortisol concentrations. * significant from minus ($p < 0.05$), ** significant from minus ($p < 0.01$). # significant from pre ($p < 0.05$), ## significant from pre ($p < 0.01$), ### significant from pre ($p < 0.001$). \$ significant from mid ($p < 0.05$), \$\$ significant from mid ($p < 0.01$).

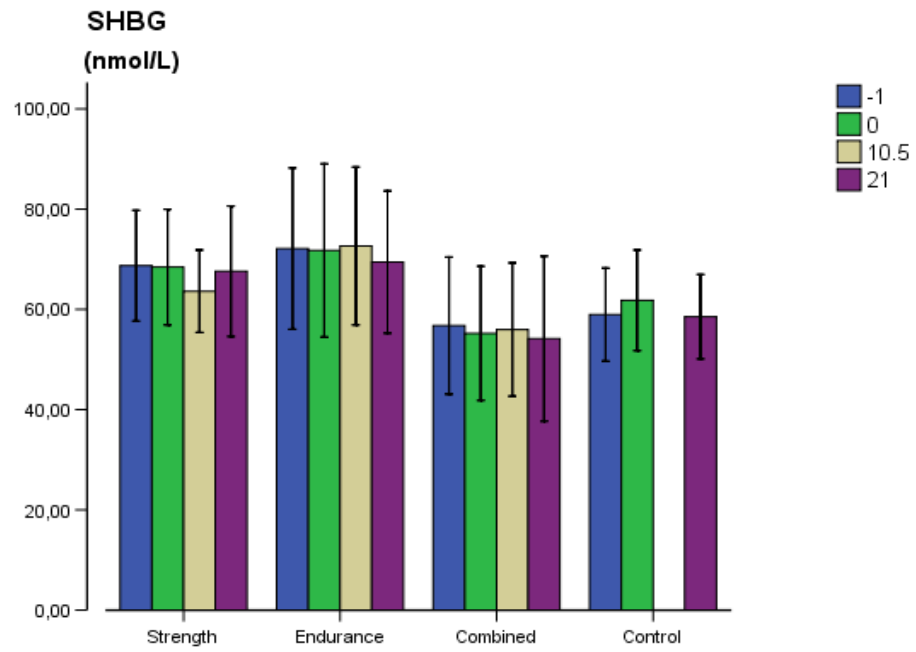


FIGURE 28. Mean (\pm 2 SE) serum SHBG concentrations.

10. DISCUSSION

This investigation compared changes in DEXA assessed regional lean body mass (arms and legs), ultrasound measured muscle thickness (BB, TB, BF, VL+VI) and resting serum hormone concentrations in women between the ages of 40-65 during a 21 week periodised strength vs. endurance vs. strength + endurance training programs. In the present investigation the SE group exhibited the largest gains in both arms and legs lean body mass, and also showed the most significant increases in muscle thickness of the legs. All three training groups exhibited significant increases in resting serum testosterone concentrations.

According to *Houtkooper et al. (2000)* DEXA is considered to be a valid technique for fat and muscle tissue assessment and also the most sensitive method for assessing small changes in body composition. The present study showed the groups who performed strength training (S, SE) benefited the most in terms of gains in lean body mass. The S group exhibited gains in lean body mass in the arms and legs, but the largest increases in both arms and legs lean body mass were shown by the SE group. The non strength training groups (E, C) both exhibited decreases in the arms lean body mass, but the E group showed a significant increase in legs lean body mass. *Chilibeck et al. (1998)* found slightly different results in a study which utilized DEXA technology to track hypertrophy in women for the arms, trunk and legs after a 10 week resistance training program. Their data showed that hypertrophy of the legs and trunk lagged behind that of the arms. Discrepancies in the duration of the studies may be one possible reason for the contradiction (10 vs. 21 wk) as well as differences in the training protocols.

A somewhat similar study to *Chilibeck et al. (1998)* was performed by *Nindle et al. (2000)*. This was a 6-month periodised training program (5 sessions per week, 1.5 hours a day combined training) that showed gains in lean soft tissue mass in the arms and legs of 0.6 and 5.5 %, respectively. These findings were similar to the present study which the SE group exhibited 2.1 and 4.0 % gains respectively. Even though these studies exhibited similar gains, one factor to consider is the average age of the subjects which was 50 in the present study (SE group) compared to 28 in *Nindle et al. (2000)*. It should also be noted that the intent of the training program for *Nindle et al.* was the improvement of female military physical performance, not physical appearance or

muscle hypertrophy as in the present study. These data from the current study and *Nindle et al. (2000)* both seem to exhibit smaller gains in the arms in comparison to *Chilibeck's* findings of womens hypertrophy of the legs and trunk lagging behind that of the arms.

In the present study the SE group showed increased lean body mass (pre-post) and muscle thickness in the legs at every time point (pre-mid, pre-post, and mid-post). When comparing to the S group, the SE group had larger gains in lean body mass and muscle thickness in the legs during the entire 21 week study. This could be explained by the form of endurance training that was selected for this study. Cycling is a concentric activity in which force is developed primarily by the quadriceps muscle group. In addition, the contraction phase of the quadriceps is more prolonged in cycling compared to running (*Hoes et al., 1968*). These findings may account for the fact that a short term cycling training program can lead to an increase in muscle fiber cross sectional area (*Andersen and Henriksson, 1977*). *Macaluso et al (2003)* used a cycling resistance training protocol and found increases in muscle strength, power, and selected functional abilities in healthy older women. Supporting the theory that endurance training by cycling may be more likely to increase muscle size (*Anderson et al. 1977, Terrados et al. 1986*) is the fact that the E group exhibited significant increases in muscle thickness of the legs, and a larger increase in legs lean body mass than the S group.

Ultrasound measurements were able to separate the upper arm into biceps brachii and triceps brachii, which was taken as the whole upper arm by DEXA. The strength training groups (S, SE) exhibited significant increases in their biceps brachii thickness, whereas the C group showed no significant changes, and E group a slight decrease. The triceps brachii muscle thickness increased in all training groups. This was not a surprise since the triceps muscles experienced some hypertrophy in the E group due to holding on to the bicycle bars during training sessions. The lower body muscle thickness measurements by ultrasound were in agreement with the upper body in which the groups with strength training (S, SE) showed the largest increases in muscle thickness. Our observations are in line with previous studies that have reported training-induced hypertrophic changes measured by ultrasound (*Alegre et al. 2006, Reeves et al. 2004*).

The strength training 2 times a week seemed to be sufficient for gains in muscle hypertrophy. These results are in agreement with a previous study by *Häkkinen et al (2001)* which found substantial gains in myofiber size in older women following a strength power training program performed 2 days per week, suggesting that older women may benefit from reduced frequency periodized resistance training and a combination of heavier and lighter loads.

In the present study it was not shown that any type of interference occurred in terms of muscular hypertrophy. The SE group had the largest gains in both arms and legs lean body mass, and also showed superior gains of the legs muscle thickness compared to both S and E groups.

In a similar study by *Sillanpää et al (2008)* men of the same age underwent the same type of periodised training with the same group types (S, E, SE, C). The present study shows agreement with *Levine et al. (1984)* and *Heyward et al. (1986)* that men hypertrophy in the upper body better than women. Nonetheless the women in the present study were able to add as much or more lean body mass in the legs compared to men in *Sillanpää et al. (2008)*. When looking at the non strength training groups the data also support the theory that women lose muscle mass in the upper body faster than men (*Nindle et al. 2000*) since the men's E group from *Sillanpää et al. (2008)* exhibited a small increase in arms lean body mass, while the women in the current study lost 1.5%. Also showing support for women losing muscle mass in the upper body faster than men are the control groups from the two studies. The men's C group exhibited no changes in arms lean body mass, while the women's C group lost 1.6%. The present study showed that women were able to maintain legs lean body mass better than men. Comparing the present investigations women's non strength training groups (E, C) to the men's non strength training groups (E,C) from *Sillanpää et al. (2008)*, we can see that the women exhibited increases in the legs lean body mass, whereas the men's groups both exhibited decreases.

All groups in the present investigation had very minimal changes in body weight and body fat %. Of the training groups only the S and SE groups had changes in body fat %, with decreases of 0.8, 0.6 % respectively. The loss in fat mass and increase in lean

mass are favourable and desired effects of exercise training programs and contribute to an enhanced level of fitness and health (*Gallagher et al. 2000*).

All training groups exhibited significant increases in resting serum testosterone during training. A possible explanation for the increases in testosterone in the current study could be the seasonal variations due to temperature and sunlight (*Andersson et al. 2003*). *Guarde et al. (2000)* found testosterone to be the highest in July-September coinciding with the months with the hottest temperatures. In the present investigation the pre measurements were administered in February, which in Finland has an average temperature of -6 °C, and 8 hours sunlight. The post measurements were administered during August, which in Finland has an average temperature of +16 °C, and 17 hours sunlight. All three training groups had significant increases in pre-post testosterone levels supporting the seasonal variations theory. The C group exhibited no significant changes in resting serum testosterone concentrations during the investigation.

Another theory possibly explaining the increases in resting serum testosterone is resistance training induced increases in resting serum testosterone (*Kraemer et al. 1999, Ahtianen et al. 2003, Häkkinen et al. 1988, Staron et al. 1994, Marx et al. 2001*). The previously mentioned investigations all found elevated acute resting testosterone concentrations during resistance training protocols, but *Marx et al. (2001)* was the only investigation to show resting testosterone increases in women. *Marx's* study was of similar duration being 24 weeks to the present 21. Some discrepancies do come from the present study and *Marx et al. (2001)*, one being the average age (23 vs. 50) and the frequency of the training protocol. The increases in resting testosterone due to resistance training found in the present study are slightly different than numerous investigations (*Hickson et al. 1994, Häkkinen et al. 1987, Häkkinen et al. 2000, Alen et al. 1988, Häkkinen et al. 1985, Reaburn et al. 1997, McCall et al. 1999*) who found no significant differences in resting serum testosterone after resistance training programs.

It could be argued that the increases in testosterone could have been due to the increased intensity of the final phase (7 weeks) of the training protocol which had the highest overall intensity. The goal of the training protocol at this particular phase was to improve muscular strength by increased intensity (70-85% of 1 RM) and lower volume

(5-8 repetitions). The endurance group during the same phase (final 7 weeks) had its most demanding sessions requiring increased amounts of time above the anaerobic threshold. It would have been interesting to see the acute testosterone response to repeated bouts of resistance training over the 21 week protocol since it has not been investigated in middle aged to older women during a periodised resistance training program of this duration.

In agreement with our previous hypothesis (*Häkkinen et al 2001*) no significant changes occurred in reference to resting serum SHBG, DHEAS, and Growth Hormone. All training groups (S, SE, E) exhibited significant increases in resting cortisol. Resting cortisol levels generally reflect a long term training stress (*Kraemer & Ratamess 2005*). The largest increases of cortisol were found in the groups who participated in the endurance aspect of the protocol (SE, E). The S group also had significant increases in cortisol but only from mid to post, as compared to the SE, and E who exhibited significant increases from all time points (pre-mid, mid-post, pre-post). These findings may lead one to speculate that long term resistance training increases resting serum cortisol, but minimal support is found for increased resting serum cortisol after chronic resistance training (*Häkkinen & Pakarinen 1991*), where as numerous studies (*Häkkinen et al. 1988, Häkkinen et al. 2000, Ahtianen et al. 2003, Potteliger et al. 1995, Häkkinen et al. 1990, Häkkinen et al. 1992, Häkkinen et al. 1988, Fry et al. 1994*) found no changes or even decreases (*Kraemer et al. 1998, Alen et al. 1988, Marx et al. 2001, Häkkinen et al. 1985, McCall et al. 1999*) in cortisol have been reported during normal strength and power training in men and women, and during short term overreaching (*Kraemer & Ratamess 2005*). No significant correlations were found between any serum hormones and hypertrophy measurements in the present study.

The S group showed the largest increases of muscle thickness in both the biceps and triceps brachii. One interesting fact is that the SE group exhibited a significantly lower ($p < .05$) level of testosterone for the post measurement, but showed larger increases in the biceps femoris muscles, and a significant ($p < .001$) increase in the quadriceps muscles (VL+VI). Although the S group exhibited the largest increases in muscle thickness in biceps and triceps brachii, but significant differences were only observed in the biceps brachii. These differences were possibly due to the fact that the SE group

would require the triceps brachii while holding the bicycle handlebars in addition to the strength training.

In conclusion, combined strength and endurance training by cycling may be more effective than strength training alone for increasing muscle hypertrophy whether being measured by DEXA or ultrasound in middle aged and older women. The present investigation showed that periodised resistance training of sufficient duration and intensity may lead to increased resting serum testosterone concentrations, but the increased testosterone concentrations did not exhibit significant correlations with any measurements of hypertrophy.

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