SERUM HORMONE CONCENTRATIONS AND PHYSICAL PERFORMANCE DURING CONCURRENT STRENGTH AND ENDURANCE TRAINING IN RECREATIONAL MALE AND FEMALE ENDURANCE RUNNERS

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ABSTRACT

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To investigate the effects of concurrent strength and endurance training on physical performance and serum hormone levels a total of 32 recreational endurance runners were trained for 18 weeks. Subjects were divided into four training groups separated by the strength training mode and gender. The groups were women's and men's combined maximal and explosive strength training group (WME; n=9 and MME; n=9), and women's and men's muscle endurance strength training group (WE; n= 8 & ME; n=8). The training was executed in three consecutive periods (I; 10 weeks, II; 4 weeks and III; 4 weeks). The endurance training in all groups was low-intensity (below lactate threshold) running throughout the whole experiment. The strength training was similar moderate-intensity resistance training for all groups during the training period I. During the training periods II and III, strength training differed between the groups (combined maximal and explosive vs. muscle endurance strength training). All groups performed two strength training sessions per week. Serum basal hormone levels, one repetition maximum (1RM), counter movement jump (CMJ), maximal oxygen consumption (VO_2max) and maximal running velocity (Vmax) mere measured prior to the experiment and after each training period. Free testosterone increased in WE from Week 10 to Week 14 (20.1 ± 20.6 %, $p < 0.05$). No other changes in basal serum hormone levels were observed within or between the groups or genders. 1RM and CMJ improved significantly in all groups ($p < 0.05$-0.001) as well as Vmax ($p < 0.05$-0.001). No significant differences in the changes in 1RM, CMJ or VO_2max were observed between the training groups. The increase in Vmax was significantly higher ($p < 0.05$) in the ME compared with the MME group ($p < 0.05$) during the differentiated strength training period. Additionally, ME had a significantly ($p < 0.05$) larger improvement in Vmax compared with WE ($p < 0.05$-0.001) during the experiment. In conclusion, hormonal responses to the present concurrent strength and endurance training seemed to be highly individual and mainly non-significant in the group level. No gender differences were observed in the hormonal responses. In addition, no gender differences were found in the changes in most of the selected physical performance variables except for the greater increase in the Vmax in ME compared to WE. Well designed concurrent strength and endurance training regimens resulted in improvements in strength and endurance in recreational endurance runners regardless of the strength training type used. However, improvements in strength and power were more systematic in the groups performing combined maximal and explosive strength training. The differences in the selected endurance performance variables were minimal except for the larger improvement in Vmax in the ME group compared with the MME group.

Keywords: concurrent strength and endurance training, hormonal responses, physical performance, gender differences

ABBREVIATIONS

1RM	one repetition maximum
β-globin	beta globin
Acetyl-CoA	Acetyl coenzyme A
CMJ	counter movement jump
EPOC	excess post-exercise oxygen consumption
FT	free testosterone
FSH	follicle-stimulating hormone
GH	growth hormone
GnRH	gonadotropin-releasing hormone
iEMG	integrated electromyography
LH	luteinizing hormone
LT	lactate threshold
ME	men’s endurance strength training group
MME	men’s maximal and explosive strength training group
RE	running economy
RER	respiratory exchange ratio
SHBG	sex hormone binding globulin
T/C ratio	testosterone/cortisol ratio
Vmax	maximal running velocity
VO_2max	maximal oxygen consumption
vVO_{2max}	running velocity corresponding to maximal oxygen consumption
WE	women’s endurance strength training group
WME	women’s maximal and explosive strength training group

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ABSTRACT

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1 INTRODUCTION

A sedentary lifestyle is a risk factor for a number of diseases that become more prevalent with age in both genders. In contrast, regular physical activity is considered a behavior with favorable consequences on a large variety of health outcomes (Bouchard & Rankinen 2001.) Concurrent strength and endurance training has proven in past years, to have a positive influence on health and physical performance (Ghahramanloo et al. 2009; Mikkola et al. 2007; Paavolainen et al. 1999; Taipale et al. 2010), although strength and endurance training are commonly known to produce divergent hormonal and physical adaptations (Leveritt et al. 1999).

The different adaptations to strength and endurance training have been of great interest to researchers. A wide range of results have been reported regarding physical and hormonal responses to strength or endurance training with gender differences and similarities (Ahtiainen el al. 2003; Grandys et al. 2009; Linnamo et al. 2005; Taipale et al. 2010; Vuorimaa et al. 2008). In relation to large benefits and incidence of concurrent strength and endurance training in every day life and exercise training, the data of physical and hormonal responses to concurrent training are relatively sparse. Especially, hormonal responses need further investigation (Sillanpää et al. 2010). Previous studies of hormonal adaptations to concurrent strength and endurance training have been conducted with highly different intervention groups and regimens and have resulted in contradictory results. Elevated serum testosterone and cortisol levels after concurrent strength and endurance training have been reported with women (Sillanpää et al. 2010). Although, the majority of previous studies have reported no changes in serum hormone levels (Ahtiainen et al. 2009; Bell et al. 2000; Mikkola et al. 2007; Taipale et al. 2010) with similar results in both genders (Bell et al. 2000).

The purpose of this study was to examine the effects of concurrent strength and endurance training on serum hormone levels and physical performance with recreational male and female endurance runners. Furthermore, the effects of different types of strength training and possible gender differences were under investigation.

2 TESTOSTERONE AND CORTISOL

Hormone secretion rarely occurs at a constant rate, but adjusts rapidly to meet the demands of changing bodily conditions (McArdle et al. 2001, p. 412). Testosterone and cortisol are commonly accepted as representatives of anabolic and catabolic hormones. Anabolic and catabolic hormones play an important role in the adaptations to exercise training. Tissue remodeling is a dual process in which catabolism initiates the process and anabolism predominates during the recovery period leading to growth and repair. Because of these major roles, testosterone and cortisol are often examined in sports sciences (Kraemer & Ratamess 2005.) The production of testosterone and cortisol in the human body are represented in the following chapters. The endocrinal glands mentioned are illustrated in Figure 1.

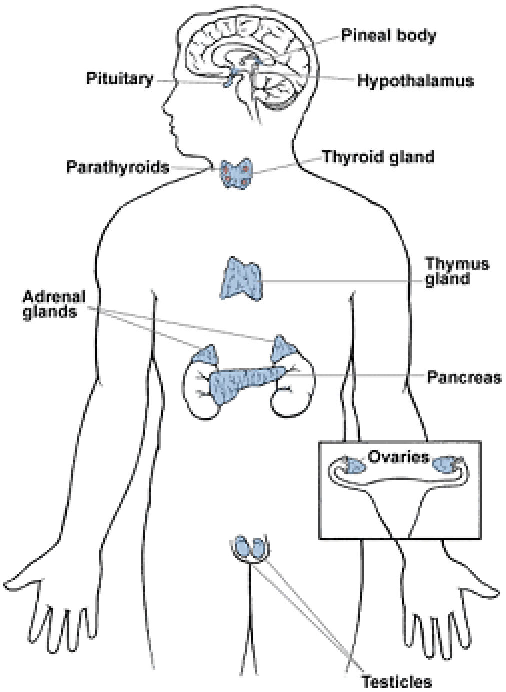


Figure 1. The endocrine glands (American Medical Association).

Testosterone. Testosterone is produced mainly in the Leydig cells of the testes in males and in the ovaries in females, however, small amounts are made in the outer layer of the adrenal glands in both sexes. Testosterone is produced from cholesterol or Acetyl coenzyme A (acetyl-CoA). The chain of events which results in the formation of testosterone starts when the cerebral cortex sends a signal to the hypothalamus. The hypothalamus then stimulates the pituitary gland with gonadotropin-releasing hormone (GnRH). This hormone, in turn, causes the gland to produce two other hormones; follicle-stimulating hormone (FSH) and luteinizing hormone (LH), collectively known as gonadotropins (Guyton & Hall 1996, p. 1009-1010.) LH is released into the bloodstream where it travels to the testes / ovaries and triggers the production of testosterone (Guyton & Hall 1996, p. 1013). After the secretion of testosterone, it is largely (97%) bound to albumin or to beta globin (β-globin), better known as sex hormone binding globulin (SHBG) (Guyton & Hall 1996, p. 1010).

Cortisol. When activated, neurons in the paraventricular nucleus of the hypothalamus secrete corticotrophin-releasing hormone which is transported to the anterior pituitary. In the anterior pituitary, adrenocorticotropic hormone (ACTH) is secreted. ATCH then stimulates the adrenal cortex to secrete glucocorticoid; cortisol in humans (Berne and Levy 1998.) Of the total plasma cortisol, 3-10% circulates in the unbound free cortisol from, namely the bioactive form (Levine et al. 2007.) Of the remaining cortisol, about 15% is bound to albumin and 75% is bound to corticosteroid-binding globulin (Kraemer & Ratamess 2005). The free cortisol molecule passes through capillaries into tissues mainly by passive diffusion (Levine et al. 2007).

3 STRENGTH AND ENDURANCE TRAINING

In this chapter the acute and chronic adaptations to exercise training are discussed. Different aspects of hormonal responses to strength and endurance training are presented in chapter 3.1. Changes in physical performance in response to strength and endurance training are discussed in chapter 3.2.

3.1 Effects of exercise training on hormone levels

3.1.1 Strength training and hormonal responses

Strength training has acute and long-term effects on circulating hormone levels and physical performance capacity. Endocrinological adaptations to resistance training are divided into four classifications: acute changes during and post resistance exercise, chronic changes in resting concentrations, chronic changes in the acute response to a resistance exercise stimulus and changes in the receptor content (Kraemer & Ratamess 2005.)

Acute effects. In general, the acute response is dependent upon a subjects background (age, training background, gender) and also by the training stimulus (intensity, volume, muscle mass involved, rest intervals and frequency). Resistance training protocols high in volume, moderate to high in intensity, using short rest intervals and stressing a large muscle mass, tend to produce the greatest acute hormonal elevations (e.g. testosterone and cortisol) (Kraemer & Ratamess 2005.) Acute increases in total testosterone concentrations have been found in studies with men (Figure 2) (Hickson, R.C 1980; Linnamo et al. 2005; Häkkinen & Pakarinen 1995) while in young women no change (Figure 2) or an elevation (Nindl et al. 2001) have been observed. Significant acute elevations occur also in cortisol levels. Elevations in cortisol after a resistance exercise training session have been reported (Ahtiainen et al. 2003; Ahtiainen et al. 2004; Kraemer et al. 1993; Kraemer et al. 1999) with the response similar between men and women (Kraemer et al. 1993).

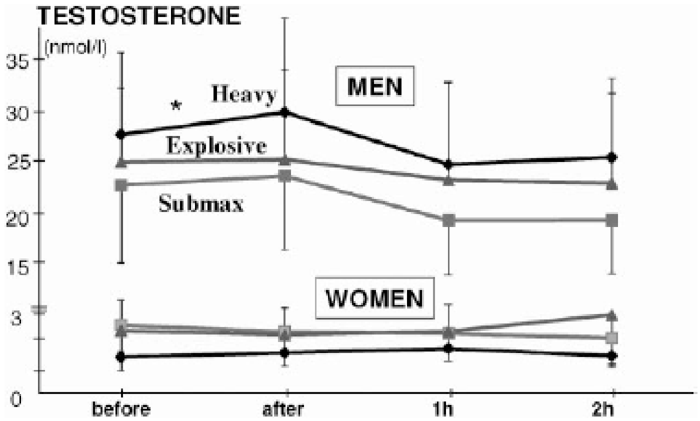


Figure 2. Mean (± SD) values for serum testosterone concentrations before and after heavy, explosive, and submaximal resistance exercises. Significant increase in serum testosterone level was observed with men after whole body heavy resistance training session. No significant alterations with women serum testosterone levels were observed (Linnamo et al. 2005).

The intensity and volume of a resistance training programme has been shown to affect the acute testosterone response (Kraemer & Ratamess 2005). When resistance is held constant, the larger acute testosterone response is observed in the protocol consisting of a higher number of sets (Gotshalk et al 1997). Similarly, if repetitions are held constant the protocol with higher loading tends to produce the greatest acute testosterone response (Raastas et al. 2000). Testosterone has been shown to be elevated for 15–30 minute post resistance exercise if an adequate stimulus is present (Kraemer & Ratamess 2005).

Metabolically demanding protocols high in total work, i.e. high volume, moderate to high intensity with short rest periods, have elicited the greatest acute lactate and cortisol response with little change during conventional strength/power training (Kraemer et al. 1993). In general, training programmes that elicit the greatest cortisol response also elicit the greatest acute growth hormone and lactate response (Kraemer & Ratamess 2005). In Ahtiainen et al. (2003), the significant changes in cortisol were observed 15 minutes after a heavy resistance loading (Figure 3) (Ahtiainen et al. 2003).

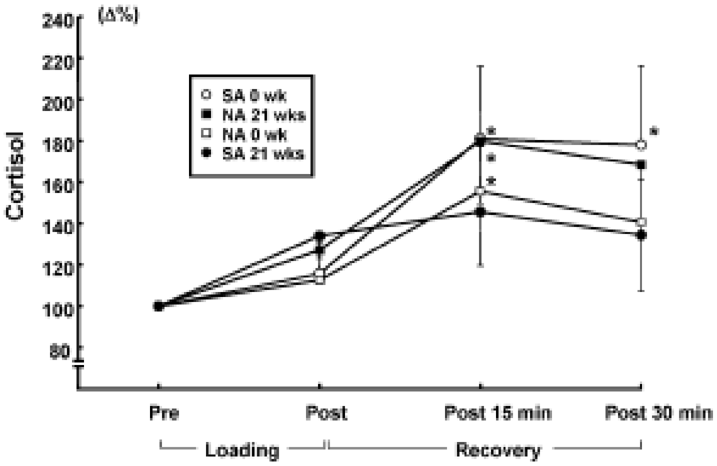


Figure 3. Acute changes (mean ± SD) in serum cortisol with men during a heavy resistance exercise loading before and after 21-week strength training period. SA= strength athletes, NA= non-athletes. (* significant difference to pre-exercise value, $p < 0.05$) (Ahtiainen et al. 2003).

The acute testosterone response in women appears limited as only few studies have shown significant elevations (Nindl et al. 2001; Kraemer & Ratamess 2005). In direct comparison, men have shown acute elevations in testosterone while no response has been detected with women following the same protocol (Häkkinen & Pakarinen 1995). Rather, it seems that other anabolic hormones such as GH may be more influential for promoting muscle hypertrophy in women (Kraemer & Ratamess 2005). Women tend to have a similar acute cortisol response to resistance exercise as men (Kraemer et al. 1993).

Chronic affects. Long-term adaptations in endocrine function appear minimal and may be related to the current intensity/volume of the training stimulus (Kraemer & Ratamess 2005). Results of changes in basal testosterone concentrations during resistance training have been inconsistent or non-existent in men and women (Ahtiainen et al. 2003; Alen et al. 1988; Häkkinen et al. 1990). Ahtiainen et al. (2003) reported significantly higher free and total testosterone concentrations after a 7-week high-volume training phase compared with pre-training values (Figure 4) (Ahtiainen et al. 2003). Thus, substantial changes in volume and intensity may elicit changes in resting testosterone concentrations, but values may return to baseline when the individual returns to normal training. Basal cortisol concentration generally reflect long-term training stress. Chronic resistance training does not appear to produce consistent patterns of cortisol secretion as no change, reductions or elevations have been reported during strength and power training in men and women (Kraemer & Ratamess 2005.)

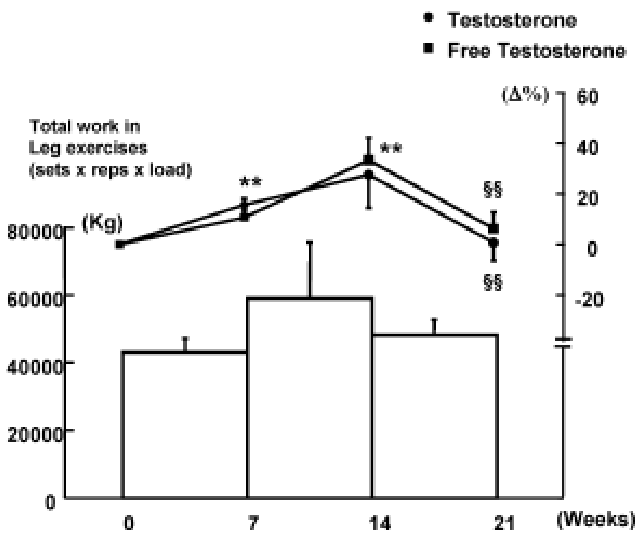


Figure 4. The relative changes (mean ± SD) in serum testosterone and free testosterone with men and total work in leg exercises (set x reps x load) during 21-week strength training period in strength athletes. (** = significant difference to pre-exercise value, p < 0.01, $$ = statistically significant difference to preceding value, p < 0.01) (Ahtiainen et al. 2003).

It appears that basal hormone concentrations reflect the current state of muscle tissue such that elevations or reductions may occur at various stages depending on substantial changes in the volume and intensity of training (Ahtiainen et al. 2003; Häkkinen et al. 1988; Kraemer & Ratamess 2005). It also appears that the acute hormonal response is more critical to tissue growth and remodeling than chronic changes in basal hormonal concentrations, as many studies have not shown a significant change in basal levels of hormones during resistance training despite increases in muscle strength and hypertrophy (Kraemer & Ratamess 2005).

Chronic affects in the acute response. There have been studies suggesting that long-term resistance training may enhance the acute endocrinological response to a workout Kraemer et al. 1999; Tremblay et al. 2004). Kraemer et al. (1999) reported that the magnitude of acute testosterone elevation was greater after 10 weeks of periodized strength training compared with the pre-training response (Kraemer et al. 1999). In Tremblay et al. (2004), the acute elevation in testosterone was greater in resistance-trained men than endurance-trained men, thereby indicating a beneficial chronic hormonal adaptation to resistance training (Tremblay et al. 2004). However, Ahtiainen et al. (2003) reported no differences in the acute response between strength-trained and non-strength-trained men before and after 21 weeks of training (Ahtiainen et al. 2003).

Changes in the receptor content. The presence of androgen receptors in tissues has been shown to correlate highly with the known functions of androgens (Kraemer & Ratamess 2005). Resistance training, or exercise in general, has been shown to modulate androgen receptor content (Bricout et al 1994). In rats, resistance training elicited a significant increase in androgen binding capacity in the exercised muscle (Deschenes et al. 1994). There are reported significant correlations between baseline androgen receptor content in the *musculus vastus lateralis* and 1RM squat, thereby suggesting that androgen receptor content, in part, assists the improvement in strength during resistance training. The catabolic effects of cortisol are mediated through interaction with glucocorticoid receptors. It appears that with consistent resistance training, a down-regulation of the glucocorticoid receptor may occur, and thereby the catabolic influence on skeletal muscle tissue is weaker (Kraemer & Ratamess 2005.)

3.1.2 Endurance training and hormonal responses

It is known that hard physical exercise induces remarkable acute hormonal responses from the pituitary-testicular axis (testosterone) and the adrenal cortex (cortisol) (Schmid et al. 1982; Bobbert et al. 2005; Vuorimaa et al. 2008). However, acute and long-term hormonal adaptations to endurance training of have not yet been precisely characterized (Bobbert et al. 2005).

After short-term intensive physical activity, remarkable exercise-induced increases in the serum concentrations of both testosterone (Slowinska-Lisowska & Majda 2002) and cortisol (Kargotich et al. 1997; Bobbert et al. 2005; Vuorimaa et al. 2008) have been documented (Figure 5). An exercise-induced shift in hormonal environment to anabolic or catabolic direction has been usually evaluated by comparing the changes in serum testosterone to changes in serum cortisol (Tremblay et al. 2005; Vuorimaa et al. 2008). In the case of low intensity and continuous types of exercises, the ratios of anabolic hormones to cortisol have been reported to depend on the exercise time; after 40 min of running, the ratio is more anabolic compared with the pre-exercise level while beyond 80 min of running there is a shift to a catabolic hormonal environment (Tremblay et al. 2005). In the study of Bobbert et al. (2005) reduced levels of serum cortisol were found even 2 days after a marathon run as an acute effect of long-term physical activity on the hormonal system (Figure 6) (Bobbert et al. 2005).

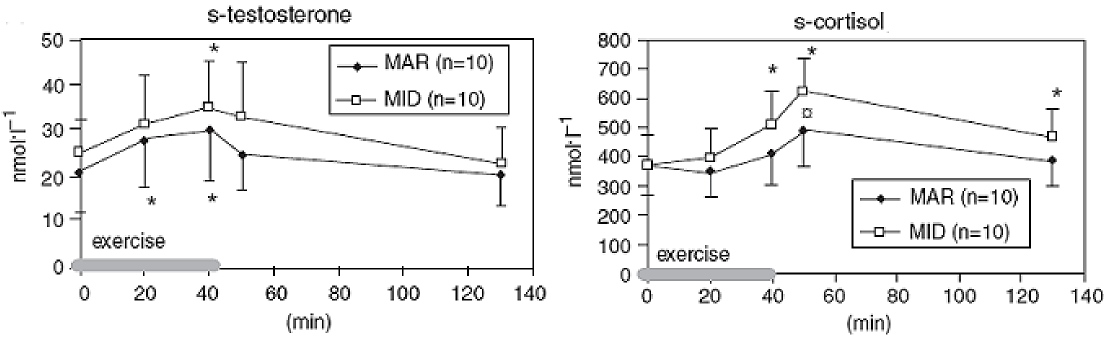


Figure 5. Hormonal responses to a 40 min exercise (2 x 20-min tempo run at a velocity corresponding to 80% vVO_{2max} with a 1-min recovery). (* significant difference to pre-exercise value $p < 0.05$, ¤ significant differences between groups, $p < 0.05$). MAR = marathon runners, MID = middle distance runners (Vuorimaa et al. 2008).

It is suggested that chronic stress or physical training leads to decreases in testosterone concentration (Grandys et al. 2009) and elevated cortisol levels (Villanueva et al. 1986). On the other hand, there is also data showing a increase in testosterone and free testosterone levels (Figure 7c and 7d) (Grandys et al. 2009) and a decrease in cortisol levels after long-term endurance training (Uusitalo et al. 1998). Furthermore, in some studies, no changes in cortisol metabolism were found (Maestu et al. 2003).

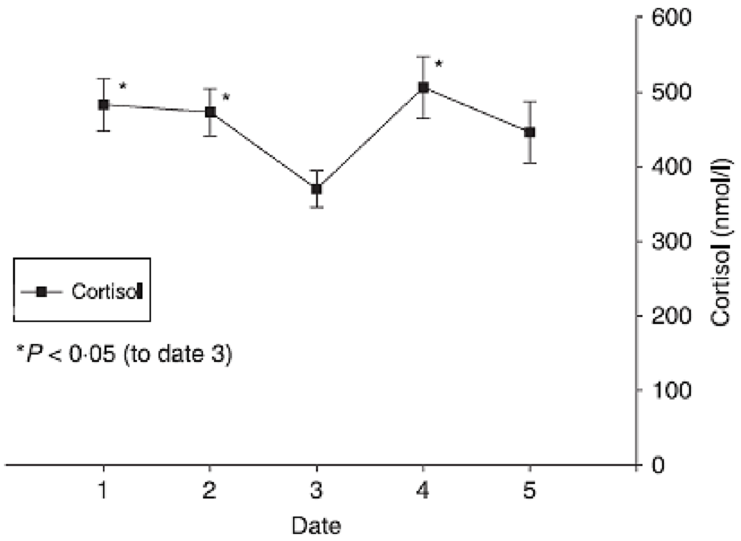


Figure 6. Cortisol levels in relation to a marathon run. Training status was high at date 1 & 2 and a low at date 4 & 5. Significant changes ($p < 0.05$) in relation to date 3 (2 days after marathon) are marked with * (date 1 = 6 weeks before marathon, date 2 = 10 days before marathon, date 3 = 2 days after marathon, date 4 = 10 days after marathon, date 5 = 6 weeks after marathon). Modified from Bobbert et al. (2005).

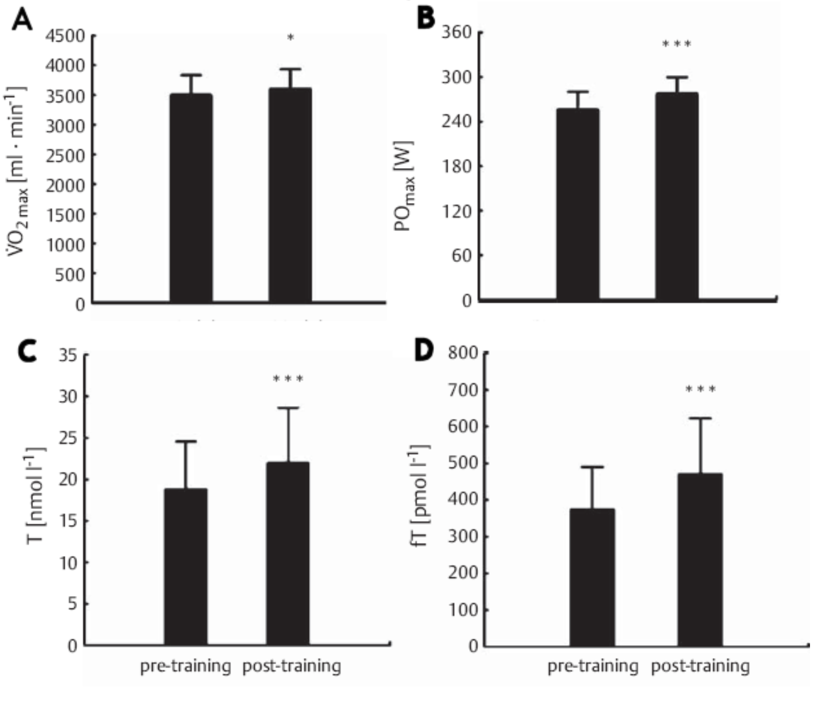


Figure 7. A: Maximal oxygen uptake (VO_2max), B: power output at VO_2max (PO_{max}), C: testosterone (T) and D: free testosterone (fT) before and after of 5 weeks of endurance training. * * * $p < 0.001$, * * $p < 0.02$, significant difference between pre and post-training value. Data on the graphs are presented as mean ± SD (Grandys et al. 2009).

3.2 Effects of exercise training on physical performance

3.2.1 Strength training and physical performance

Strength training has acute and long-term effects to physical performance capacity (Kraemer & Ratamess 2005). Strength training can be classified into three general subdivisions: maximal, explosive and endurance strength. Maximal training represents actions where muscle activation level increases to maximal and the rate of force development is therefore relatively long. Explosive strength includes muscle actions where the rate of force development is short and therefore the load used is relatively low. Endurance strength is, in general, a muscle action where certain force level is produced for a relatively long period of time or certain force levels are repeated consecutively multiple times with short recovery periods (Keskinen et al. 2004.)

Acute responses. In the study of Linnamo et al. (2005) eight young adult men and women performed separately three different loading sessions: submaximal heavy resistance exercise, maximal heavy resistance exercise, and explosive resistance exercise. Maximal force decreased significantly after all exercises ($p < 0.05$) in both genders, and the greatest decrease and the slowest recovery were observed from maximal heavy resistance exercise in both groups. The maximal force decreased by 16.9 ± 4.8% and 16.2 ± 7.1% after submaximal heavy resistance exercise in men and women, respectively. The maximal force decreased in men and women by 23.7 ± 16.3% and 18.8 ± 7.7% after maximal heavy resistance exercise, and after maximal explosive resistance exercise by 11.0 ± 8.2% and 12.2 ± 6.8%, respectively (Figure 8) (Linnamo et al. 2005.)

In the study of Ahtiainen et al. (2004), high resistance exercise led to neuromuscular fatigue with significant acute decreases in isometric strength (32-52%, $p < 0.001$) (Figure 9a) and in maximal iEMG (15-19%, $p < 0.05$, $p < 0.01$) (Figure 9b) (Ahtiainen et al. 2004).

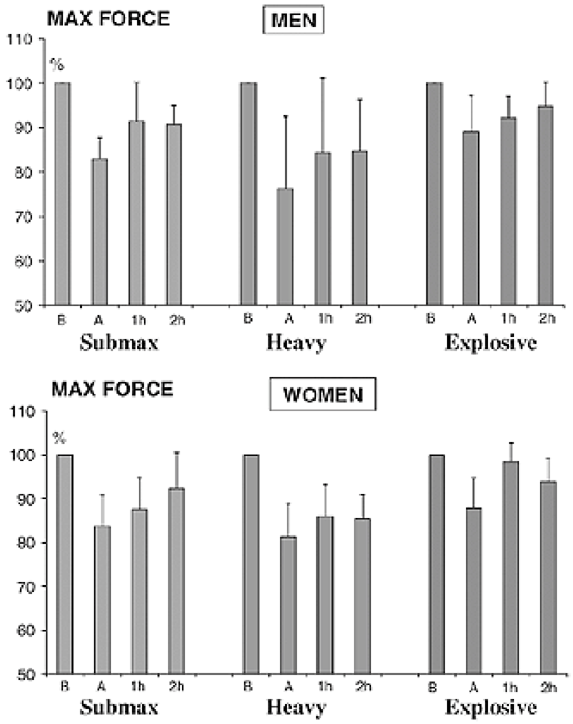


Figure 8. Mean (± SD) changes in maximal force after the submaximal heavy resistance exercise, maximal heavy resistance exercise and explosive resistance exercise. B = before, A = after, 1h = one hour after, 2h = two hours after (Linnamo et al. 2005).

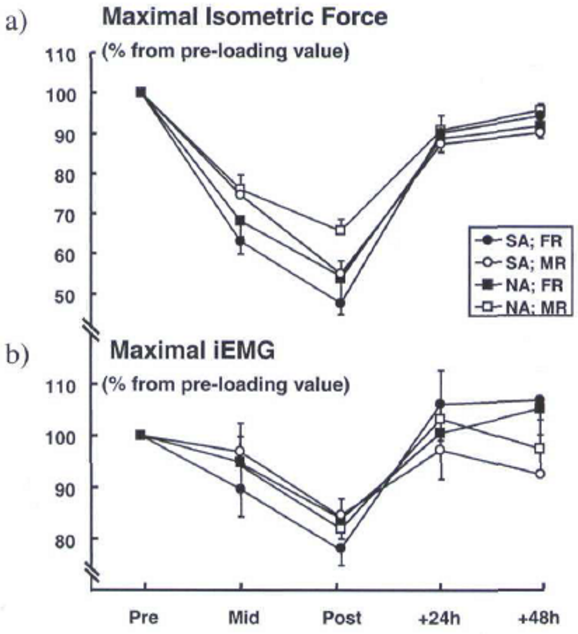


Figure 9. Relative changes (mean ± SD) in maximal isometric force and EMG activity during and 2 days after the maximal (MR) and forced (FR) resistance loadings in strength athletes (SA) and in non-athletes (NA) (Ahtiainen et al. 2004).

Long-term effects. Depending on the specific program design, resistance training can enhance strength, power or local muscular endurance (Deschenes & Kraemer 2002). One basic principle in strength training is the progressive increase in the training load (Ahtiainen et al. 2004). A stimulus exceeding a previous stimulus is necessary to cause muscular adaptations during a resistance training program (Izquierdo et al. 2009). However, because of the risk for overtraining, it is not appropriate for long term training purposes to increase repeatedly the volume or frequency of training (Ahtiainen et al. 2004).

Moritani and deVries (1979) found that neural factors accounted for the significant strength improvements observed during the first 4 weeks of an 8-week resistance-training program (Figure 10). After 4–6 week of training, further strength gains were attributable mainly to muscle hypertrophy (Moritani & deVries 1979.) Subsequent to this landmark study, numerous other investigators have reported similar conclusions, although specific timelines have differed (Deschenes & Kraemer 2002).

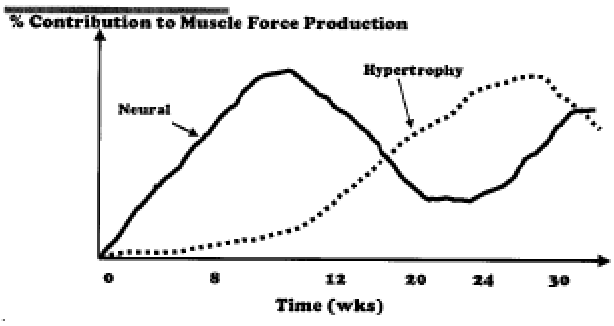


Figure 10. The interplay of neural adaptations and muscle hypertrophy on muscle force production (Deschenes & Kraemer 2002).

Optimal resistance training programs are individualized to meet specific training goals. When trained with similar intensity and volume, these functional and physiologic adaptations are similarly impressive among women and men. Yet, in contrast to relative measurements, sex and age differences exist in the absolute magnitude of adaptation (Deschenes, & Kraemer 2002.) It is important to recognize, however, that even when using optimal and appropriate training methods, an individual’s initial training status greatly influences (Figure 11) training response (Deschenes & Kraemer 2002).

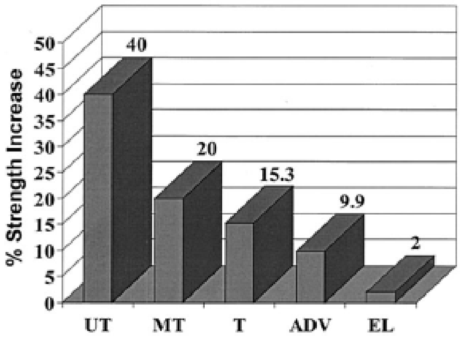


Figure 11. Effect of initial training status on resistance training induced strength gains: Data from approximately 150 studies. UT = untrained, MT = moderately trained, T = trained, ADV = advanced training, EL = elite training. (Deschenes & Kraemer 2002).

3.2.2 Endurance training and physical performance

Traditionally, endurance running performance is thought to be determined by certain characteristics, including maximum oxygen consumption (VO_2max), lactate threshold (LT), and running economy (Figure 12) (Jung, A.P. 2003; Bassett & Howley 1997). The primary adaptations to endurance training are improved oxygen transportation and utilization, e.g. increased capillary and mitochondrial density, as well as increased enzyme activities, which improve oxidative energy metabolism (Abernethy et al. 1994).

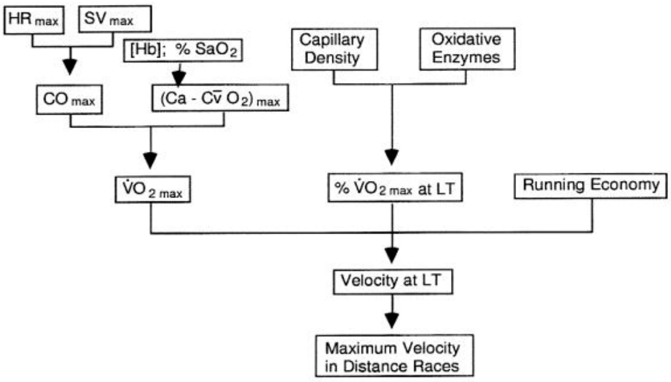


Figure 12. Major variables related to maximum running velocity in distance races (Bassett & Howley 1997).

During exercise, there is an increase in oxygen uptake (VO_2) to support the increased energy need. After exercise, VO_2 does not return to resting levels immediately and may be elevated for some period of time. This increase in oxygen uptake is termed the excess post-exercise oxygen consumption (EPOC) which is highly dependent on the intensity and duration of the exercise. EPOC consists of several components i.a. accelerated oxidative energy metabolism (Borsheim & Bahr 2003.) As an acute reaction to endurance exercise, Short & Sedlock (1997) found a significant decrease in respiratory exchange ratio (RER) compared to the baseline (Figure 13), thus providing evidence of increased fat oxidation after endurance exercise (Short & Sedlock 1997). The data suggests that there are no gender differences in the acute response to exercise determined with EPOC when comparing the relative values (Borsheim & Bahr 2003) and taking into account the possible changes in women's basal energy levels with menstrual phase (Henry et al. 2003).

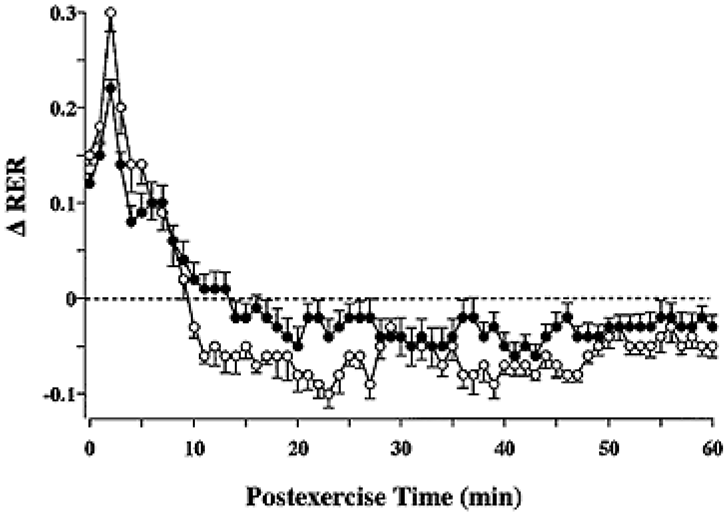


Figure 13. Change (means ± SD) of respiratory exchange ratio (RER) during postexercise period in trained (●) and untrained (○) subjects after performing an 30 min exercise at 70% VO_2peak. RER was significantly ($p > 0.05$) below baseline after the exercise (Short & Sedlock 1997).

Athletes who perform well in endurance activities typically possess high VO_2max values (Figure 14) (Costill, D.L. 1967; Bassett & Howley 1997) and therefore the goal in endurance training is commonly to improve VO_2max (Jung, A.P. 2003). Improvements in VO_2max have been shown to be best achieved through prolonged bouts of running at a moderate to high intensity (approximately 65–85% of VO_2max) or shorter, repeated bouts of running at a high intensity (80–100% of VO_2max). Prolonged bouts may last between 30 and 120 minutes depending on the intensity, while high intensity intervals usually last 5 minutes or less (Jones & Carter 2000.) Training at or near VO_2max has been suggested to elicit improvements particularly in well trained athletes (Laursen et al. 2002). However, training intensities as low as of 40–50% of VO_2max can significantly increase maximal oxygen consumption in untrained individuals and therefore the minimum training intensity that elicits enhancement in VO_2max is highly dependent on the individuals' initial VO_2max (Midgley et al. 2006). These methods of training challenge the oxidative system in such a way that an adaptation in the body results in greater maximal oxygen consumption (Jung, A.P. 2003). With effective training, increases in VO_2max have reached up to 25% with recreational trainees (Hickson & Rosenkoetter 1981).

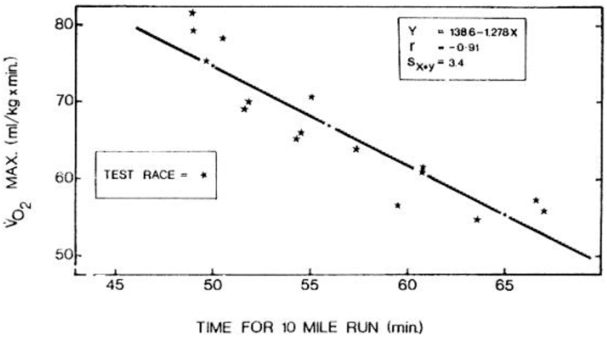


Figure 14. Relationship between maximal oxygen consumption and distance running performance (Bassett & Howley 1997).

Sparling & Cureton (1983) investigated the physical determinants of gender difference in a 12-min running performance. Men differed significantly ($p < 0.05$) from women in VO_2max (68.6 and 65.1 ml · min^{-1} · kg FFW^{-1}) fat%, (10.8 and 19.8%), but not in running economy (39.0 and 39.1 ml · min^{-1} · kg BW^{-1}, respectively). The results suggested that in similarly trained male and female distance runners, the difference in running performance is largely due to percentage of body fat, less to cardiorespiratory fitness, and least to running economy (Sparling & Cureton 1983.) Furthermore Pate & Kriska (1984) stated that men and women, who are capable of similar performances, do not differ in body composition or cardiorespiratory variables (Pate & Kriska 1984). Iwaoka et. al (1988) found that men had significantly higher LT than women, but no significant gender difference was observed in LT when expressed as %VO_2max (Iwaoka et. al 1988). There appear to be no differences in relative increases in VO_2max for men and women when they are trained under the same intensity, frequency and duration (Lewis et al. 1986).

4 CONCURRENT STRENGTH AND ENDURANCE TRAINING

4.1 Hormonal responses

It is difficult to compare results of studies which differ markedly in a number of design factors including the mode, frequency, duration and intensity of training, training history of participants and scheduling of training sessions (Leveritt et al. 1999). Previous studies of hormonal adaptations to concurrent strength and endurance training have been conducted with highly different intervention groups and regimes and resulted into contradictory results. Sillanpää et al. (2010) reported elevated serum testosterone and cortisol levels after concurrent strength and endurance training (Sillanpää et al. 2010). However, reports with no changes in the serum hormones have been in the majority (Bell et al. 2000; Ahtiainen et al. 2009; Mikkola et al. 2007; Taipale et al. 2010) with similar outcomes in both genders (Bell et al. 2000).

In the study of Sillanpää et al. (2010), middle-aged women performed concurrent strength and endurance training for 21 weeks. The experiment group trained on different days four times a week, performing moderate intensity whole body strength training and low- to high-intensity endurance training. Serum testosterone and cortisol increased significantly ($p < 0.05$ and $p < 0.01$, respectively) during the experiment (Figure 15). It was suggested that intensive strength training may stimulate an increase in serum basal testosterone in middle-aged women despite the concurrent endurance training and increase in serum cortisol levels (Sillanpää et al. 2010.)

In the study of Mikkola et al. (2007) young distance runners trained for eight weeks with the same total training volume but 19% of the endurance training in the experiment group was replaced by explosive strength training. No significant changes were observed in serum testosterone, free testosterone or cortisol concentrations measured from the male subjects (Mikkola et al. 2007.)

In the study of Bell et al. (2000), no significant changes were observed in either serum testosterone or SHBG in men or women after performing 6 days a week for 12 weeks concurrent strength and endurance training (three resistance training sessions and three endurance training sessions on alternative days) (Bell et al. 2000).

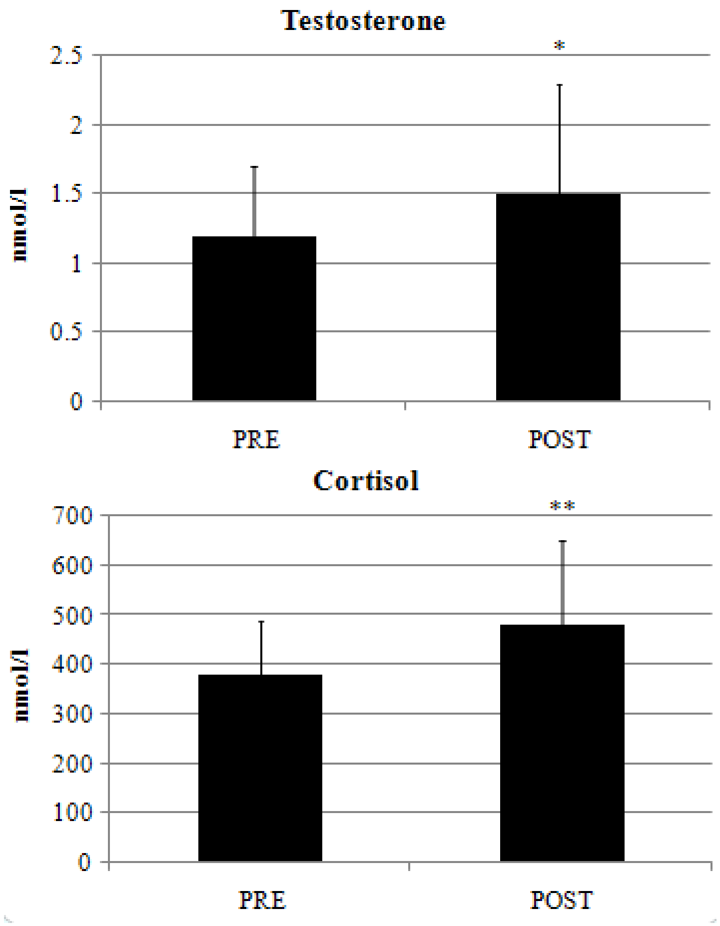


Figure 15. The change in serum testosterone and cortisol levels after concurrent strength and endurance training. Reproduced from the data of Sillanpää et al. (2010). */** = significant increase from PRE to POST measurement ($p < 0.05$ / $p < 0.01$).

4.2 Effects on physical performance

Combining endurance training with strength training appears to inhibit strength development (Figure 16) (Leveritt et al. 1999; Hickson et al. 1980). Both chronic and acute hypotheses have been proposed to explain the phenomenon (Leveritt et al. 1999).

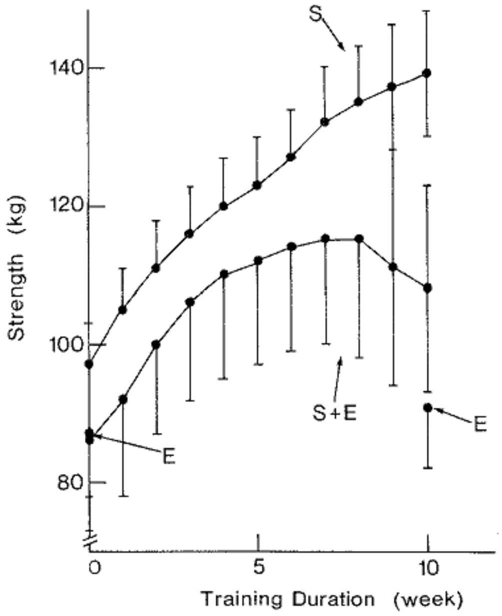


Figure 16. Strength changes in response to strength (S), strength and endurance (S and E) and endurance (E) training (Hickson et al. 1980).

The acute hypothesis suggests that residual fatigue from endurance training compromises the ability to develop tension during the strength training session (Craig et al. 1991). If sufficient tension cannot be generated, optimal strength development and adaptation may not occur. Therefore, strength training quality is reduced causing impaired strength development (Leveritt et al. 1999.)

The chronic hypothesis suggests that skeletal muscle is placed in a situation of conflict when endurance training and strength training are performed concurrently (Leveritt et al. 1999). The effects on fiber hypertrophy, endogenous substrates, metabolic enzyme activity, contractile protein structure and capillarisation by strength training are markedly different, and sometimes opposite, from the adaptations associated with endurance training (Abernethy et al. 1994). The muscle is therefore unable to adapt optimally to the strength training (Leveritt et al. 1999). Also overtraining resulting from simultaneously training strength and endurance has been suggested as a possible inhibitor of strength development (Dudley & Fleck 1987). Nevertheless, improvements in strength performance after concurrent strength and endurance training have been reported. In the study of Mikkola et al. (2007), young male distance runners performing explosive strength training three times a week accompanied by endurance training had a significant increase in 1RM of leg extensors (4 ± 5%) ($p < 0.05$) (Mikkola et al. 2007).

Distance running performance is determined by certain characteristics, including VO$_2$max, LT, and RE. Even a small improvement in RE could have a large impact on distance running performance, particularly in longer events, such as marathons or ultra-marathons (Jung, A.P. 2003.) Inconsistent results with RE due to concurrent strength and endurance training have been reported with no change (Mikkola et al. 2007) and improvement (Jung, A.P. 2003; Paavolainen et al. 2003) (Figure 17) in running economy.

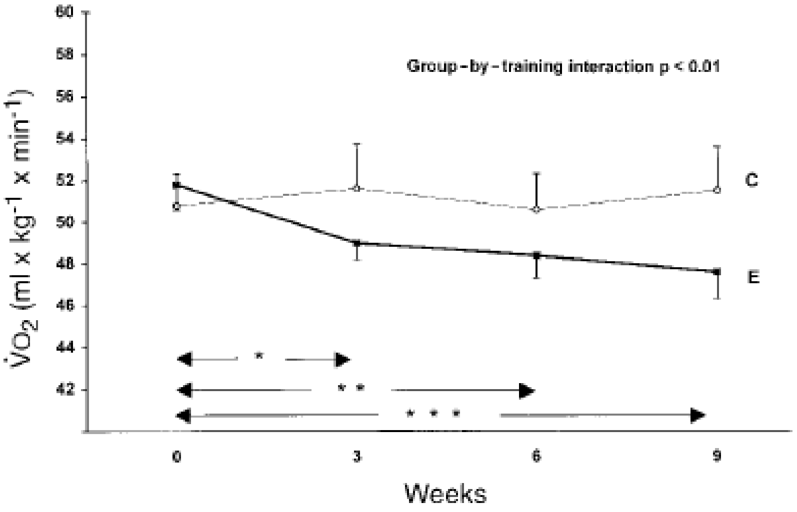


Figure 17. Average (± SD) steady-state O$_2$ uptake during last minute of running at submaximal velocity of 4.17 m/s velocity in experiment (E) and control (C) groups during course of 9-wk simultaneous explosive-type strength and endurance training. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. (Paavolainen et al. 2003).

No changes in endurance runners VO$_2$max or Vmax were reported after concurrent strength and endurance training experiment (Mikkola et al. 2007; Jung, A.P. 2003; Paavolainen et al. 2003). Because resistance training is unlikely to elicit aerobic stimulus of greater than 50% of VO$_{2max}$, it is unlikely that resistance training would improve VO$_2$max in trained endurance runners (Jung, A.P. 2003). However, it appears that distance runners can participate in a resistance-training programme (< 16 weeks) without the concern of a decrease in aerobic performance (Mikkola et al. 2007; Jung, A.P. 2003). As much as 19% of endurance training can be replaced with explosive strength training without impairing endurance performance capacity (Mikkola et al. 2007). However, resistance training may improve VO_2max and LT in aerobically unfit individuals (Jung, A.P. 2003; Paavolainen et al. 2003). Intensive circuit training has been reported to increase maximal oxygen consumption up to 12% with previously untrained subjects (Haennel et al. 1989). The stimulus of resistance exercise is not intense enough to challenge the aerobic system of the trained endurance athlete (Dudley, G.A. 1988) and this seems to be the case regardless of the type of resistance training performed (Jung, A.P. 2003).

Noakes (1988) has suggested that endurance running performance may be limited by muscle power factors. A study with trained distance runners found a correlation between leg power and 10 km running time, suggesting that skeletal muscle contractility differs between fast and slow runners (Noakes, T.D. 1988.) Neuromuscular factors appear to be important in distinguishing endurance athletes who have similar levels of VO_2max, LT, and RE (Paavolainen et al. 1999; Houmard et al. 1991). In the study of Paavolainen et al. (1999) explosive-strength training had a significant effect on neuromuscular characteristics (Figure 18) (Paavolainen et al. 1999). Whether the changes are a result of increased motor unit firing patterns, improved muscle coordination, improved mechanical efficiency, or simply increased strength requires further investigation (Jung, A.P. 2003).

Ultimately, the key measurement to determine the success of a resistance training program for a distance runner is race performance. Studies have found improvements in a laboratory setting and in physiological correlates that are related to distance running performance (Jung,A.P. 2003.), however, only in few studies improvement in running time has been found as a result of resistance training (Figure 19) (Paavolainen et al. 1999; Jung, A.P. 2003).

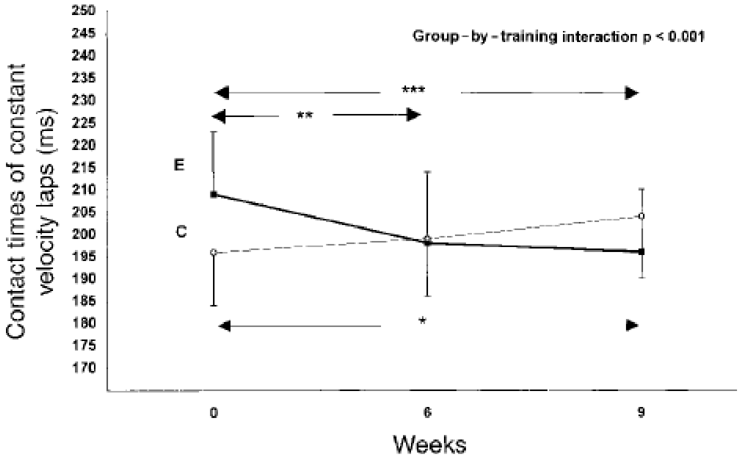


Figure 18. Average (± SD) ground contact times at constant-velocity in E and C groups during course of 9-week simultaneous explosive-type strength and endurance training. E = experimental group, C = control group (* p < 0.05, ** p < 0.01, *** p < 0.001) (Paavolainen et al. 2003).

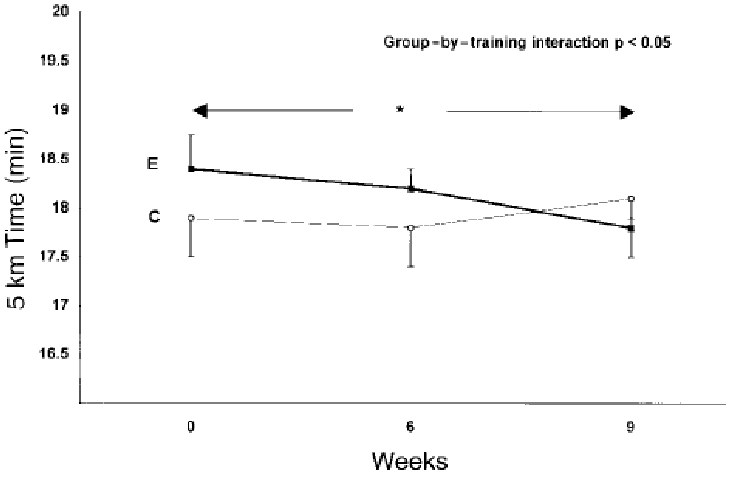


Figure 19. Average (± SD) 5-km running time in E and C groups during course of 9-week simultaneous explosive-type strength and endurance training. E = experimental group, C = control group. (* p < 0.05) (Paavolainen et al. 2003).

5 PURPOSE OF THE STUDY

The purpose of this study was to examine the effects of concurrent strength and endurance training on serum hormone levels and physical performance in recreational male and female endurance runners. The primary focus of this study was to examine the effects of different types of strength training (maximal and explosive vs. endurance strength training) accompanied by low intensity endurance training on hormone levels and physical performance. The secondary focus of this study was to examine gender differences in hormonal and physical performance responses to concurrent strength and endurance training.

5.1 Research problems

1) Will concurrent strength and endurance training cause changes in the basal serum hormone levels?

2) How does the physical performance change in recreational endurance runners during 18 weeks of concurrent strength and endurance training?

3) Are there differences in the changes of serum hormone levels or physical performance between the training groups?

4) Are there differences in the changes of serum hormone levels or physical performance between genders?

6 METHODS

This study was part of a larger study design. Two training studies were conducted in consecutive years where volunteers enrolled for two separate marathon schools aiming for success in the Finlandia Marathon 2008 or 31st Stockholm Marathon in 2009. These experiments were executed in cooperation with the Department of Biology of Physical Activity from the University of Jyväskylä and KIHU - Research Institute for Olympic Sports.

The 18-week intervention period was divided into three mesocycles (training period I, II and III) which included progressive concurrent strength and endurance training. Physiological measurements were performed in the beginning of the experiment (PRE) and at the end of each training period (Week 10, Week 14 and POST) (Figure 20), except the endurance performance variables were not tested at week 14.

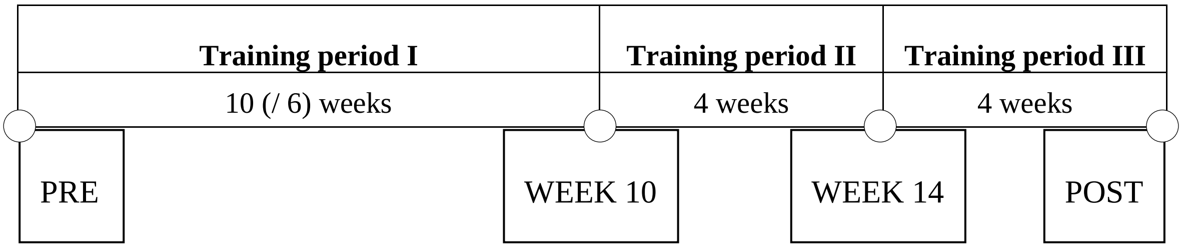


Figure 20. The study design.

6.1 Subjects

A total of forty female and male recreational endurance runners participated in this study. Subjects were a heterogeneous population of recreational endurance runners with no active strength training background. Subjects underwent a medical examination prior to the study and were not on any medications that would affect physical performance or hormone levels. Subjects were carefully informed about the design and possible risks of the study and they also signed an informed consent document. The study was approved by the Ethics Committee of the University of Jyväskylä, Finland.

Subjects were divided after 10 weeks of similar training into four groups; women's maximal and explosive strength training group (WME), women's endurance strength training group (WE), men's maximal and explosive strength training group (MME) and men's endurance strength training group (ME). The ME group participated to the 2008 study and other groups to the study of 2009. Therefore, the ME group's training period I was shorter than the others – 6 weeks long. The groups were controlled for age, anthropometrics and training background (Table 1). Eight subjects were excluded from the final analysis, two from each group. These subjects did not reach the required training activity.

Table 1. Group sizes and subject characteristics (average ± SD).

	n	**Age (years)**	**Height (cm)**	**Weight (kg)**	**Fat %**
WME	9	27.7 ± 5.6	167.9 ± 4.5	63.4 ± 5.5	24.8 ± 4.1
WE	8	35.4 ± 6.5	165.2 ± 6.7	61.1 ± 7.7	24.3 ± 6.4
MME	9	32.4 ± 8.9	178.5 ± 5.5	79.5 ± 6.5	18.2 ± 4.2
ME	6	34.3 ± 9.5	180.5 ± 5.1	83.6 ± 11.5	20.4 ± 5.9

6.2 Test procedures

Physiological measurements included blood sampling, anthropometric measurements, strength and endurance testing. Blood sampling and anthropometric measurements were done in a fasting state and consecutively in the morning between 7:30 and 8:30 AM by medical personnel. The anthropometric measurements included height, weight and body composition measurements. Height was measured with a tape measure in a standing position only in the beginning of the experiment. Weight and fat% were measured with bioimpedance (Inbody 720 body composition analyzer, Biospace Co. Ltd, Seoul, South Korea). The strength and endurance measurements were done in succession between 8:00 AM and 4:00 PM. The strength tests included measurements of counter movement jump (CMJ) and one repetition maximum (1RM). An incremental maximal running test on a treadmill was selected to determine endurance variables; maximal oxygen uptake (VO_2max) and maximal running velocity (Vmax).

Hormones. Venous blood samples (10 ml) were collected into serum tubes (Venosafe, Terumo Medical Co., Leuven, Belgium) for the determination of basal serum testosterone and cortisol concentrations. The whole blood was centrifuged at 3500 rpm (Megafuge 1.0R, Heraeus, Germany) for ten minutes after which serum was removed and stored at - 80 °C until analysis. The concentrations of testosterone and cortisol were determined by using a chemical luminescence techniques (Immulite 1 000) and hormone specific immunoassay kits (Siemens, New York, NY, USA). The sensitivity of testosterone and cortisol assays were 0.05 nmol $\cdot$ L^{-1} and 5.5 nmol $\cdot$ L^{-1}, respectively. The intra-assay coefficients of variation for testosterone and cortisol were 3.9 % and 4.6 %, respectively. All the assays were carried out according to instructions of the manufactures. All samples of the test subject were analyzed in the same assay for each hormone.

CMJ. The jump height in counter movement jump was measured with a force plate. Jump height was analyzed from impulse with computer software (Signal 2.14, CED, Cambridge, UK). The subjects were familiarized with the jumping technique before testing. Subjects had one warm-up jump before three measurement jumps. If the last jump was 5% or more higher than the session best, an additional jump was measured.

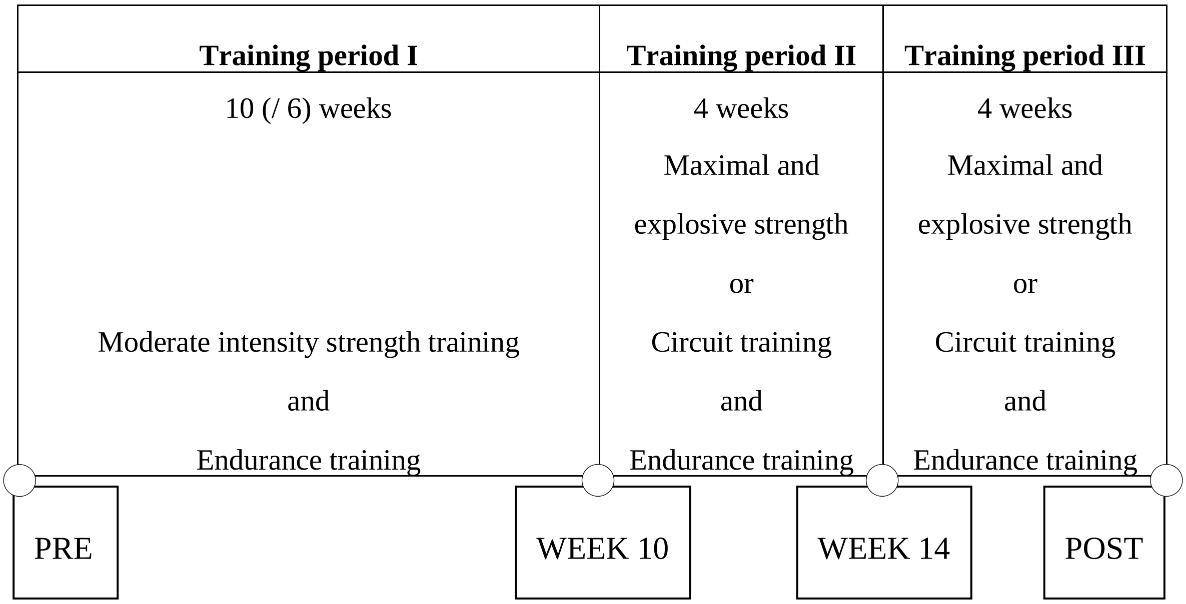
1RM. One repetition maximum (maximal dynamic bilateral horizontal leg press in a seated position) was measured using a David 210 dynamometer (David Sports Ltd., Helsinki, Finland). The seat and/or backrest position were adjusted to optimize knee angle between 60-70°. Subjects performed a controlled warm-up: 5 x 70%, 3 x 80% and 1 x 90% of the presumed 1RM. Following this warm-up, no more than 5 attempts were made to reach 1RM. The minimum weight increase was 2.5 kg and verbal encouragement was given to promote maximal effort. The rest interval was 2-3 minutes between warm-up sets and measurement trials.

VO_2max and Vmax. VO_2max and Vmax were measured during an incremental maximal running test. The initial velocity was 8 km$\cdot$ h $^{-1}$ and increased by 1 km$\cdot$ h $^{-1}$ every third minute until exhaustion. The incline was kept at 0.5 degrees during the whole test.

Oxygen consumption was measured breath-by-breath throughout the test using a portable gas analyzer (Oxycon Mobile®, Jaeger, Hoechberg, Germany). The highest 60 s VO_2 value during the treadmill test was considered as maximal oxygen consumption (VO_2max). The maximal running velocity was determined as the treadmill velocity when the subject became exhausted. If the subject could not complete the whole 3 min load until exhaustion, Vmax was calculated as follows: speed of the last completed stage (km· h^{-1}) + (running time (s) of the speed at exhaustion – 30 seconds) / 180 – 30 seconds) * 1 km· h^{-1}.

6.3 Training

The study included 18-weeks of concurrent strength and endurance training. Training was divided into three training periods. Training period I endured ten weeks (6 weeks with the ME) and the two following periods four weeks each (Figure 21).



Training period I	Training period II	Training period III
10 (/ 6) weeks Moderate intensity strength training and Endurance training	4 weeks Maximal and explosive strength or Circuit training and Endurance training	4 weeks Maximal and explosive strength or Circuit training and Endurance training

Figure 21. Training and testing schedule.

In the training period I, strength training program included all body exercises with and without additional weights (Table 2). Strength training was similar moderate intensity strength training in all groups. The amount of strength training varied from 1-2 sessions per week alternating between odd and even calendar weeks. Endurance training intensity was chosen to be low to moderate throughout the whole experiment and was conducted primarily by running. The endurance training intensity was set below the lactate threshold. Heart rate levels for training were defined individually by the method presented by Aunola, S. (1991). In the evaluation of training prescription training background and results of the PRE test were taken into account. The amount of endurance training was set in the range of 3-6 sessions/week.

Table 2. Moderate intensity strength training program during training period I.

Strength training Training period I	**Sets**	**Repetitions**	**Load**	**Recovery between sets (min)**
Squat / Leg press	2 → 3	15 → 10	50 → 70% 1RM	2 − 3
Bilateral knee extension	2 → 3	15 → 10	50 → 70% 1RM	2 − 3
Bilateral knee flexion	2 → 3	15 → 10	50 → 70% 1RM	2 − 3
Bench press	2 → 3	15 → 12	50 → 60% 1RM	2
Heel rise	1 − 2	10	50 → 60% 1RM	2
Sit-up	3	20 − 30	body weight	2
Back extension	2	8	body weight	2
Counter movement jump	2	3	body weight	2

After training period I, subjects were divided into different training groups with distinctive strength training regimes. Women’s and men’s maximal and explosive strength training groups (WME and MME) performed maximal and explosive strength training and women’s and men’s endurance strength training groups (WE and ME) performed circuit training. All groups performed two strength training sessions per week. Training periods II and III included 3-5 endurance training sessions per week following the progressive training design (Figure 22).

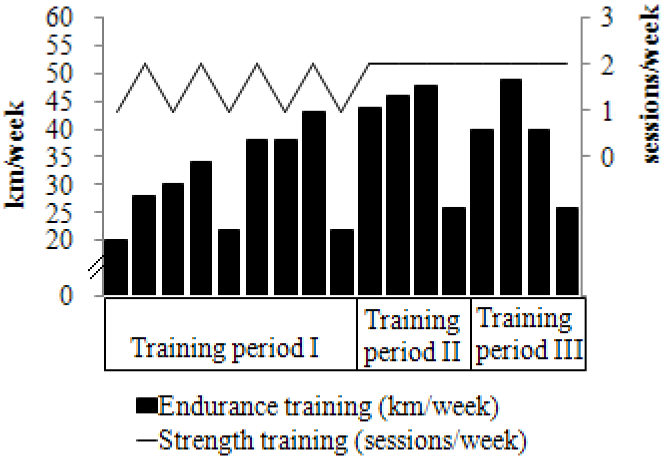


Figure 22. The progressive training design.

During training periods II and III groups WME and MME strength training consisted of maximal and explosive type of strength training. Groups WME and MME performed two supervised strength training sessions every week at the gym. One gym session included 15-30 minutes of aerobic warm-up, maximal strength training, explosive strength training and additional moderate intensity strength training to other than leg muscles. The strength training program was designed as progressive and therefore the training program differed between training periods II and III (Table 3 and 4).

Table 3. Strength training program of WME and MME groups during Training period II.

Training period II WME and MME	**Sets**	**Repetitions**	**Load**	**Recovery between sets (min)**
Squat				
warm up	1 – 2	10	50 > 70% of 1RM	2
max training	2	6	6RM	3
Leg press				
warm up	1 – 2	10	50 > 70% of 1RM	2
max training	2	6	6RM	3
Box jumps	2	8	body weight	2 – 3
Vertical jumps	2	8	body weight	2 – 3
Sit-ups, Back extension	3	20 – 30	body weight	2

Table 4. Strength training program of WME and MME groups during Training period III.

Training period III WME and MME Session I	**Sets**	**Repetitions**	**Load**	**Recovery between sets (min)**
Squat				
warm up	2	10	50 > 70% of 1RM	2
max training	3	4	4RM	3
Box jumps	3	10	body weight	2 – 3
Vertical jumps	3	10	body weight	2 – 3
Sit-ups, Back extension	3	20 – 30	body weight	2

Training period III WME and MME Session II	**Sets**	**Repetitions**	**Load**	**Recovery between sets (min)**
Leg press				
warm up	2	10	50 > 70% of 1RM	2
max training	3	4	4RM	3
Box jumps	3	10	body weight	2 – 3
Vertical jumps	3	10	body weight	2 – 3
Sit-ups, Back extension	3	20 – 30	body weight	2

During training periods II and III, groups WE and ME practiced endurance strength training. Strength training was performed as circuit training. One session lasted approximately 30 minutes where three rounds of eight different exercises were performed (Appendix 1).

6.4 Statistical analysis

Standard statistical methods were used for the calculation of means, standard deviations (SD) and Pearson product moment correlation coefficients. Normality of the data was confirmed with Q-Q Plots test. Ln-transformation was used for hormonal data in order to meet the assumptions of parametric statistical analysis. The data were then analyzed with SPSS Statistics 17.0 (SPSS Inc, Chicago, IL) utilizing multivariate analysis of variance (MANOVA) with repeated measures (group-by-training interactions). Differences between different measurement points within the groups were analyzed using paired samples t-tests. Also the differences in the relative (percentage, %) changes during the training periods between the groups were tested by t-test (unpaired). The $p < 0.05$ criterion was used for establishing statistical significance.

7 RESULTS

Group descriptives. No differences were found in the PRE values of weight or fat% between the WME and WE, and MME and ME groups. No differences were found in the PRE values of 1RM, CMJ, VO_2max and Vmax between the WME and WE groups. No differences were either observed between the MME and ME in CMJ and VO_2max PRE values. 1RM and Vmax values differed significantly between the MME and ME groups in the PRE measurement values (Table 5).

Table 5. PRE values of physical variables (AVG ± SD). ! = Significant difference between MME and ME groups ($p < 0.05$).

	1RM (kg)	**CMJ (cm)**	**VO_2max (l/min)**	**VO_2max (ml/kg/min)**	**Vmax**
WME	116.9 ± 12.5	20.8 ± 1.9	2.7 ± 0.3	43.7 ± 2.4	12.9 ± 0.9
WE	121.3 ± 14.6	18.3 ± 3.3	2.6 ± 0.5	42.9 ± 6.3	13.2 ± 1.6
MME	192.2 ± 11.3	30.5 ± 4.4	3.9 ± 0.5	50.9 ± 5.4	14.9 ± 1.2
ME	165.4 ± 21.5 !	24.4 ± 6.8	3.9 ± 0.5	46.4 ± 3.6	14.1 ± 0.8 !

Anthropometry. Body weight changed in the WME and ME groups during the experiment. The WME showed significant decrease in body weight from PRE to Week 14 (63.4 ± 5.5 kg and 62.5 ± 5.2 kg, respectively) (Figure 23). The ME group’s weight declined significantly from Week 10 to Week 14 and Post (84.2 ± 10.4 kg, 83.8 ± 10.8 kg and 82.2 ± 10.3 kg, respectively) (Figure 23). Body fat% decreased with all groups during the experiment expect in the WE group (Table 6).

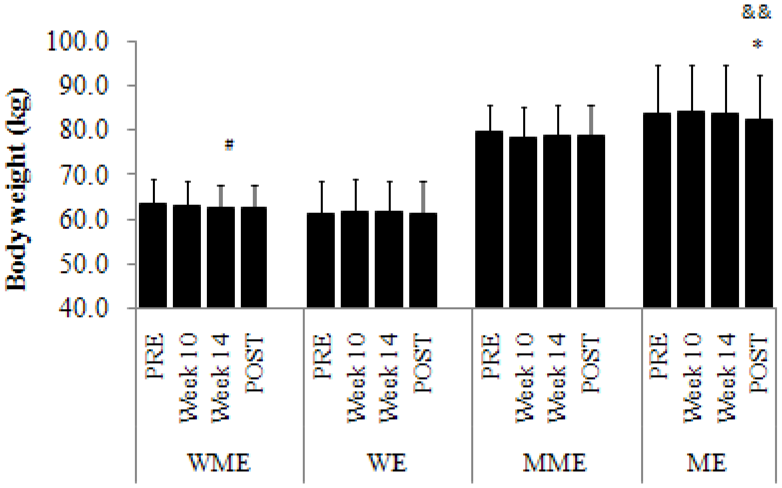


Figure 23. Body weight during the experiment (AVG ± SD). * = significant difference to preceding measurement, $p < 0.05$, # = significant difference to PRE measurement, $p < 0.05$ and && = significant difference to Week 10 measurement, $p < 0.01$.

Table 6. Body fat% during the experiment (AVG ± SD). * = significant difference to preceding measurement, $p < 0.05$, # / ## = significant difference to PRE measurement, $p < 0.05$, $p < 0.01$ and & = significant difference to Week 10 measurement, $p < 0.01$.

Fat%	**PRE**	**Week 10**	**Week 14**	**POST**
WME	24.8 ± 4.1	23.8 ± 4.6	23.3 ± 4.6 $^{\#\#}$	23.5 ± 4.4
WE	24.3 ± 6.4	24.0 ± 5.9	23.6 ± 5.7	23.5 ± 5.7
MME	18.2 ± 4.8	16.2 ± 5.4 *	15.9 ± 5.5 $^{\#}$	15.8 ± 4.0 $^{\#}$
ME	20.4 ± 5.9	20.4 ± 5.9	19.7 ± 5.7	19.1 ± 5.5 $^{\#\,\&}$

Physical performance. Concurrent strength and endurance training resulted into significant increases in strength and endurance performance. 1RM, CMJ and Vmax improved significantly in all groups (Figure 24, Table 7 and 8) during the experiment. VO_2max ($l \cdot min^{-1}$) increased significantly in the WE group only (Table 8, Figure 25), where VO_2max increased from PRE to Week 10 and from PRE to POST measurement points ($p < 0.05$-0.01). The ME group had a trend in improvement of VO_2max ($l \cdot min^{-1}$) between Week 10 and POST measurements (Figure 25) ($p = 0.055$).

Table 7. CMJ performance during the experiment (AVG ± SD). * = significant difference to preceding measurement, # = significant difference to PRE measurement, & = significant difference to Week 10 measurement. (* # &; $p < 0.05$, ** ## &&; $p < 0.01$, *** ### &&&; $p < 0.001$)

CMJ (cm)	PRE	Week 10	Week 14	POST
WME	20.8 ± 1.9	21.6 ± 1.9	23.1 ± 1.8 $^{*\ \#\#}$	23.5 ± 2.1 $^{\#\#\#\ \&\&}$
WE	18.3 ± 3.3	18.3 ± 3.2	19.6 ± 3.8	19.6 ± 3.8 $^{\#\#\ \&}$
MME	30.5 ± 4.4	32.0 ± 4.5 **	32.6 ± 5.3 $^{\#\#}$	34.0 ± 5.4 $^{\#\#\ \&\&}$
ME	24.4 ± 6.8	26.5 ± 6.4	26.8 ± 6.0 $^{\#}$	27.5 ± 5.3

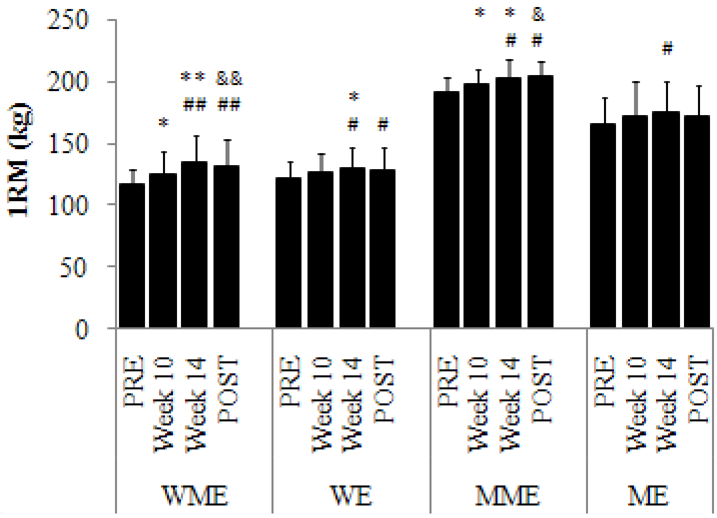


Figure 24. 1RM during the experiment (AVG ± SD). * = significant difference to preceding measurement, # = significant difference to PRE measurement, & = significant difference to Week 10 measurement. (* # &; $p < 0.05$, ** ## &&; $p < 0.01$)

Table 8. Endurance performance during the experiment (AVG ± SD). * = significant difference to preceding measurement, # = significant difference to PRE measurement, (* #; $p < 0.05$, ** ##; $p < 0.01$, *** ###; $p < 0.001$),

VO2max (ml/kg/min)	**PRE**	**Week 10**	**POST**
WME	43.7 ± 2.4	43.6 ± 1.8	45.4 ± 2.7
WE	42.9 ± 6.3	44.1 ± 6.6	44.5 ± 6.8 $^{\#\#}$
MME	50.9 ± 5.4	51.3 ± 5.2	51.7 ± 5.4
ME	46.4 ± 3.6	47.7 ± 5.8	50.2 ± 6.7

Vmax (km/h)	**PRE**	**Week 10**	**POST**
WME	12.9 ± 0.9	13.3 ± 0.9 **	13.5 ± 0.8 $^{\#\#\#}$
WE	13.2 ± 1.6	13.5 ± 1.5 **	13.6 ± 1.4 $^{\#\#}$
MME	14.9 ± 1.2	15.2 ± 1.2 *	15.6 ± 1.2 $^{*\ \#\#}$
ME	14.1 ± 0.8	14.5 ± 0.9	15.2 ± 1.0 $^{***\ \#\#}$

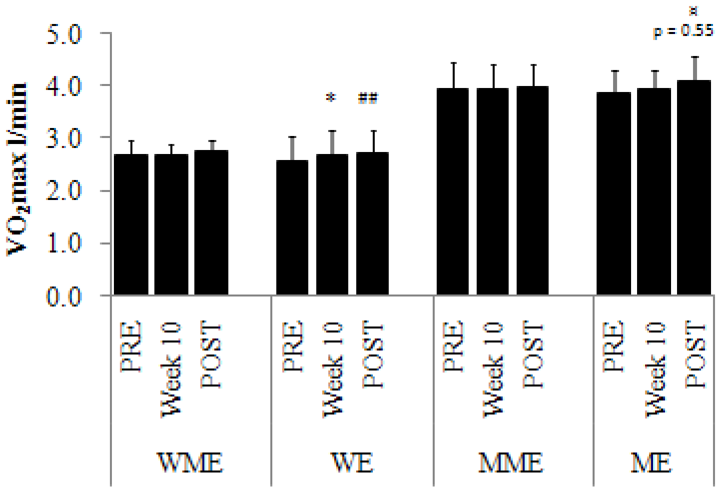


Figure 25. VO_2max ($l \cdot min^{-1}$) performance during the experiment (AVG ± SD). * = significant increase from PRE to Week 10 measurement ($p < 0.05$), ## = significant increase from PRE to POST measurement ($p < 0.01$). ¤ = non significant trend in VO_2max increase with group ME between measurements Week 10 and POST ($p = 0.055$).

Hormones. No significant changes were observed in the serum testosterone, cortisol or testosterone/cortisol ratio (T/C ratio) concentrations between any measurement points in any of the groups (Table 9). A significant increase in FT was observed with the WE group from Week 10 to Week 14 (0.018 ± 0.011 and 0.020 ± 0.011 nmol/l, respectively, $p < 0.05$) (Figure 26).

Table 9. Serum testosterone and cortisol concentrations and testosterone/cortisol ratio (T/C ratio) during the experiment (AVG ± SD).

Testosterone (nmol/l)	**PRE**	**Week 10**	**Week 14**	**POST**
WME	1.8 ± 0.6	1.7 ± 0.6	1.7 ± 0.6	1.6 ± 0.6
WE	1.6 ± 0.7	1.6 ± 0.7	1.8 ± 1.0	1.7 ± 0.7
MME	21.9 ± 5.0	23.2 ± 4.2	23.7 ± 5.0	20.1 ± 5.7
ME	14.8 ± 5.2	16.2 ± 4.5	16.0 ± 2.8	14.3 ± 3.6
Cortisol (nmol/l)	**PRE**	**Week 10**	**Week 14**	**POST**
WME	659 ± 202	621 ± 127	650 ± 175	630 ± 171
WE	626 ± 161	603 ± 169	610 ± 97	589 ± 145
MME	496 ± 159	497 ± 148	543 ± 103	482 ± 199
ME	473 ± 81	428 ± 97	453 ± 91	399 ± 91
T/C ratio (nmol/l)	**PRE**	**Week 10**	**Week 14**	**POST**
WME	0.003 ± 0.001	0.003 ± 0.001	0.003 ± 0.001	0.003 ± 0.001
WE	0.003 ± 0.001	0.003 ± 0.001	0.003 ± 0.001	0.003 ± 0.002
MME	0.046 ± 0.010	0.050 ± 0.015	0.045 ± 0.012	0.047 ± 0.027
ME	0.031 ± 0.008	0.037 ± 0.005	0.036 ± 0.006	0.038 ± 0.015

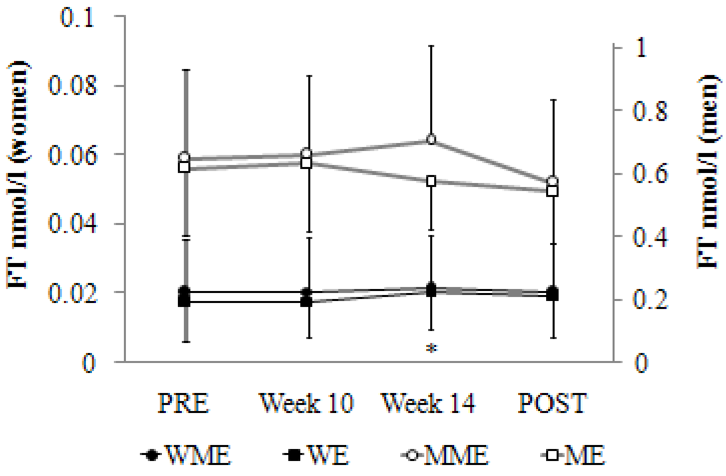


Figure 26. Serum free testosterone (FT) concentration during the experiment in different groups (AVG ± SD). * $p < 0.05$.

Effect of training group and gender. Relative changes in the hormone levels, 1RM, CMJ and in VO_2max between different groups were non significant in all measurement points. Significant differences were found only in the relative changes of Vmax. The increase in Vmax was significantly higher ($p < 0.05$) in ME compared with MME group; 5.2 ± 1.4 % and 2.4 ± 2.5 %, respectively (Figure 27). Additionally, ME had a significantly ($p < 0.05$) larger improvement in Vmax compared with WE 5.2 ± 1.4 %, 0.3 ± 2.0 %, respectively (Figure 28).

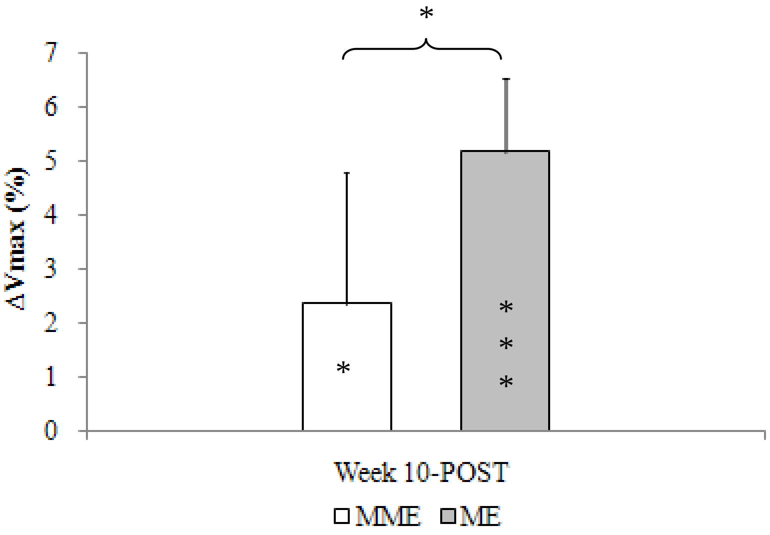


Figure 27. The MME and ME groups improvement in Vmax (AVG ± SD) from Week10 to POST. Both groups improved Vmax significantly (marks inside bars, * $p < 0.05$, *** $p < 0.001$), but the ME group significantly more than the MME group ($p < 0.05$).

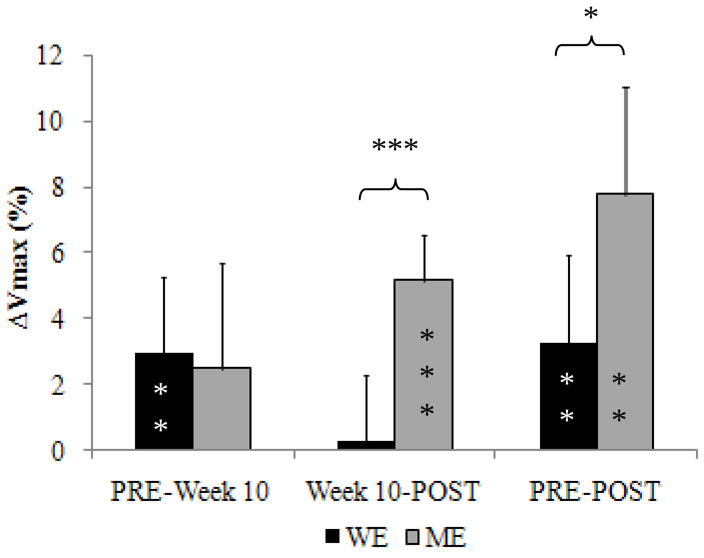


Figure 28. The change in Vmax in the WE and ME groups (AVG ± SD) during the experiment. Both groups improved their Vmax significantly (marks inside bars) during the experiment. However, the increase was significantly larger in ME, * p < 0.05, ** p < 0.01, *** p < 0.001.

A positive correlation was found in WME group between Week10 serum FT concentration and improvement in 1RM during the maximal and explosive strength training period (r = 0.75, p < 0.05) (Figure 29). MME showed a positive correlation between serum FT and improvement in Vmax between Week10 and POST measurements (r = 0.73, p < 0.05) (Figure 30).

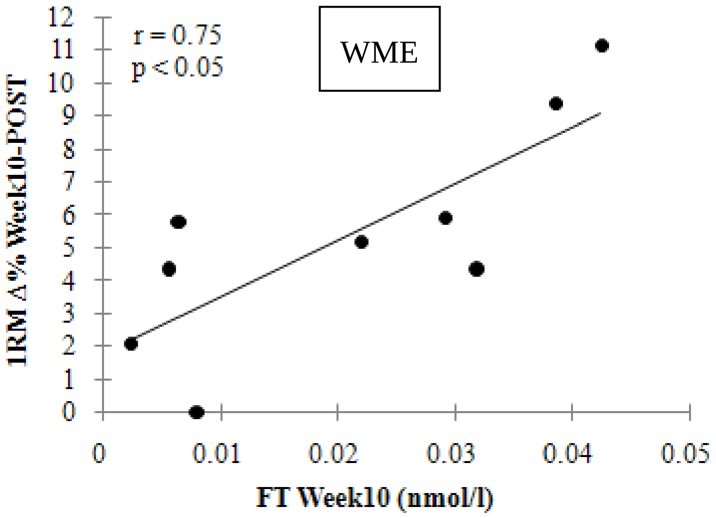


Figure 29. Correlation between Week10 serum FT concentration and improvement in 1RM in WME during the experimental strength training period.

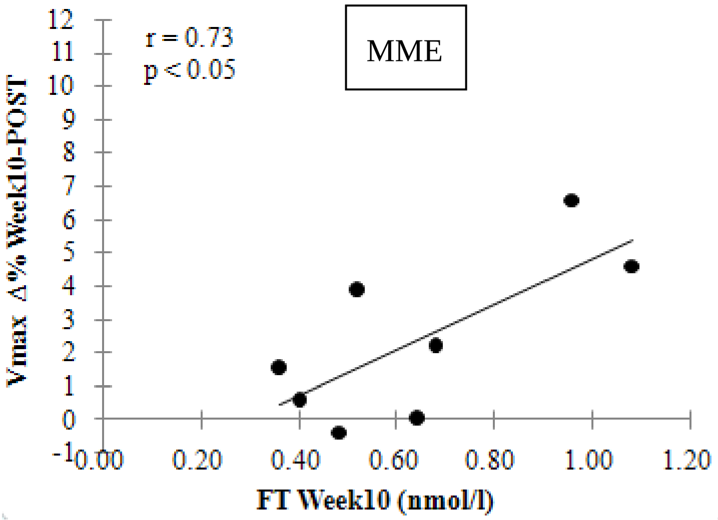


Figure 30. Correlation between Week10 serum FT concentration and improvement in Vmax in MME during the experimental strength training period.

8 DISCUSSION

Primary findings. The results showed that FT increased in WE from Week 10 to Week 14 (20.1 ± 20.6 %, $p < 0.05$). No other changes in basal serum hormone levels were observed within or between the groups or genders. 1RM and CMJ improved significantly in all groups ($p < 0.05$-0.001) as well as Vmax ($p < 0.05$-0.001). No significant differences in the changes in 1RM, CMJ or VO_2max were observed between the training groups. The increase in Vmax was significantly higher ($p < 0.05$) in the ME compared with the MME group ($p < 0.05$) during the differentiated strength training period. Additionally, ME had a significantly ($p < 0.05$) larger improvement in Vmax compared with WE ($p < 0.05$-0.001) during the experiment.

Effects of concurrent strength and endurance training on serum hormone levels. No significant changes were observed in serum testosterone, cortisol or testosterone/cortisol ratio during the experiment. This finding supports the previous studies where no significant changes in serum hormone concentrations were found (Mikkola et al. 2007; Bell et al. 2000; Häkkinen et al. 2005), although it is difficult to compare results between studies due to the differences in the study design (Leveritt et al. 1999). Nevertheless, a significant increase in FT was observed with the WE group from Week 10 to Week 14 ($p < 0.05$) (Figure 26). The relative change in FT during the same time period had no correlations between relative changes in 1RM or CMJ. Direct analysis of the FT elevation and VO_2max ($l \cdot min^{-1}$, $ml \cdot kg \cdot min^{-1}$) or Vmax cannot be made due to the absence of the treadmill test on Week14. However, no significant relationships were found between ΔFT, ΔVmax and ΔVO_2max between Week10 and POST. A possible reason for the increase in FT in WE is the change of training mode at Week10. In addition to progressively increasing endurance training, the amount of strength training (= circuit training in the WE group) increased. The training period II involved two strength training sessions per week instead of previous average of 1.5 sessions per week. Therefore, it seems that the change in training volume might have elicited transient changes in resting FT concentrations with the WE group. Transient changes in resting androgen levels have been previously reported due to changes in training intensity (Kraemer & Ratamess 2005). Although the training program changed similarly in all training groups, the changes in FT were obvious only in the WE group. Sillanpää et al. (2010) suggested that with women, who perform strength training two times per week accompanied by endurance training, an increase in serum basal androgen hormones can occur (Sillanpää et al. 2010).

The correlation analysis showed that those women in the WME group with highest serum FT at Week10, benefited the most from the maximal and explosive strength training by having largest improvement of 1RM. In the MME group, those with highest serum FT at Week10 had largest improvements in Vmax from Week10 to POST measurements. Therefore, the initial hormonal status of the individual may have contributed to their training response. Women with high serum FT seemed to have the greatest improvement in strength with maximal and explosive strength training, whereas men with high serum FT and maximal and explosive strength training seemed to improve their maximal running performance the most. Testosterone has previously been stated to have a key role in tissue remodeling, which leads to muscle growth and repair and resulting into improved performances (Kraemer & Ratamess 2005).

Effects of different type of strength training on strength performance. Changes in 1RM or CMJ were not statistically different between different strength training groups. All the groups significantly improved their performances in 1RM and CMJ during the experiment. Concurrent endurance training may inhibit gains in muscle strength and mass (Hickson, R.C. 1980). However, this interference effect holds true only when training intensity and / or volume is high (Sillanpää et al. 2010). Most of the research has shown that short-term (less than 7 ± 10 weeks), concurrent strength and endurance training can result in improvements in strength performance (Bell et al. 2000). Both groups performing combined maximal and explosive strength training improved their 1RM significantly already during the training period I (PRE to Week 10), when no improvement was detected in the WE and ME groups. This development in the early phase of the experiment might be an explanation as to why combined maximal and explosive strength training did not result in significantly higher improvements in the 1RM during the training periods II and III. The WME and MME groups improved their 1RM significantly throughout the experiment in contrast to the WE and ME groups. Nevertheless, the Δ1RM (%) did not exceed significance level between the groups. The

WME and MME groups also improved results in CMJ consistently during training period II and III when combined maximal and explosive strength training was performed. The WE and ME groups developed their CMJ result also during the same time period but not as consistently as the WME and MME. Again, the differences in ΔCMJ (%) did not exceed the significance level between the groups but the changes in maximal strength and power were more systematic in those groups performing combined maximal and explosive strength training.

Effects of different type of strength training on endurance performance. All groups improved their performance in Vmax, but only the WE group succeeded in improving VO_2max ($p < 0.05$-0.01). The WE groups VO_2max improved during the experiment, but not from Week10 to POST when WE group performed the circuit training. Therefore it seems that the significant improvement in WE group's VO_2max was largely due to the lowest initial VO_2max status and the effect of concurrent training in general, not for the specific strength training mode used. The ME group approached significant level in improvement of VO_2max from Week10 to POST (Figure 25) but this phenomenon remained as a trend as no statistical significance was observed ($p = 0.55$).

The statistically significant difference between different groups was observed in the change of Vmax. A significant difference was observed between the MME and ME group in the development of Vmax (Figure 27) therefore suggesting a difference in training response between these two strength training groups. The ME group improved Vmax 5.2 ± 1.4 % from Week 10 to POST measurement, while in the MME the improvement was only 2.4 ± 2.5 %. This result is partly in contrast with the findings of Paavolainen et al. (1999) where explosive-strength training combined with endurance training had a significant effect on running economy and neuromuscular characteristics and therefore resulting into improved 5-km running time in trained endurance runners (Paavolainen et al. 1999). Though, it is speculated that neuromuscular factors become increasingly important mainly with athletes and especially in distinguishing endurance runners who have similar levels of VO_2max, LT, and running economy (Paavolainen et al. 1999; Houmard et al. 1991). The greater improvement of the ME group's Vmax might be a result of their strength training performed as circuit training which activates the aerobic system. It has been reported that the stimulus of resistance exercise is not intense enough to challenge the aerobic system of the trained endurance athlete (Dudley, G.A. 1988), but with previously untrained subjects, intensive circuit training can result into increased maximal oxygen uptake (Haennel et al. 1989). This result suggests that the use of endurance type strength training in concurrent training could be more advantageous in improving endurance capacity than maximal and explosive type of strength training. This might be the case with especially recreational endurance runners who can activate the aerobic system with circuit training and therefore have additional endurance training sessions on weekly basis. On the other hand, the ME group had a significantly lower initial Vmax value compared to MME at the PRE measurements (Table 5). This might explain the higher training response in Vmax of ME. Individual’s initial physical performance level has been reported to have a considerable impact to the training response (Bouchard & Rankinen 2001).

Gender differences. No previous reports have been published about gender differences in the training responses to concurrent strength and endurance training. Gender differences in the acute testosterone response to strength training have been reported earlier (Linnamo et al. 2005). Therefore, it was plausible to assume that gender differences could be observed in the hormonal responses to concurrent training. A significant increase in FT was observed with the WE group from Week 10 to Week 14 ($p < 0.05$), but this phenomenon could be explained with transient changes in serum hormone levels. Long-term adaptations in endocrine function appear minimal and may be related to the current intensity/volume of the training stimulus (Kraemer & Ratamess 2005). No actual gender differences were found in the hormonal responses to training.

This study revealed one plausible gender and physical performance related difference. A difference was found in the relative improvement of Vmax between the WE and ME groups (Figure 28). Both groups trained similarly, but men’s relative improvement in Vmax was significantly higher. Significant differences were observed in the relative improvement of Vmax from Week 10 to POST ($p < 0.001$) and PRE to POST ($p < 0.05$). More interestingly, no differences were observed between the WE and ME in the initial values of Vmax or VO_2max ($ml \cdot kg \cdot min^{-1}$). This suggests that men have better trainability in Vmax when performing circuit training and endurance running. No further gender differences were observed in other physical performance adaptations analyzed from the absolute values and relative changes. It appears that there are no differences in the relative increases of physical performance between men and women when they are trained under the same relative intensity, frequency and duration (Lewis et al. 1986; Deschenes & Kraemer 2002).

Limitations of the study. This study was a part of a larger training study conducted in two consecutive years where two separate marathon schools were arranged. The ME group performed their training and measurements during the first marathon school while other training groups of this study participated to the latter marathon school. The significantly different initial values of 1RM and Vmax between the MME and ME groups were thereby observed.

The control groups performing only endurance or only strength training were not used in this study. The WE and ME groups were used as control groups for the WME and MME. The use of control groups performing only endurance or strength training would have strengthened the analysis of the effects of concurrent training to hormone levels and physical performance. However, the subjects enrolled into a marathon school aiming to participate in an actual marathon race. Therefore all subjects were chosen to have similar possibilities to train and succeed in their goal.

The limitations of the DAVID 210 apparatus used in 1RM (stepped adjustment possibilities, 250kg at the maximum) caused variations in the knee angle while testing 1RM. The knee angle of the subjects ranged between 57° to 69° during the strength tests and also differed from the knee angle used in gym training (c. 90°, no data available). These factors might have had an effect in detecting the actual 1RM training response.

Conclusions and practical applications. Hormonal responses in serum basal levels to concurrent strength and endurance training seem to be limited and mainly non significant in the group level. FT levels in WE changed significantly possibly due to changes in the training mode and intensity. No gender differences were discovered in the hormonal responses. There were positive correlations with basal FT level and improvements in maximal strength and running performance during the training periods with differentiated strength training in women and men, respectively, therefore suggesting an important role of testosterone in the individual training response. The gender differences in the changes in the selected physical performance variables were minimal. However, as an exception, higher improvements occurred in Vmax in the ME group compared with the WE, although their training regimen was similar.

In recreational endurance runners who have no active strength training background, a progressive concurrent strength and endurance training regimen results in improvements in strength and endurance regardless of the strength training type used. No statistical differences were observed in the development of VO_2max between the groups. A significant difference was detected in the improvement of Vmax between men’s different strength training groups. However, the initial Vmax level of the circuit training group was significantly lower which may explain the larger improvement in Vmax. The results show that the improvements in strength and power were more systematic in the groups performing combined maximal and explosive strength training. Therefore, maximal and explosive strength training can be recommended for recreational runners to ensure consistent improvements in strength and power while differences in the selected endurance performance variables proved to be minimal between the different strength training types.

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APPENDIX

1) Circuit training program for WE and ME groups during training periods II and III

Movements of one round:

1. Squat
2. Push-ups
3. Lunge
4. Ab-crunch
5. Heel-rise
6. Back extension
7. Plank
8. Step-up

Weeks 10-14

	Work time (s)	Rest time (s)
1. Round	40	20
2. Round	45	15
3. Round	45	15

Weeks 15-18

	Work time (s)	Rest time (s)
1. Round	45	15
2. Round	50	10
3. Round	50	10