THE EFFECTS OF A 10-WEEK HIGH INTENSITY STRENGTH AND ENDURANCE TRAINING INTERVENTION FOLLOWED BY COLD WATER IMMERSION OR ACTIVE RECOVERY

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ABSTRACT

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Combined strength and endurance training has been noted to produce significant improvements in strength and endurance performances of men. However, there seems to be moderate inhibitory effect regarding strength adaptations, especially considering power production. The effects of training have been well documented over the years yet very little has been investigated about recovery, even though athletes spend more of their time recovering than they do training. This study was conducted to investigate the effects of a 10-week combined strength and endurance training period on muscular performance and 3km time-trial in males with each training session followed by cold water immersion (CWI) or active recovery (AR).

A total of 19 healthy recreationally trained subjects (AR: 10, CWI: 9) completed a 10-week combined strength and endurance training period. All subjects trained twice a week strength and twice a week endurance. Strength training consisted of maximal resistance training (~85%1RM) and plyometric exercises for the lower extremities. Endurance training sessions were 4x4min and 3x3x100m running, with each of these being performed once a week. Strength measurements and 3km time-trial were conducted before (PRE) and after (POST) the 10-week training period. Strength measurements consisted of countermovement jump, maximal isometric bilateral leg press, maximal isometric unilateral knee extension and flexion, and 1RM dynamic leg press. From pre- to mid-measurements only AR group improved CMJ height by 7.3% (±9.9%, $p=0.064$). Only CWI group improved CMJ from mid- to post-measurements (6.6±7.9%, $p<0.05$). During the whole intervention both groups improved CMJ from pre- to post-measurements (AR: 10.0±8.0%, $p<0.01$; CWI: 9.7±5.9%, $p<0.01$). There were no significant differences between AR and CWI groups when comparing the relative changes between any measurement time points. As well as there were no significant differences between AR (pre: 787±79s; post: 767±62s) and CWI (pre: 761±69s; post: 729±53s) groups in mean 3km time-trial performance at any measurement time points.

In summary, there were no significant differences between AR and CWI at the end of the 10-week intervention. However, in the AR group, there were significant changes from PRE-to MID measurements with very little improvements from MID to POST. In the CWI group, there were no significant changes from PRE-to MID measurements while there were significant changes from MID to POST. These findings suggest that combined maximal and explosive strength and high-intensity endurance training seems to be efficient training modality even for recreationally active people and it appears CWI and AR likely assist in recovery of exercise performance; however, it is unclear which method is most effective. Further research is required to obtain a more complete understanding of the effects on performance.

Keywords: Combined training, active recovery, cold water immersion

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ABBREVIATIONS

1RM	1 repetition maximum
ANOVA	analysis of variance
AR	active recovery
ATP	adenosine triphosphate
BMR	basal metabolic rate
BP	block periodization
CWI	cold water immersion
CWT	contrast water therapy
DOMS	delayed onset muscle soreness
ECG	electrocardiogram
HR	heart rate
HR_{max}	maximal heart rate
IGH-1	insulin like growth factor 1
MVC	maximal voluntary contraction
nmol	nanomole
O_2	oxygen
pH	measure of acidity
PR	passive recovery
Q	cardiac output
RE	running economy
RFD	rate of force development
RM	repetition maximum
SD	standard déviation
VL	vastus lateralis
VM	vastus medialis
VO_{2max}	maximal oxygen uptake

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1 INTRODUCTION

Physical training consists of exposing the body to higher workloads than usual, therefore, improving physical capabilities and athletic performance. These training programs must be intense and induce fatigue. Both strength and endurance athletes will face a challenge of balancing high training loads with enough rest and recovery daily. At the highest level, the improvements in aerobic capacity are subtle and require an optimal amount of training stress so there is not too much of a disturbance in the body's homeostasis and a non-desired state of fatigue (Plews et al. 2012; Stanley et al. 2013). Indeed, planning daily athletic training to maximize training adaptation is a continuous battle of trial and error.

Chronic adaptations in strength training are a result of consistent acute changes in skeletal muscle and persist for longer periods of time. These acute responses to strength training occur primarily in the neurological, muscular (Sale 1987) and endocrine systems. Chronic responses include adaptations in body composition, the muscular, skeletal, endocrine, cardiovascular, and neurological systems. Muscular hypertrophy, or growth, is the primary chronic adaptation to strength training. This can be attributed to increased protein synthesis, or building, within the muscle fibers and satellite cell proliferation in the muscle (Seynnes et al. 2007).

One of the fundamental responses to aerobic endurance training is an increase in the aerobic capacity of the trained musculature. This adaptation allows the athlete to perform a given absolute intensity of exercise with greater ease after aerobic endurance training. Chronic adaptations to endurance training include a change in muscle fiber type. Highly trained endurance athletes have larger slow-twitch muscle fibers than fast-twitch fibers. There is also an increase in mitochondria density and number (Hoppeler & Flück 2003) and increased myoglobin stores (Whipple 1926).

When combining strength and endurance training, it has been reported that strength training can be beneficial to endurance performance (Hoff et al. 2002; Chtara et al. 2004) and that it has no negative effect on endurance performance (Hickson et al. 1988; Bell et al. 1991; Sale et al. 1990; Kraemer et al. 1995). On the other hand, it has been reported that endurance training can have a negative effect on strength adaptations (Hickson et al. 1980; Hunter et al. 1987; Nelson et al. 1990). However, combining these training methods continues to be popular because of positive reporting (Mikkola et al. 2007; McCarthy et al. 1995; Paavolainen et al. 1999; Hoff et al. 2002).

As a coach, knowing when the athlete is ready to train again and when his/her body needs rest is something that could truly help the athlete in structuring training programs. The best way to ensure recovery and maximize training adaptations is to incorporate recovery modalities into a well prepared periodized training plan and to use a combination of recovery techniques if possible. Most research on exercise training and performance has focused solely on the training methods, although most adaptations to training take place during the recovery period (McLester 2003). There are several different recovery methods used by today's coaches and athletes. The most used methods include active recovery, cold water immersion (CWI), contrast water therapy (CWT), thermal ambiance, and massage to name a few. Although some of these methods have shown some sort of increase in performance capabilities, either by themselves or combined with other methods, this thesis will concentrate on active recovery (AR) versus AR followed by CWI during 10 weeks of intense strength and endurance training.

2 REVIEW OF LITERATURE

It is well known that endurance and strength training each have a unique contribution to athletic performance. Athletes and coaches are ever changing these training modes and sometimes combining the two while trying to maximize gains. Current exercise recommendations (Kraemer et al. 2002b) call for moderate intensity of both strength and endurance training to be completed weekly to ensure basic fitness and health. The other important aspect of the athletic training model is recovery and how it is integrated into the athletes training. Athletes and coaches are continuously trying to not only enhance each training session but also to maximize recovery between training sets and sessions. The following will be a brief discussion of the chronic muscular, cardiorespiratory, and endocrine adaptations to strength, endurance, and combined training for athletes. Also, discussed at length will be fatigue. It is a common consequence of strength and endurance training and understanding its duration for recovery purposes is necessary in planning an effective training program. Therefore, the different recovery methods utilized by athletes will also be discussed.

2.1 Chronic adaptations to strength training

Introduction to Strength Training. Human locomotion relies on the neuromuscular system and the true functional unit of the neuromuscular system is the motor unit. A motor unit is an alpha motoneuron (originating in the spinal cord) and all the muscle fibers that it innervates. The motor unit can be divided into groups based on the contractile and fatigue characteristics of the muscle fibers that they innervate (Macintosh et al. 2006) and be classified as either slow-twitch or fast-twitch. The fast-twitch fibers are broken down even further into how quickly they fatigue. The fast-twitch types and subtypes primarily use anaerobic metabolism and are capable of contractions that produce energy at a rapid rate with more force per cross sectional area than the slow-twitch muscle type (Kraemer & Häkkinen 2002). Adaptations from strength training can be noticed in the muscles that have been used and recruited during a training period. High intensity training has been proven to mostly activate type II muscle fibers. Although it is important to understand the intricacies of the neuromuscular system, this thesis only examines muscular changes/adaptations.

Muscles are made up of multiple fibers enclosed in parallel bundle known as fascicles. The fibers have been classified into different types and subtypes using many different methods i.e. mATPase, myosin heavy chain, and biochemical (Scott et al. 2001). Acute adaptations or responses of skeletal muscle to strength training occur during or shortly after a bout of exercise. Chronic adaptations, on the other hand, are changes that manifest long term because of strength training. Muscular hypertrophy or growth, is the primary chronic adaptation to strength training. Hypertrophy is the increase in the cross-sectional area of the muscle fibers (Baechle & Earle 2008). The cross-sectioning of the fibers in skeletal muscle increases their force and power capabilities. Trained strength athletes can produce greater absolute maximal force and a higher maximal force per unit of cross sectional area than endurance athletes (Häkkinen & Keskinen 1989). Increases in the cross-sectional area of muscle fibers range from 20% to 45% (Staron et al., 1991) and muscle fiber hypertrophy has been shown to require more than 16 workouts to produce significant effects (Staron et al. 1994).

Muscular adaptations to strength training. The muscular responses and adaptations are determined by the type of strength training utilized including frequency, intensity, and duration of rest between sets and subsequent training days. Loadings that require more muscular activation will induce fatigue more quickly than less strenuous (Häkkinen et al. 1998). Hypertrophic strength training has been defined as approaching 80% 1RM with 8-12 repetitions and about 1-2 minutes of rest periods between sets (Kraemer & Häkkinen 2002) and induces acute muscular fatigue and increased blood lactate accumulation (McCaulley et al. 2009). This type of fatigue is also seen in maximal strength training with loads approaching 90% 1RM (Häkkinen & Komi 1983; Ahtiainen et al. 2003).

Recovery from acute training sessions is important to consider when trying to minimize chronic overuse of muscles and reduce the chances of injury. The time needed for recovery is dependent on the intensity and duration of each training session. Recovery of force production capabilities is usually completed at approximately 48 h after intense strength training (Häkkinen & Pakarinen 1993). It has also been shown that DOMS symptoms start to appear between 8 and 20 hours after the damage and reach their peak between 24 and 48 hours after the training session (Byrne et al. 2004). Thus, the frequency of training sessions with higher anaerobic lactic demands should be carefully limited to prevent overtraining (Urhausen et al. 1995).

Cardiorespiratory adaptations to strength training. The focus of strength training is to improve the athletes muscular force production but there have also been cardiorespiratory adaptations induced by strength training. Heart rate is acutely elevated immediately following a training session and affected by the amount of resistance, the number of repetitions and the muscle mass involved in the contraction (Fleck 2011). These increases in HR and O_2 consumption have been seen to induce small gains in cardiorespiratory fitness if performed over a prolonged period (Katch et al. 1985). There have also been changes observed in cardiac output (Q) with strength training (Stone et al. 1991; Weiner & Baggish 2012). An athlete's current training status will undoubtedly influence cardiorespiratory responses and adaptations to strength training.

Some researchers have shown that circuit-based strength training, is very effective for increasing maximum oxygen consumption, maximum pulmonary ventilation, functional capacity, and strength while improving body composition (Harber et al. 2004; Gettman et al. 1979). To optimize the circuit weight training prescription, it seems reasonable to identify the most effective combination of intensity, volume, work to rest ratio, weekly frequency and exercise sequence to promote muscular, cardiorespiratory and body composition adaptations.

2.2 Chronic adaptations to endurance training

Introduction to endurance training. There are several different modes of endurance training with running and cycling being the most prominent worldwide. Although most of the endurance exercises that are conducted differ in movement patterns, they all stress the cardiorespiratory system. Training adaptations are induced specifically in the muscles actively used in the exercise and these adaptations are sustained by continued activity and lost following inactivity. Both intensity and duration of exercise training sessions are important factors influencing muscle adaptations for endurance training.

The muscles must be recruited during the exercise task to adapt to the training program (Holloszy 1967). The fibers not involved will not adapt. Muscle (slow-twitch fibers) adapt to aerobic exercise training to become a more effective energy provider. An improved capacity for oxygen extraction from the blood supply and an altered cellular control of energy metabolism likely contribute to the improved muscle performance evident with training (Fink 1977). The slow-twitch fibers exhibit a relatively high blood flow capacity, a high capillary density, and a high mitochondrial content. This fiber type is impressively fatigue resistant, if blood flow is sufficient. Thus, endurance athletes (e.g. marathoners and triathletes) rely on a greater capacity of type I. Both intensity and duration of exercise training sessions are important factors influencing muscle adaptations and any gains will be lost due to detraining. The major physiological determinants for endurance performance are work economy, lactate threshold, and VO_2max (Pate & Kriska 1984).

Muscular adaptations to endurance training. The different muscle contractions and differences in training modes has been shown to affect muscle damage differently (Millet et al. 2009). Skeletal muscle adapts to endurance training chiefly through a small increase in the cross-sectional area of slow-twitch fibers, because low- to moderate-intensity aerobic activity primarily recruits these fibers (Abernethy et al. 1994). Endurance training also increases the number of capillaries in trained skeletal muscle, thereby allowing a greater capacity for blood flow in the active muscle (Terjung 1995). A study by (Luden et al. 2012) showed that a 16 weeks of moderate marathon training for recreational runners induced the size of the muscle, contractile properties and fiber type distribution. Other studies have shown that running longer distances induces lean muscles with shorter fascicle lengths and smaller pennation angles (Abe et al. 2000). These findings support the idea that training mode favors specific muscle characteristics or that these characteristics are the result of prolonged specific training.

Cardiorespiratory adaptations to endurance training. Endurance training leads to significant cardiorespiratory/ cardiovascular changes at rest and during steady state exercise at both submaximal and maximal rates of work. Again, the magnitude of these adaptations largely depends on the person's initial fitness level; on mode, intensity, duration, and frequency of exercise; and on the length of training. Cardiac output (Q) at rest or during submaximal exercise is unchanged after an endurance training program but when training nears maximal rates of work (Q) is increased up to 30% (Saltin and Rowell 1980). Therefore, per the Fick Principle that suggests improving oxygen consumption (VO_2) one must improve (Q), this study suggests that endurance training can give this positive cardiorespiratory outcome. The major changes in the respiratory system from endurance training are an increase in the maximal rate of pulmonary ventilation, which is the result of increases in both tidal volume and respiration rate, and an increase in pulmonary diffusion at maximal rates of work, primarily due to increases in pulmonary blood flow, particularly to the upper regions of the lung.

Running economy. (RE) consists of many physiological and biomechanical factors that contribute to running performance, and is measured to quantify energy utilization while running at an aerobic intensity. Oxygen Consumption (VO_2) is the most direct method for measuring running economy, as the exchange of gases in the body, specifically oxygen and carbon dioxide, closely reflects energy metabolism. Other factors that contribute to running economy include; "vertical motion while running, the ability of the muscles to absorb energy during the shock of landing and transfer it to push-off, technique and type of activity, fitness and training, age, fatigue, gender, race, weight of clothing and shoes, and environmental conditions" (Noakes 2003).

2.3 Chronic adaptations in combined strength and endurance training

Introduction to combined training. A person's physical fitness is defined as a series of attributes (e.g., aerobic capacity, muscular strength and endurance, flexibility) that enables them to perform physical activity and improves functional ability (Avlund et al. 1994). Both strength and endurance exercise elicit highly specific positive physiological adaptations and are needed to sustain daily physical activities. Thus, these modes are commonly integrated into the exercise programs of athletes and non-athletes. However, likely because of their divergent nature, this combination of strength and endurance training can also limit various adaptive outcomes and there is still a debate as to the optimal ordering of these modes. With that said, a combination of endurance training and strength training may be the most promising solution to reap the benefits of a healthy life.

Strength training and endurance training both cause muscular and cardiovascular adaptations, which differ depending on various training parameters, including intensity, volume, and frequency, among others. Strength training primarily leads to increases in strength, muscle size, rate of force development (RFD) and muscular power. Endurance training primarily leads to increases in maximum oxygen consumption and time-to-exhaustion in incremental or constant-load endurance tests. Combined strength and endurance training is considered an optimal stimulus to promote both muscular and cardiovascular gains (Cadore et al. 2012 and Izquierdo et al. 2009). However, it has been shown that combined training may result in lower strength gains compared with just strength training (Leveritt et al. 2003; McCarthy et al. 2002; Hunter et al. 1987; Bell et al. 2000) and this is called the "interference effect" and will be discussed in a later section. This effect has been attributed to a blunting action due to endurance training (Bell et al. 2000). However, in a 12-week study, combining both modes of exercise into one session 3 days/ week produced an increase in strength equal to that of a strength only group, and an increase in aerobic capacity equal to that of an endurance only group (McCarthy et al. 1995).

Muscular adaptations to combined training. It is believed that performing endurance training immediately before or after strength training may diminish strength gains because of the muscle fatigue resulting from the preceding training and the inability of the muscle to adapt optimally to two different stimuli with different energy pathways during the same session (Doucherty & Sporer et al. 2000; Wilson et al. 2012). Other research that has compared combined training to just strength training has indicated adaptations in strength but not endurance, may be compromised when strength and endurance are combined during training, when compared to only strength training (Hickson et al. 1980; Häkkinen et al. 2003). When designing, and prescribing an exercise program, the typical goal is to maximize benefit. A 10-week study comparing the effects of endurance or strength training only to combined training found that strength only produced improvements in BMR and muscular strength, while endurance only produced a decrease in body fat with an increase in aerobic capacity. The combined group provided similar benefits, but not always of the same magnitude (Dolezal and Potteiger 1998). In a recent study (Eklund et al. 2015) spanning 24-weeks of either same-session or different day combined training in different orders found that gains in strength, hypertrophy and maximal power output during cycling were significant for all groups following the intervention with no between-group differences. These findings are similar to a 12-week low-frequency combined exercise program that investigated the influence of manipulating the order of strength and endurance training on the pattern of the adaptation of physiological functions and revealed that for all the effect of endurance + strength and strength + endurance training on maximal muscular strength, strength endurance, and explosive strength, there were no differences between the groups with different sequence orders. Chronic participation in these two exercise modalities sheds light on the implications each has on body composition as well as changes in endurance capacity and strength.

Cardiorespiratory adaptations to combined training. Cardiorespiratory responses to a single session of combined strength and endurance training at low volume and intensity may be expected to produce similar responses when compared to muscular responses. Studies examining combined strength and endurance training appear to primarily target muscular capabilities and performance. These muscular capabilities may be independent of VO_{2max}, which is a well-established relationship of exercise intensity and exercise duration. However, combined strength and endurance training does not appear to induce large increases in VO_{2max}, when the subjects are already physically active (Millet et al. 2002; Mikkola et al. 2007). A few studies have indicated that VO_{2max} and other aerobic capacities may be compromised following prolonged periods of combined strength and endurance training (Nelson et al. 1990; Glowick et al. 2014). However, a recent meta-analysis (Wilson et al. 2012) showed that the majority of studies indicated no attenuations of combined training induced changes in aerobic capacities.

Endocrine adaptations to combined training. The physical stress applied to the human body during exercise causes the endocrine system to release the hormones that control physiological functions in the body. The differences in muscular adaptations for strength and endurance training performed separately has been well documented (Hawley 2009 and Nader 2006) and the adaptations to combined training are certainly unique.

Conducting both strength and endurance training together can generate a higher metabolic demand, resulting in increased release of cortisol, which may negatively influence the release of testosterone during the training session (Brownlee et al. 2005). There are several factors that can negatively affect strength gains when conducting combined training. These include low muscle glycogen which leads to a chronic catabolic state, antagonistic protein synthesis signaling, which ultimately interfers with the magnitude of muscle hypertrophy (Nader 2006; Putnam et al. 2004). This is reagrded to as the interfernce effect (Hickson 1980) and will be discussed more in a later section.

The large volume of training that occurs from combined training can lead to a steep rise in the resting levels of cortisol and an imbalance among the anabolic hormones (i.e., testosterone, growth hormone) and catabolic hormones (i.e., cortisol), consequently producing an unfavorable environment for developing muscle mass (Bell et al. 2000). Some research observed an interference effect on developing strength and muscle mass that paralleled the increase in resting cortisol concentrations (Bell et al. 2000 and Kraemer et al. 1995). The role of hormone concentrations in the interference effect is typically investigated by assessing circulating testosterone and cortisol at rest (Bell et al. 2000 and Cadore et al. 2010). The following section will briefly describe the interfernce effect on combined training.

Interference effect. The interference effect of concurrent training is now widely known. This phenomenon has received its name because it has been observed on many occasions that performing both strength and endurance exercise concurrently in a training program appears to lead to inferior gains in most if not all of the main strength adaptations in comparison with a program comprising solely strength training (Hickson 1980). In this study, strength improvements leveled off after 7 weeks of combined strength and endurance training, while the strength training only group continues to improve after 10 weeks of training (Hickson 1980). However, a recent meta-analysis by Wilson (2012), reported on the effects of combined training vs. strength training only for muscular hypertrophy of the upper and lower body, strength of the upper and lower body, and power of the upper and lower body. In the meta-analysis, the reviewers found that gains in muscular hypertrophy and strength were not significantly different between strength-training-only and combined training groups. However, they found that power was significantly lower in combined training groups than in strength-training-only groups. This indicates that power is more sensitive to the interference effect than either strength or hypertrophy (Wilson et al. 2012).

2.4 Periodization & recovery modalities

Periodization. As athletic training becomes more strenuous and professional, the need for a scientific background for conscious planning becomes more desirable. In the 1950s a Soviet biochemist, Yakovlev, reported on supercompensation (Issurin 2010). The phenomenon of supercompensation is based on the interaction between load and recovery. (Figure 1). The best way to ensure recovery and maximize training adaptations is to incorporate recovery modalities into a well prepared periodized training plan and to use a combination of recovery techniques when possible. Although all types of training can be periodized here in this study only periodization of strength training took place.

For this study, we used a linear/ traditional periodized training plan. Long-term programs of classic, linear or traditional strength periodization programs begin with high volume-low high-intensity training and progress towards low-volume high intensity training (Fleck 2011). These types of training plans are used maximize strength and fitness gains by utilizing planned changes in volume and intensity. In periodized training studies lasting 10 weeks, as in this study, it has been shown that maximum strength gains increased 16% (Jones et al. 2001) and gains in maximum strength of 22% (Lamas et al. 2010). A meta-analysis indicates periodized strength training programs result in greater strength increases in both untrained or trained individuals compared to programs that do not change (Rhea & Alderman 2004).

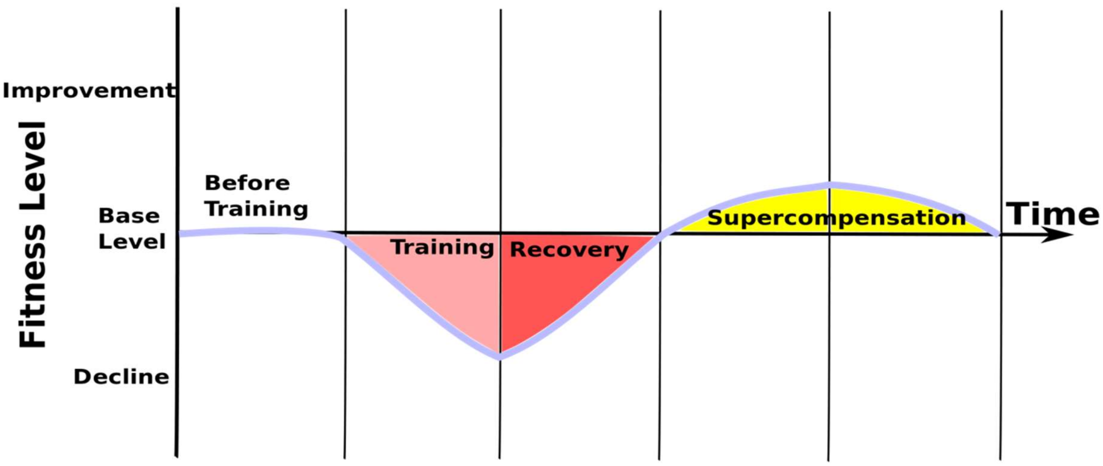

Figure 1. A well-known model of supercompensation. Training leads to fatigue, which is reversed following recovery. After sufficient recovery, work capability reaches a higher level. (Issurin 2010.)

Recovery. Recovery from exercise can be an important factor in performance during repeated bouts of exercise. It has several factors each requiring the coach and athlete to understand the physiological makeup of the athlete, the physiological effects of both training and recovery interventions, and the effects of integrating training and recovery strategies (Bishop et al. 2008). Many athletes, both elite and recreational, try to achieve an appropriate balance between the many different training stresses and proper recovery is important in maximizing their performance. A wide range of recovery modalities are now used as integral parts of the training programs of athletes to help attain this balance. Recovery modalities have largely been investigated regarding their ability to enhance the rate of blood lactate removal following high-intensity exercise or to reduce the severity and duration of exercise-induced muscle injury and delayed onset muscle soreness (Barnett 2010). After high-intensity exercise, rest alone will return blood lactate to baseline levels well within the normal period between the training sessions of athletes. The following sections will discuss the many recovery methods used by athletes and coaches today.

2.4.1 Different recovery interventions

Recovery refers to the body's restoration of physiological and psychological processes of its pre-fatigue state (Vaile 2007). Each athlete (recreational or elite) has specific physiological and psychological needs and preferences and should be taken into consideration before beginning a periodized training plan. Besides sleep, other recovery modalities include massage, active recovery, cryotherapy, contrast temperature water immersion therapy, hyperbaric oxygen therapy, nonsteroidal anti-inflammatory drugs, compression garments, stretching, and electrostimulation. Although the following recovery methods are not used by the subjects in this study it is very important to realize the potential for future studies to include these methods both individually or in combination with several methods. The following is a list of some of the most used recovery methods.

*Passive Recovery (PR)***.** PR is the most basic of all recovery is passive recovery with sleep being the most used technique (Wilcock et al. 2006). Sleep deprivation is the term used when an athlete is encountering acute or chronic sleep disturbances. This can be detrimental to the athletes training because of sleeps central role it plays in aiding recovery. Adequate sleep appears to be integral in promoting recovery and adaptations to training and optimizing performance in training. The amount of sleep recommended depends on the level of the athlete. The higher the level the more sleep needed with the daily recommendation being around 9 hours/ day with short naps throughout the day for elite athletes (Tietzel & Lack 2002). Sleep ensures several physiological and psychological functions of both cognitive and physical aspects (Frank 2006).

*Massage***.** Massage has been around for many years and has many various techniques all depending on the therapist's experience and outcome desired. Massage is used to reduce anxiety, improve mood, and increase relaxation (Weinber et al. 1988). There has also been a perception of recovery among some athletes (Hemmings et al. 2000). It appears that the only significant effects are psychological in nature. It should be considered to use this in combination with other methods in the future.

*Thermal Ambience***.** Artificial heating and cooling of ambient temperature has been used for quite some time and seems to be expanding in it use by coaches and athletes. The areas discussed here will be saunas/steam rooms, and cryotherapy. During sauna sessions, the optimal temperature of exposure is about 85 C with a relative humidity between 15-30%

(Kukkonen-Harjula & Kauppinen 2006). Some authors (Nadler et al. 2004) have shown that sauna use reduces perceived pain after use. The use of sauna does come at a cost and in order not to hinder future athletic performance, replenishment of lost fluids should take place immediately (Gutierrez et al. 2003). Whole body cryotherapy has also given indications of treating inflammatory conditions (Hausswirth et al. 2011) and reducing muscle pain. These methods are considered safe but safety precautions must be considered.

*Contrast Water Therapy (CWT)***.** CWT is a method used consisting of alternating immersion in cold water (<15 C) and hot water (>36 C). CWT seems to be the most preferred method of the water immersion techniques based on scientific data. CWT has shown a greater increase in 300m sprint performances by rugby athletes compared to cold water immersion (CWI) or PR (Higgins et al. 2011) and greater performance in CMJ compared to PR (King & Duffield 2009). CWT has also shown a greater decrease in the muscle damage marker creatine kinase (CK) (Gill et al. 2006) than PR and a greater decrease in muscle soreness than PR and AR (King & Duffield 2009).

Fatigue can compromise competition performance, quality and quantity of training, and increase injury risks in athletes (both recreational and elite). Ideally, fatigue levels should be minimized by recovering as fast as possible. The best way to ensure recovery and maximize training adaptations is to incorporate recovery modalities into a well prepared periodized training plan and to use a combination of recovery techniques if possible. The following sections will take a closer look at the recovery methods used for the subjects of this study.

2.4.2 Cold water immersion (CWI)

Introduction. Scientist, coaches, and athletes hoping to enhance exercise performance have looked to a wide range of techniques designed to better their short-term recovery by investigating the different mechanisms of fatigue. It is believed that accelerated recovery will decrease fatigue levels and enhance performance in competition scenarios. In theory, increased training load should produce a greater adaptation and improve performance. For these reasons, post-exercise recovery techniques are being increasingly used by athletes and investigated by the scientific community.

Overview. Water immersion has been used in some cultures for centuries as a means of health restoration. Recently, water immersion has gained popularity to improve recovery from exercise, although much of its use is based on unreliable information (Halson 2011; Higgnis et al. 2011). Cold water immersion is increasingly being used at special recovery facilities in specially built pools, however, some athletes find this inconvenient and prefer having portable pools because they can travel with them at all times. Cold water immersion is performed in either water, or a combination of water and ice. This study utilized the latter method. Most of the literature has examined temperatures ranging from $5^0 – 20^0$ C, however temperatures of $15^0 – 20^0$ C (Lane & Wenger 2004; Roswell et al. 2011; Vaile et al. 2008a; Vaile et al. 2008b; Bailey et al. 2007; Peiffer et al. 2010; Ingram et al. 2009; Montgomery et al. 2008) are the most common. It is this reason that we utilized an ice water bath at 12^0 C; $\pm 1^0$ C. The total immersion time usually ranges from 3-20 minutes (Lane & Wenger 2004; Vaile et al. 2008a; Vaile et al. 2008b; Bailey et al. 2007; Peiffer et al. 2010) and depended on the temperature of the water. In this study, the subjects were immersed for ten minutes. The immersion depth may vary from waist to shoulder height but this study utilized a seated immersion level to just below the pectoral muscles. The subjects in this study remained passive during the immersion.

Effects on performance. The effects of post-exercise CWI on recovery after an exercise bout has been investigated in several studies (Lane & Wenger 2004; Roswell et al 2011; Bailey et al. 2007; Vaile et al. 2008a; Vaile et al. 2008b; Peiffer et al. 2010; Ingram et al. 2009; Montgomery et al. 2008; Yeargin et al. 2006). These studies have reported that CWI did assist the subjects in recovery after exercise. Interestingly, these studies include post-exercise CWI improvements in several different forms of exercise, such as cycling (Lane & Wenger 2004; Vaile et al. 2008a; Vaile et al. 2010; Peiffer et al. 2010), running, (Roswell et al 2011; Montgomery et al. 2008; Yeargin et al. 2006), counter movement jumps (Montgomery et al. 2008; King & Duffield 2009) and leg strength (Bailey et al. 2007; Ingram et al. 2009). These findings would indicate the positive effects of CWI are not limited to specific movements. These studies found the improvements to last minutes (Yeargin et al. 2006; Bailey et al. 2007) and up to several days (Lane & Wenger 2004; Vaile et al. 2008a; Vaile et al. 2010; Peiffer et al. 2010; Roswell et al. 2011; Montgomery et al. 2008; Bailey et al. 2007; Ingram et al. 2009) after CWI. However, other studies have reported no change in performance (Sellwood et al. 2007; Paddon-Jones & Quigley 1997; Jakeman et al. 2009) or even a negative effect on recovery after a fatiguing exercise session (Yamane et al. 2006; Crowe et al. 2007; Schniepp et al. 2002).

Physiological Responses. Physiological changes have been mainly attributed to effects of hydrostatic pressure and water temperature (Wilcock et al. 2006). The hydrostatic pressure exerted on the body during CWI may also help to reduce muscle damage and soreness by altering the tissue temperature and improving the blood flow (Wilcock et al. 2006). The reported benefits of CWI include an improvement in perceived recovery and parasympathetic cardiac activity (Al Haddad et al. 2010; Bahnert et al. 2013; Buchheit et al. 2009; Higgins et al. 2012; Ingram et al. 2009; King & Duffield 2009; Versey et al. 2011). The reduced level of perceived pain may be due to slower nerve conduction velocities and reduced excitability and neural transmission (Bieuzen et al. 2013). Alongside the effect of hydrostatic pressure this produces an increase in substrate transport and cardiac output (Wilcock et al. 2006). A number of recent studies have reviewed the benefits of using cold water immersion to prevent and treat muscle soreness after exercise (Bleakley et al. 2012; Leeder et al. 2012; White & Wells 2013). These reviews conclude that CWI reduces and delays the onset of muscle soreness in comparison with the effects of both PR and AR. Several studies have also reported a decrease in skin, muscle and core temperature with cold water immersion, which ultimately may benefit recovery (Peiffer et al. 2009; White & Wells 2013).

2.4.3 Active Recovery (AR)

Introduction. A recovery strategy involves the implementation of a technique or a combination of techniques to accelerate the time to achieve full recovery and potentially reduce the risk of injury. Coaches, trainers and athletes use active recovery as a method of improving recovery and maintaining or improving performance (Calder 2003). Active recovery is a post-training exercise at an intensity that is lower than during the training. The intensity and mode of active recovery may vary, but most research indicates that the intensity is normally less than the anaerobic threshold (< 65% O2max) and researchers use a similar mode to the exercise that was performed (Lattier et al. 2004; Monedero & Donne 2000; Thiriet et al. 1993; Weltman et al., 1977). The duration of active recovery in research is normally between four and 20 minutes (Lattier et al. 2004; Monedero & Donne, 2000; Thiriet et al. 1993; Weltman et al. 1977).

Effects on performance. This recovery strategy is often implemented in aerobic type sports (i.e. soccer) and has been reported to enhanced blood lactate removal or accelerated pH recovery (Sairyo et al. 2003) when AR is engaged for 15 minutes at 30-60% $VO2_{max}$ (Belcastro & Bonen

1975; Taoutaou et al. 1996). Also, it has been shown in canoeist and footballers that 20 minutes of post-exercise active recovery involving the same muscles that were active during the fatiguing exercise is more effective in fatigue recovery than active exercise using the muscles that were not involved in the exercise (Mika et al. 2016). Although, it is important to highlight that some studies have shown lactate enhanced removal is not a valid indicator of recovery quality (Allen & Westerblad 2004; Cairns 2006). Even though this may be the case, a study analyzing several different recovery protocols (passive, active, massage, and active followed by massage) has shown that the combination of active recovery and massage was the most efficient intervention for maintaining maximal performance time in eighteen trained cyclists (Monedero & Donne 2000).

Physiological Responses. Increased blood flow during light-intensity exercise has been postulated as the mechanism that improves recovery. Signorile et al. (1993) suggested that the contraction-relaxation action of active muscles may increase the clearance of metabolic waste. By increasing blood flow the removal of metabolites, such as lactate, and the replenishment of substrates within the muscles could be enhanced (Bonen & Belcasro 1977). Over the short-term active recovery may increase the muscles contractile ability and over the longer-term aide in healing (McEniery et al. 1997; Sayers et al. 2000). However, while low intensity activity may improve recovery higher-intensity active recovery may inhibit recovery by increasing metabolic waste and depleting nutrients (McEniery et al. 1997).

3 PURPOSES OF THE STUDY AND RESEARCH QUESTIONS

The purpose of this study was to examine the chronic muscular and cardiorespiratory adaptations to combined strength and endurance training and to evaluate the effects of two recovery methods; active recovery versus active recovery and cold-water immersion, on healthy men that are recreationally active.

3.1 Research problems

1. Is combined maximal strength and high-intensity endurance training capable of improving muscular performance in recreationally trained men?

Hypothesis: Combined maximal strength training and high intensity endurance training can improve muscular performance.

Rationale: In previous studies, it has been noted that combined strength and endurance training can improve both strength and endurance performance (Barrett-O'Keefe et al. 2012; Hoff et al. 2002), even with athletes (Millet et al. 2002). However, it seems that endurance training might inhibit development of rapid force production (Hunter et al. 1987; Leveritt et al. 1999).

2. Is combined maximal strength training and high-intensity endurance training capable of improving endurance performance in recreationally trained men?

Hypothesis: Combined maximal strength training and high intensity endurance training can improve endurance performance in trained men and this is due to improved running economy provided by improved muscular performance.

Rationale: It has been shown that combined strength and endurance training can improve both strength and endurance performance, and most of the studies show that strength training does not inhibit adaptations to endurance training (Hickson et al. 1988; Laursen et al. 2005). Recent studies also show that strength training is one of the key factors of improving endurance performance due to improved running economy (Rønnestad & Mujika 2014).

3. Are there major differences in muscular adaptations after a 10-week combined maximal strength and high-intensity endurance training intervention between the recovery methods used in this study?

Hypothesis: Both groups of men, AR and CWI, will experience the same muscular adaptations throughout the intervention.

Rationale: Most studies that have investigated the effect of post exercise CWI have shown it to assist in post exercise recovery (Lane & Wagner 2004; Roswell et al. 2011; Vaile et al. 2008b). However, some studies have shown it to have no effect (Paddon-Jones & Quigley 1997; Sellwood et al. 2007). Performance improvements have been recorded for cycling (Vaile 2008a), running (Yeargin et al. 2006; Roswell et al. 2011), CMJ (Montgomery et al. 2008; King & Duffield 2009), and leg strength tests (Bailey et al. 2007 and Ingram et al. 2009), implying that the positive effects of CWI are not limited to certain movements.

4. Are there major differences in endurance running performance after a 10-week maximal combined strength and high-intensity endurance intervention between the recovery methods used in this study?

Hypothesis: The men that utilized AR might see bigger gains in their 3k time trials.

Rationale: The positive acute changes in endurance running performance after post-exercise CWI are well documented. In a study by Brophy-Williams et al (2011), immediate, post-exercise CWI showed significant next day improvements for a high-intensity shuttle run compared to the passive recovery group. Other researchers have reported that CWI performed immediately post-exercise resulted in benefit to subsequent exercise performed ~1 h compared to active recovery (Vaile et al. 2010) and 24 h compared to passive control; (Bosak et al. 2006; Lane & Wenger 2004) post CWI. However, the continuous long-term physical adaptations are less known. A few studies suggest that continual CWI has no negative effects on chronic adaptations (Ihsan et al. 2015; Machado et al. 2016). While other studies suggest that continual use of CWI can reduce vascular and muscular adaptations from both endurance and strength training (Yamane et al. 2006; Yamane et al. 2015; Frohlich et al. 2015).

4 METHODS

4.1 Subjects

Twenty-four healthy male subjects (n=24) aged 18-40 from the Jyväskylä region were recruited by advertisements in newspapers and social media to participate in this study (VoKe project). Recruited subjects were healthy, non-smoking, and recreationally participated physical activities. Inclusion criteria were BMI <30 kg/m^2 and a Cooper running test results minimum of 2300m. Exclusion criteria included any diseases, musculoskeletal or cardiac problems, or medications that would preclude a subject's ability to perform strength and endurance training and testing. Prior to participating in this study subject resting ECG and health questionnaires were screened by a medical doctor. Ethical approval was granted by the University Ethical Committee.

Participants were informed about the upcoming measurements and training, and about their option to stop participating in the study at any time. During this meeting, the men agreed to participate in the study and signed an informed consent. Subjects acted as their own controls over a 2-3-month period prior to the 10-week high-intensity combined strength and endurance training intervention. This thesis concentrates only on the 10-week intervention period and in the pre- and post-measurements, excluding the prior control period.

This thesis is part of a broader study (VoKe project). There were thirty-nine subjects in the beginning of the intervention, twenty male subjects and nineteen female subjects, from which thirty-eight (one male drop-out) finished the study. Ten of the subjects had to drop out during summer's control period, because of minor injuries unrelated to the project or personal reasons. This thesis only focuses on the results of the nine male subjects that belonged in an active recovery/ cold water immersion group (n=9) and the ten male subjects that belonged to an active recovery-only group (n=10).

Anthropometrical data of the subjects used in this thesis are presented in table 3. Heights of the subject were not measured and thus presented values are based on self-reported information collected from subjects. Weight was measured from dual-energy x-ray absorptiometry (DXA) measurements with a 0.1kg accuracy, with the subjects being in a fasted (12h) state and in underwear. Body mass, muscle, and fat tissue were measured using bio impedance (InBody

3.0, Biospace Co.), and total body estimates of muscle and fat tissues as well as bone mineral density with DXA (Gallagher et al. 2000).

TABLE 1. Anthropometric data for all subjects measured at pre-tests.

Group	**n**	**Age (years)**	**Height (cm)**	**Weight (kg)**	**BMI (kg/m^2)**	**Body fat (%)**
AR-O	10	31.5 (±4.9)	181.8 (±4.6)	79.3 (±8.5)	23.6 (±1.4)	17.5 (±5.2)
AR-CWI	9	28.3 (±5.4)	180.3 (±5.1)	79.5 (±5.8)	20.8 (±1.7)	18.6 (±6.7)

4.2 Study Design

The study was conducted between June and December 2014. The control measurements were conducted during the summer (June & July). Pre-measurements started in the beginning of September and post-measurements in beginning of December. The 10-week high intensity strength and endurance intervention was conducted during the fall and between the pre- and post-measurements. Subjects also participated in mid-measurements that were conducted during training week five. A separate familiarization meeting was not arranged, but subjects were familiar with the testing equipment and the protocol in the pre-measurements. They experienced the control measurements during the summer and prior to the intervention.

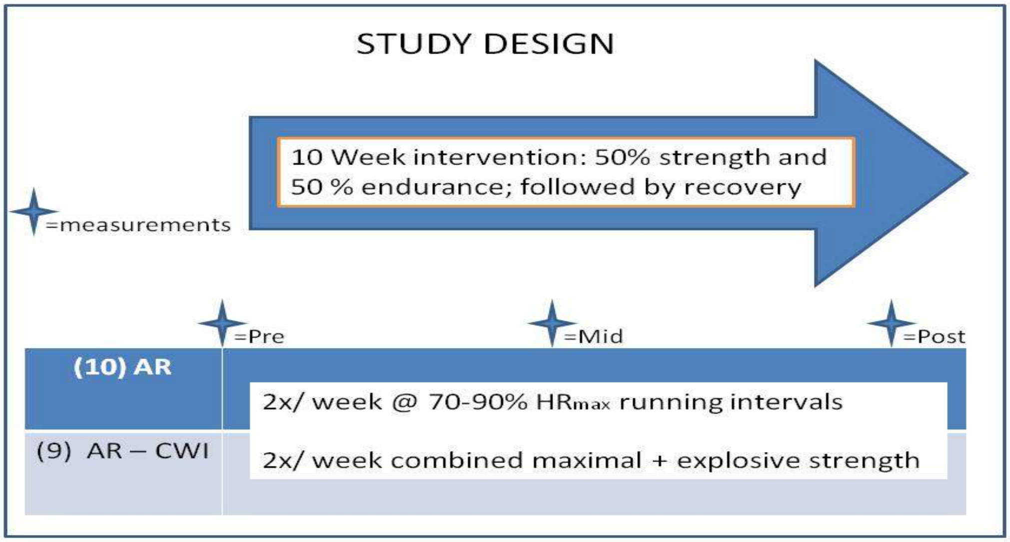

FIGURE 2. Study design: Modified to present the part of the study this thesis concentrates.

Pre- and post-measurements consisted of collection of blood and saliva samples, anthropometrical measurements, strength measurements, treadmill running test performed until volitional exhaustion and field tests.

The strength measurements and treadmill running test were performed during same measurement session, so that the strength measurements were conducted prior and treadmill running test immediately after. The duration of these laboratory performance measurements was an hour each, two hours combined. Field test consisted of 3-k time trial running test and dynamic muscle endurance tests. All measurements were performed during same time of the day (± 1 hour), with few exceptions.

The training consisted of maximal and explosive strength training and high intensity endurance training. Both training modalities were performed separately twice a week. The overall duration of each training session varied from 45 to 90 minutes. The contents of measurements and training sessions concentrated in this thesis are explained in more detail later.

4.3 Training/ Recovery

Subjects completed the 10-week combined maximal and explosive strength and high-intensity endurance training period. Both strength and endurance training were performed twice a week separately. Subjects were informed not to complete four training sessions in a row, recommendation being two training days in a row continued with a rest day. Subjects could train in which ever order they preferred, but two same training modalities were not allowed subsequent days. During the 10-week intervention subjects executed 99.1% of the training sessions.

Training weeks one and two can be classified as preparatory training weeks, as training intensity was kept slightly lower. Training weeks five and ten were reduced on volume due to testing. During training week five subjects trained once strength (workout A, Tables 4, 5 & 7) and once endurance (workout A, Table 8), since they performed the mid-measurements during same week. Mid-measurements were fused with training so that subjects performed the plyometric exercises of strength workout B (Table 6) immediately after the mid-measurements. During training week ten, volume was decreased and subjects performed one strength (workout A) and one endurance (workout A) training session. Training period was designed progressive, and training intensity in both strength and endurance training was increased throughout the intervention.

Subjects could continue other physical activities during the study. However, training sessions involved in this study were commanded to be performed with high quality, and other physical activity was not to inhibit these training sessions. Subjects were recommended to perform one low-intensity aerobic exercise per week as a recovering exercise.

4.3.1 Strength training

Strength training sessions consisted of a mixture of maximal and explosive strength training for the lower extremities. Traditional core exercises were also included as they are a typical part of training programs for all athletes (Willardson 2007). Strength training sessions involved some complex training characteristics. Subjects performed multi-joint movements for lower extremities with relative high loads, and continued with biomechanically similar power movement, for example heavy squats were followed by countermovement jumps (table 4). Subjects performed similar pattern with leg press and calf raise as well. Knee flexion exercise was performed a bit differently, since movement was only performed with knee flexion machine and training intensity was kept on hypertrophic zone throughout the study. The program presented in table 4 was performed during every strength training session. There was no exercise order, because of the size of the gym and number of subjects training at the same time. However, contrast movements (countermovement jumps, explosive leg press, and calf jumps) were always performed after the biomechanically similar heavier movement.

Strength training sessions were mostly supervised by members of research staff (one supervisor). Due to personal reasons (for example, travelling for work) some training sessions had to be performed individually and without supervision. The supervised strength training sessions were performed in a gym that was built for research purposes. The subjects performed sets, reps and loads were recorded on individual training sheets.

TABLE 2. Overview of strength training sessions. The dispersion in loads means that at the beginning of study the exercise intensity was lower and was increased throughout the study.

Exercise	Sets	Reps	Load (%1RM)	Rests
Squat (~100° knee angle)	1-2 warm-ups	8-10	50-70	1
	2	4-6	70-85+	2
Countermovement jumps	2	10	BW	2
Leg press	1-2 warm-ups	8-10	50-70	1
	2	4-6	70-85+	2
Explosive leg press	2	10	30-60	2
Knee flexion	1-2 warm-ups	8-10	50-60	1
	2	8-10	70-85	2
Calf raise	1 warm up	8-10	50-70	1
	2	5-6	70-85+	2
Calf jumps	2	6	BW	2

In addition, subjects also performed some plyometric exercises. After the exercises listed in table 2, subjects performed either bounding and hurdle jump exercises (A), or broad jump and step-up exercises (B). Subjects performed additional plyometric exercises A (table 3) during the first strength training session of the week, and additional plyometric exercises B (table 4) during the second strength training session of the week. Bounding and step-up exercises are unilateral; thus, the repetitions were performed with each leg.

TABLE 3. Additional plyometric exercises (A). All exercises were performed with body weight. Rest intervals were two minutes at the beginning of the study, but were reduced to one minute during the training period.

Exercise	Sets	Reps	Load (%1RM)	Rests
Bounding	2	6+6	BW	1-2
Hurdle jumps	2	6	BW	1-2

TABLE 4. Additional plyometric exercises (B). All exercises were performed with body weight. Rest intervals were two minutes at the beginning of the study, but were reduced to one minute during the training period.

Exercise	Sets	Reps	Load (%1RM)	Rests
Standing 6-jump	2	6	BW	1-2
Step-ups	2	6+6	BW	1-2

After these plyometric exercises, subjects performed upper-body and core exercises. For upper-body subjects performed hypertrophic bench press training, and as core exercises subjects performed plank, back extension, and torso rotation (table 5). The core exercises were performed mainly as muscular endurance training. After these exercises subjects were ready, but could continue their strength training session individually if they wanted.

TABLE 5. Upper-body and core exercises. *=HUR is an exercise unit that stabilizes ankles, leaving lower extremities to rest on an upward diagonal position allowing upper body to bend from hip joint, and thus is used for strengthening back extensor muscles, **=FRAPP is an exercise unit that stabilizes hips and legs, but allows proper torso movement, and thus is used for strengthening rotating muscles of the core section, ***=Loads in core exercises varied individually.

Exercise	Sets	Reps	Load (%1RM)	Rests (min)
Bench press	2-4	8-10	70-80	1-2
Plank	2	60 seconds	***	1
Back extension (HUR*)	2	10-15	***	1
Torso rotation (FRAPP)**	2	10-15	***	1

4.3.2 Endurance training

Endurance training sessions included 4x4 min running intervals at approximately 90% of HR_{max} or 3x3x100m sprints at approximately 100% of HR_{max} (table 6), which was measured on a treadmill. The 4x4 min running intervals were chosen based on the article by Helgerud et al. (2007) in which these intervals were considered the equally as effective as multiple high-intensity sprints in increasing aerobic capacity. The 3x3x100m sprints were mainly selected to improve the subjects' running velocity.

For both endurance training sessions, subjects warmed up for 10 minutes, approximately 60-70% HR_{max}, and cooled down after the exercise for 15 minutes with same intensity that warm-up was performed. Warm-up and cool down included some dynamic stretching performed individually.

The members of research staff organized supervised endurance training sessions around Jyväskylä region. However, subjects were also allowed to perform endurance training on their own without supervision. From endurance training sessions, the HR values were recorded and collected before and after every interval, and thus used to monitor training intensity. Even if subjects trained individually, they collected the HR values and delivered them to the staff of the project.

TABLE 6. Overview of endurance training sessions. The dispersion in intensity means that at the beginning of study the running intensity was lower and was increased throughout the study. *=Subjects rested 2 minutes between every sprint and 5 minutes between every set. During rest period subjects were informed to do active recovery so that their HR stayed around 60-70% of their individual HR_{max}.

Exercise	**Intensity (%HRmax)**	**Rests**
4x4 min	75-90%	4 min (60-70%Hrmax)
3x3x100m	80-100%	2min/5min* (60-70%HRmax)

4.3.3 Recovery Protocols

Before completing the workout of the day, the subjects agreed to partake in one of two recovery protocols. The first was an active recovery group (AR). The men in this group were asked to complete 15 minutes of post-exercise active recovery, ~35% of their HR_{max}, on either cycle ergometer or to do so running. Most men on most occasions chose to run. The other recovery method was cold water immersion (CWI) for 10 minutes followed by 5 minutes of AR, same as above. The cold-water immersion tub was in Hippos Hall and prepared before the daily workouts began with the water being set at 12^0C; ±1^0C. After the workout, subjects that were part of this group would complete their 5 minutes of AR by jogging up to Hippos Hall being careful to stay at ~35% of their HR_{max}. The subjects would submerge their bodies into the tub with the water line reaching somewhere between the naval and nipples. The subject's arms were not submerged.

4.4 Measurements

All subjects participated in pre-, mid- and post-measurements. Pre- and post-measurements were identical and consisted of strength measurements, treadmill running test until voluntary exhaustion, field tests, anthropometric measurements and collection of blood samples. Mid-measurements only consisted of a lower number of strength measurements (countermovement jump, isometric leg press, isometric knee extension and isometric knee flexion) and blood samples.

4.4.1 Strength measurements

Before starting the actual strength measurements, subjects warmed up for five minutes with a cycle-ergometer. Subjects could adjust the ergometer themselves and intensity of warm-up was individually decided.

Countermovement jump (CMJ). The CMJ test was performed to measure the power characteristics of lower extremities. Subjects were instructed to jump as high as possible on a force plate with an explosive countermovement action before the concentric phase of the movement. The depth of the squat at the beginning of countermovement jump was not standardized, and subjects could jump as they felt the most natural with. Nevertheless, subjects had to keep their hands on their hips during the whole performance, and were not allowed to bend their legs during the flight time. When ground contact was achieved, subjects could bend their knees to ease off the landing. Subjects performed three jumps with one minute rests between. An additional trial was performed if the flight time from the third trial was greater than 5% compared to the previous trial. However, the maximum amount of trials was five. From CMJ's force production and flight time were measured (Signal 4.10, CED, UK), and jump height was calculated manually from the force-time curve based on impulse, since it has been stated to be more valid measure than flight-time based evaluation (Kirby et al. 2011).

Maximal bilateral isometric leg press. Isometric strength of leg extensor muscles was measured by using an isometric horizontal bilateral leg press (figure 18, designed and manufactured by the Department of Biology of Physical Activity, University of Jyväskylä, Finland). Leg press was adjusted so that subjects' knee angle was 107 degrees, measured using the greater trochanter, lateral tibiofemoral joint space and lateral malleolus as reference points. Subjects were instructed to produce force as fast as possible as much as possible. Regarding duration subjects were instructed to produce force until the test leader told them to stop, and the duration of isometric performances were approximately 3 seconds. Force data was collected at a sampling frequency of 2000 Hz, and then filtered (20 Hz low pass filter). Force data was analyzed using customized scripts (Signal 4.10, CED, UK). Subjects performed the minimum of three maximum voluntary contractions (Häkkinen et al. 1998). If the maximum force during the last trial was greater than 5% compared to the previous trial, and additional trial was performed. However, no more than five maximal trials were performed. The best performance trial, in terms of maximal force measured in Newtons (N), was used for statistical analysis. The reliability of these measurement techniques has been previously reported (Viitasalo et al. 1980).

FIGURE 3. Isometric horizontal bilateral leg press, designed and manufactured by the Department of Biology of Physical Activity, University of Jyväskylä, Finland.

Maximal unilateral isometric knee extension and flexion. The isometric knee extension and flexion force were measured in modified David 200 gym equipment (Figure 19). Both extension and flexion force were measured unilaterally. Knee angle was also measured to be 107 degrees by using the same reference points that were used before, and subjects were tied to the seat with seat belt. In addition, in isometric knee extension subjects' ankle was tied to inhibit "kicking" during the trials. This was not necessary for knee flexion. Otherwise the measurement protocol, force collection and computer program were the same as in isometric leg press.

FIGURE 4. Modified David 200. Used for isometric knee extension and isometric knee flexion.

Maximal bilateral dynamic leg press. The maximal concentric strength (1RM) of leg extensor muscles were measured with leg press (Figure 20, David Sports Ltd., Helsinki, Finland). Prior to attempting 1RM, subjects warmed up with following sets; 5x ~70%1RM, 3x ~80%1RM and 2x ~90%1RM, with one minute rests between sets. Following warm-up, subjects performed one repetition at the time, and load was increased till the individual maximum was found. However, no more than 5 attempts to reach 1RM were performed. At the beginning of the movement the leg press was adjusted so that subjects' knee angle was approximately 60 degrees, measured from the same reference points as was in isometric leg press. Subjects were instructed to grasp handles located under the seat of the leg press and to keep constant contact with the seat and backrest during leg extension to a full range of motion (180 degrees), however subjects were instructed not to lock their knee joints at full extension. Verbal encouragement was given to promote maximal effort. The greatest weight that subject could successfully lift was recorded with the accuracy of 1.25 kilograms.

FIGURE 5. Maximal bilateral dynamic leg press (David Sports Ltd., Helsinki, Finland).

4.4.2 Field tests

Field tests were performed on the indoor athletics track (Hippos-hall), which has a 200m track and a sand pit for standing long jump measurements. Subjects had 10 minutes to warm-up before the measurements started. After the warm-up subjects ran a 3k time-trial, as fast as possible, and the split times for each kilometer were recorded. After the time-trial, subjects had approximately 5 minutes to rest before the dynamic muscle endurance tests. Dynamic muscle endurance was evaluated by performing sit-ups, pushups and standing long jump per the guidelines of the Finnish Defense Forces (Pihlainen et al. 2009). From the field tests performed in this project, this thesis will only concentrate on 3k time-trial.

4.4.3 Blood samples

Blood lactate. Blood lactates were analyzed using a Biosen S_line Lab+ lactate analyzer (EKF Diagnostic, Magdeburg, Germany).

Serum Hormones. Venous blood samples (10 ml) were drawn from the antecubital vein using sterile needles into serum tubes by a qualified lab technician for examination of serum hormones. Subjects were tested early in the morning after fasting throughout the night. The tests occurred at the same time of day as their respective loadings and follow-up measurements in order to take into consideration daily variation in hormone concentrations. Samples were taken from the seated position with the arm extended. The blood was centrifuged (Megafuge 1.0R, Heraeus, Germany) for 10 minutes after which serum was removed and stored at -80 C until analysis. Samples were used for determination of serum hormone concentrations. Analysis were performed using chemical luminescence techniques (Imunlite 1000, DCP Diagnostic Corporation, Los Angeles, California, USA) and hormone specific immunoassay kits (Siemens, New York, NY, USA). For this study, blood samples were used for the determination of testosterone, cortisol, and IGF-1 with the sensitivity of the assays being 0.5 $nmol \cdot l^{-1}$, 5.5 $nmol \cdot l^{-1}$ and 2.6 $nmol \cdot l^{-1}$, respectively.

4.5 Statistical analysis

Means and standard-deviations (SD) were calculated with conventional statistical methods. Independent-samples T-test and one-way analysis of variance (Oneway ANOVA) were applied for analyzing between group differences. Repeated levels ANOVA with three levels (PRE, MID, POST) and dependent-samples T-tests were applied for analyzing within group differences at different time points. Pearson –product- moment correlation was used for 3k time-trial and strength variables. The significance for all tests were set at $*p \leq 0.05$, $**p \leq 0.01$ and $p \leq 0.001$. Also, $\#p \leq 0.075$ presents a statistical trend. All data was analyzed and graphed by using Microsoft Excel 2010 and IBM SPSS Statistics v.20 computer software.

5 RESULTS

5.1 Strength performance

Countermovement jump. There were no significant differences between AR (pre: 35.4±5.4cm; mid: 38.16±5.4cm; post: 38.8±5.3cm) and CWI (pre: 34.0±5.1cm; mid: 34.9±5.1cm; post: 37.3±6.5cm) groups mean countermovement jump heights at any measurement time points. From pre- to mid-measurements only AR group improved CMJ height by 7.3% (±9.9%, p=0.064), however results only presented a statistical trend (p≤0.075) (figure 6). Only CWI group improved from mid- to post-measurements (6.6±7.9%, p<0.05). During the whole intervention both groups improved from pre- to post-measurements (AR: 10.0±8.0%, p<0.01; CWI: 9.7±5.9%, p<0.01). There were no significant differences between AR and CWI groups when comparing the relative changes between any measurement time points.

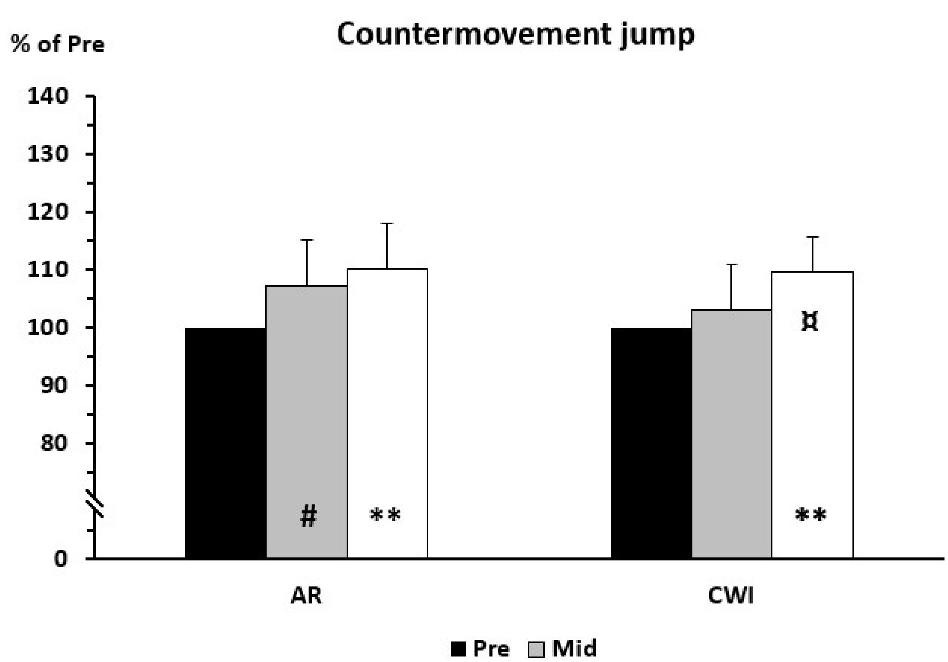

FIGURE 6. Changes in countermovement jump height expressed relatively to pre-values in both groups (AR and CWI). *p<0.05 and **p<0.01 present a statistically significant difference, and #p=0.064 presents a statistical trend. ¤p<0.05 presents a significant difference compared to mid values. (AR: n=9, CWI: n=9).

Isometric bilateral leg press. There were no significant differences between AR (pre: 4114±934N; mid: 4293±1137N; post: 4606±1201N) and CWI (pre: 4287±765N; mid: 4418±817N; post: 4802±786N) groups mean isometric bilateral force at any measurement time points. Both groups improved their isometric bilateral force from mid- to post-measurements significantly (AR: 7.9±9.1%, $p<0.05$; CWI: 9.8±6.8%, $p<0.01$) (figure 7). Both groups also improved during the whole intervention from pre- to post-measurements (AR: 11.9±11.3%, $p<0.05$; CWI: 13.1±14.8%, $p<0.05$). There were no significant differences between AR and CWI groups when comparing the relative changes between any measurement time points.

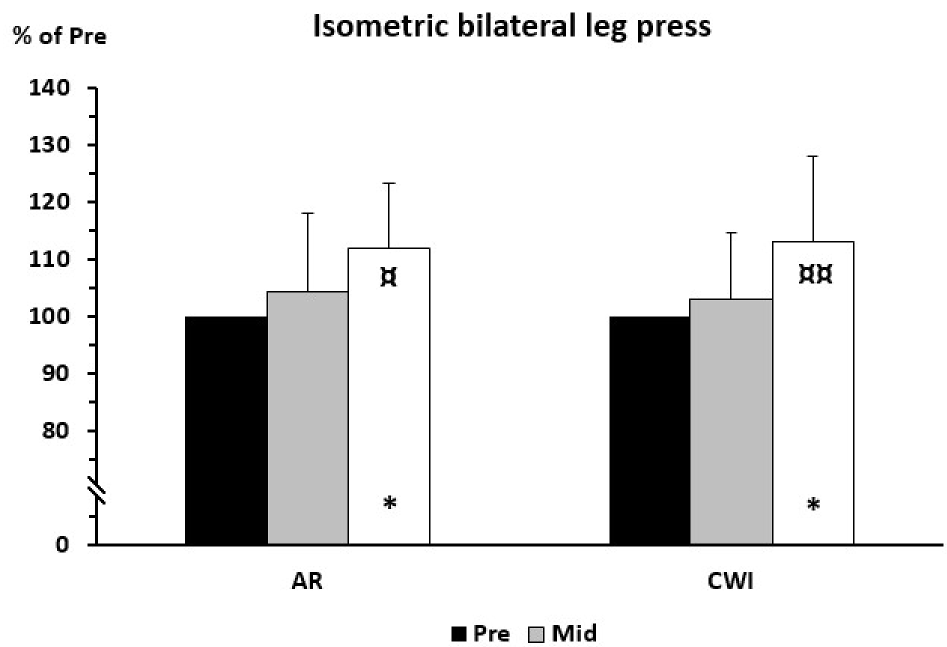

FIGURE 7. Changes in isometric bilateral force expressed relatively to pre-values in both groups (AR and CWI). *p<0.05 presents a statistically significant difference. ¤p<0.05 and ¤¤p<0.01 present a significant difference compared to mid values.

Isometric unilateral knee extension. There were no significant differences between AR (pre: 938±169N; mid: 1007±156N; post: 1039±172N) and CWI (pre: 971±195N; mid: 980±201N; post: 1048±227N) groups mean isometric unilateral knee extension force at any measurement time points. Only AR group improved their isometric knee extension force from pre- to mid-measurements (7.9±6.8%, $p<0.01$), and only CWI group improved their isometric knee extension force from mid- to post-measurements (6.5±5.0%, p<0.01) (figure 8). Both groups also improved during the whole intervention from pre- to post-measurements (AR: 11.2±6.0%, p<0.001; CWI: 7.9±7.9%, p<0.05). The improvement from pre- to post-measurements were found to be statistically significantly greater for AR group (p<0.05).

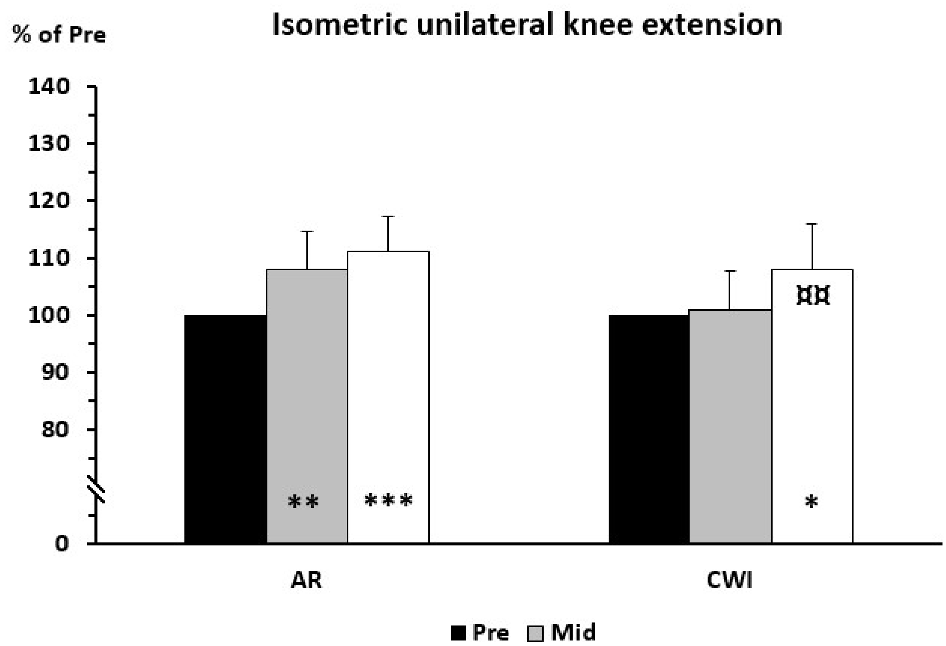

FIGURE 8. Changes in isometric unilateral knee extension force expressed relatively to pre-values in both groups (AR and CWI). *p<0.05, **p<0.01 and ***p<0.001 present a statistically significant difference. ¤¤p<0.01 presents a significant difference compared to mid values.

Isometric knee flexion. There were no significant differences between AR (pre: 413±64N; mid: 441±76N; post: 449±68N) and CWI (pre: 458±96N; mid: 452±95N; post: 461±88N) groups mean isometric unilateral knee flexion force at any measurement time points. Only AR group improved their isometric knee extension force from pre- to mid-measurements (7.0±10.9%, p=0.055) (figure 9), however the improvement only showed a statistical trend (p<0.075). Additionally, only AR group improved during the whole intervention from pre- to post-measurements (9.0±8.6%, p<0.01).

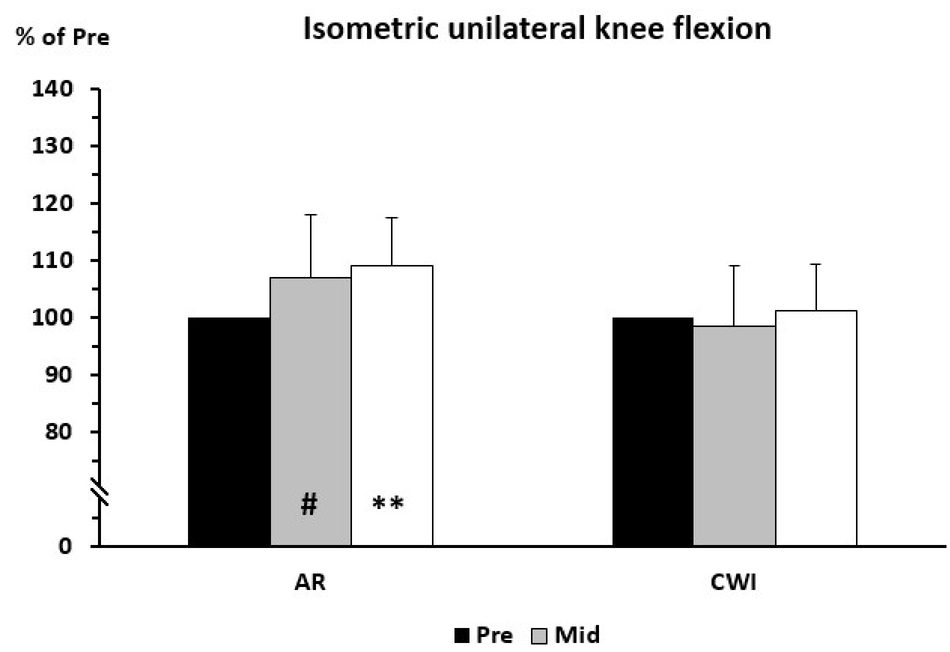

FIGURE 9. Changes in isometric unilateral knee flexion force expressed relatively to pre-values in both groups (AR and CWI). **p<0.01 presents a statistically significant difference, and #p=0.055 presents a statistical trend.

Concentric bilateral leg press. There were no significant differences between AR (166.0±25.6kg) and CWI (183.6±25.0kg) groups mean concentric bilateral force at pre-measurements, but at post-measurements CWI groups mean concentric bilateral force (200.3±19.0kg) was found to be almost statistically significantly higher (p=0.056) than AR groups mean force (179.8±24.1kg). Both groups improved during the whole intervention from pre- to post-measurements significantly (AR: 8.7±4.7%, p<0.001; CWI: 9.7±7.2%, p<0.01) (figure 10). There were no significant differences between AR and CWI groups when comparing the relative changes between any measurement time points.

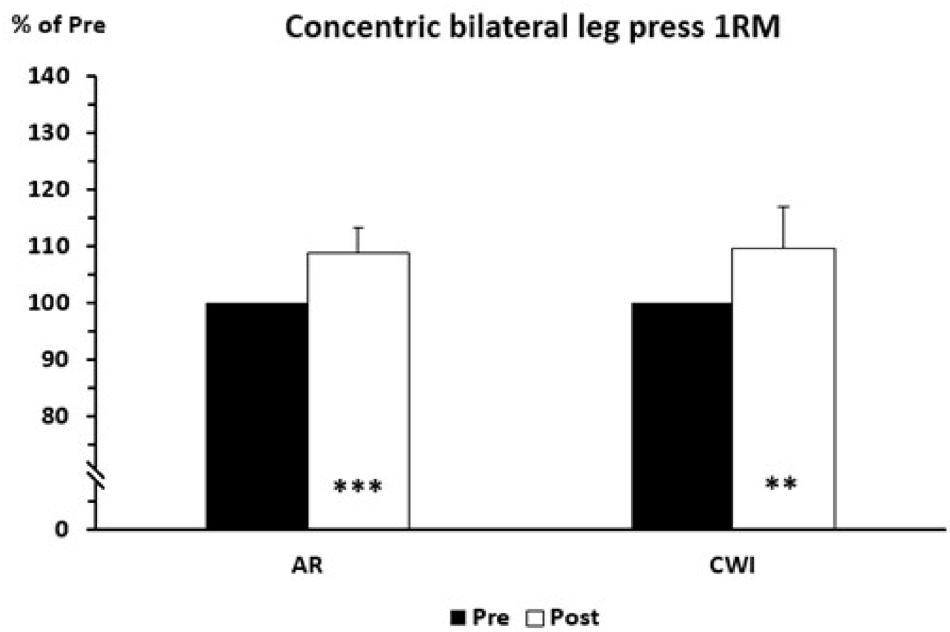

FIGURE 10. Changes in concentric bilateral leg press 1RM expressed relatively to pre-values in both groups (AR and CWI). **p<0.01 and ***p<0.001 present a statistically significant difference.

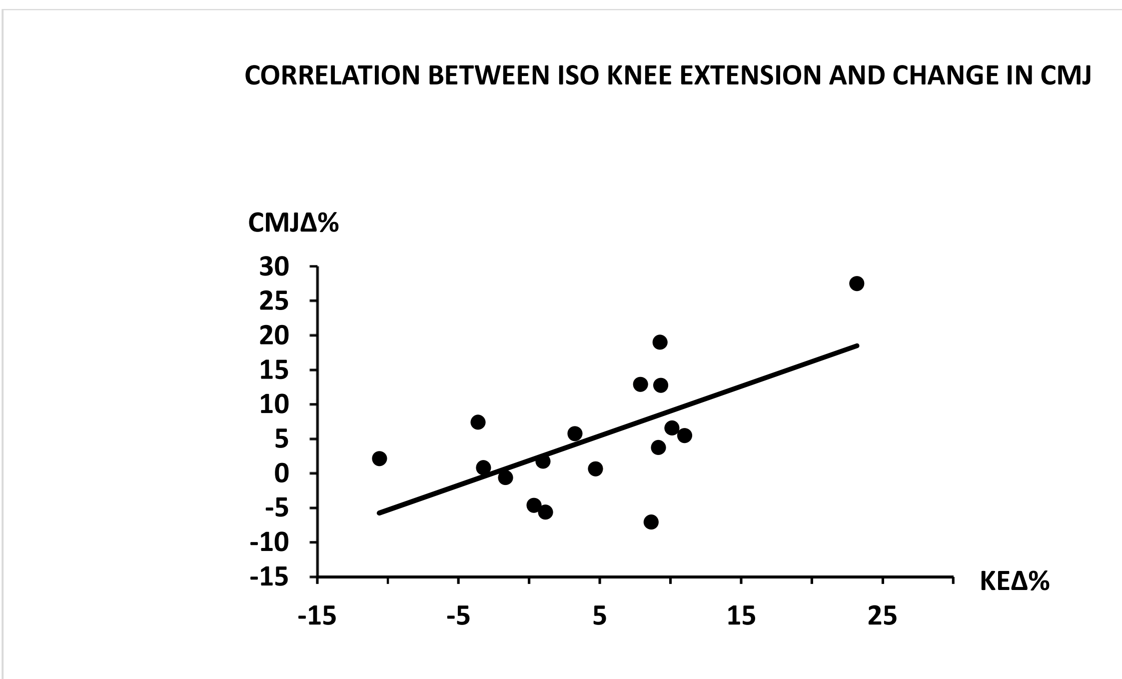

FIGURE 11. Correlation between changes in isometric knee extension and CMJ in both groups from pre- to mid-measurements (r=0.620, p=0.010).

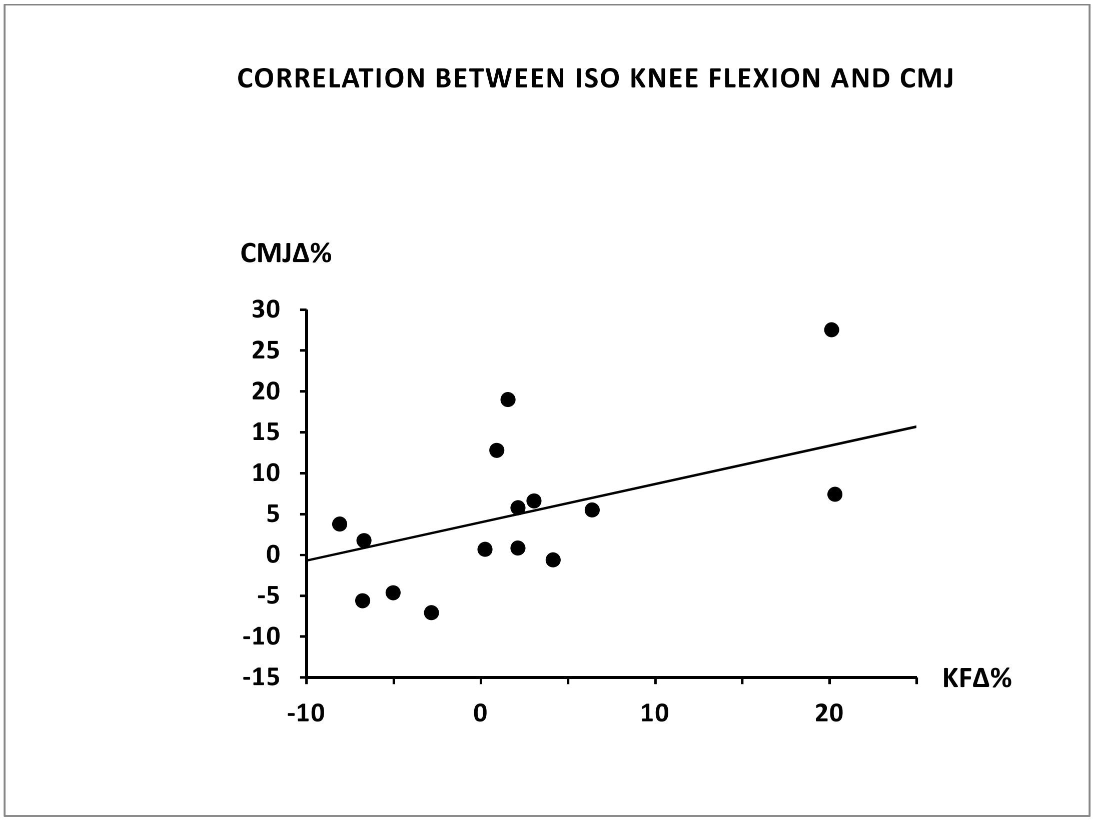

FIGURE 11. Correlation between changes in isometric knee flexion and CMJ in both groups from pre- to mid-measurements (r=0.657, p=0.006).

5.2 3k time-trial

There were no significant differences between AR (pre: 787±79s; post: 767±62s) and CWI (pre: 761±69s; post: 729±53s) groups mean 3k time-trial performance at any measurement time point. Both groups improved during the whole intervention from pre- to post-measurements significantly (AR: -19±26s, 2.2±3.0%, $p<0.05$; CWI: -31±34s, 3.8±3.6%, $p<0.05$) (figure 10). There were no significant differences between AR and CWI groups when comparing the relative changes between any measurement time points.

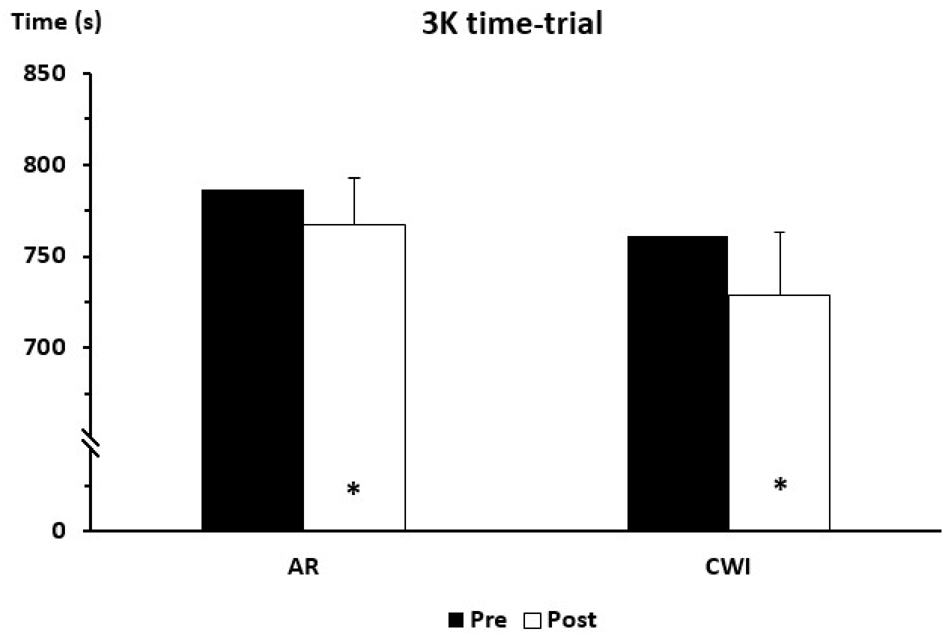

FIGURE 11. Changes in 3K time-trial time expressed relatively to pre-values in both groups (AR and CWI). *p<0.05 presents a statistically significant difference.

5.3 Serum hormone levels

There were no significant differences between groups in any selected hormones at any measurement time point throughout the study (Table 7, 8 & 9). There were also no significant differences between measurement time points in any hormones in neither of the groups.

TABLE 7. Overview of basal testosterone level over the 10-week strength and endurance training intervention.

		TESTOSTERONE					
		Pre	Mid	Post	Pre-Mid Δ%	Mid-Post Δ%	Pre-Post Δ%
CWI (n=7)	**Mean**	17.8	16.8	18.5	-5.1	12.6	6.6
	SD	3.5	3.8	3.5	15.8	22.7	25.5
	p-value				0.409	0.249	0.698
AR (n=9)	**Mean**	15.7	16.1	15.5	9.4	-5.2	2.5
	SD	5.0	3.5	4.7	30.7	15.1	28.1
	p-value				0.666	0.449	0.861

TABLE 8. Overview of basal cortisol level over the 10-week strength and endurance training intervention.

				CORTISOL			
		Pre	**Mid**	**Post**	**Pre-Mid Δ%**	**Mid-Post Δ%**	**Pre-Post Δ%**
CWI (n=7)	**Mean**	463.4	476.6	467.4	4.7	-0.9	3.2
	SD	87.0	91.7	116.9	22.9	23.7	29.3
	p-value				0.747	0.832	0.943
AR (n=9)	**Mean**	451.0	419.1	411.3	-2.7	-1.0	-7.2
	SD	126.4	81.3	133.6	23.9	33.2	22.0
	p-value				0.409	0.862	0.354

TABLE 9. Overview of basal Insulin-like growth factor 1 (IGF-1) level over the 10-week strength and endurance training intervention.

				IGF1			
		Pre	**Mid**	**Post**	**Pre-Mid Δ%**	**Mid-Post Δ%**	**Pre-Post Δ%**
CWI (n=7)	**Mean**	32.4	33.3	32.3	3.4	-0.7	1.7
	SD	8.6	9.8	7.2	8.8	13.7	11.9
	p-value				0.225	0.557	0.927
AR (n=9)	**Mean**	34.4	35.6	35.1	2.8	0.8	2.7
	SD	10.6	12.8	10.1	10.7	14.2	10.5
	p-value				0.418	0.815	0.624

6 DISCUSSION

The present study investigated the effects of the 10-week maximal and explosive strength and high-intensity endurance training period on muscular performance and 3k time-trial running performance. The main findings in this study were:

1) Both groups improved their muscular performance due to combined maximal strength and high-intensity endurance training.

2) Both groups significantly improved their 3k time-trial running performance.

3) There were no significant differences between groups in any improvements or changes during the 10-week training period, however, muscular adaptations seemed to be more systematic in the AR group.

4) There were no significant differences between groups in any selected hormones at any measurement time point and no significant differences between measurement time points in any hormones in both groups.

6.1 Muscular performance

6.1.1 Force production

As expected, each group presented greater absolute values in all variables measured from pre- to mid and post in all executed strength measurements. The AR group improved their muscular performance more during the first five weeks of training, whereas improvements in the CWI seemed to occur mostly after the mid-measurements, however, these findings were not significant.

Isometric bilateral leg press. Both groups improved their maximal isometric leg extension force significantly and all subjects improved through the whole 10-week training period. The magnitude of improvements is supported by previous studies as well (Häkkinen et al. 2003;

Taipale et al. 2013; Eklund et al. 2015), when comparing results obtained from similar period of training interventions.

The effect of CWI on recovery of exercise performance has been investigated in numerous studies and improvements in similar movements to the isometric bilateral leg press have been reported (Vaile et al. 2008b). In that study, CWI was found to be effective in reducing the physiological and functional deficits associated with DOMS, including improved recovery of isometric squat force and dynamic power for next day performance.

Isometric unilateral knee extension. The results gathered from the isometric unilateral knee extension are similar to the results obtained from the isometric bilateral leg press. most of the movements performed during the training period required action from quadriceps muscles, and thus improvements in this measurement were estimated for both sexes. Also, the improvements in isometric knee extension force are at similar magnitude compared to previous studies (McCarthy et al. 1995; Eklund et al. 2015). Both groups significantly improved their muscular activation from pre- to post-measurements during isometric knee extension, which suggests that the improved force production was somewhat due to improved neural drive.

The effect CWI has had on isometric knee extension have been reported (Ingram et al. 2009). In that study, CWI resulted in significantly lower muscle soreness ratings, as well as in reduced decrements to isometric leg extension and flexion strength in the 48-h post-exercise period.

Isometric unilateral knee flexion. The training of the knee flexors was performed as hypertrophic training and therefore, differed from other actions applied to the lower extremities during strength training. However, both the training action and the pre- mid- and post-measurements were applied similarly in a seated position. Therefore, the correlation between these two should be high (de Alvares et al. 2015). Nevertheless, maximal strength training has been stated to lead to greater increases in force production than hypertrophic training (Naclerio et al. 2013). Throughout the study the loads were increased so that the training would be stressful enough to create some muscular adaptations.

The effect CWI has had on isometric knee flexion have been reported (Bailey et al. 2007; Ingram et al. 2009). In these studies, CWI administered immediately after exercise reduced muscle soreness at 24 and 48 h post exercise. Also decrements in isometric maximal voluntary contraction of the knee flexors were reduced after CWI treatment at 24 and 48 h compared with the control group (Bailey et al. 2007).

Concentric dynamic bilateral leg press. Both groups improved leg press strength significantly during the 10-week training period. There were no significant differences found between the improvements made among the two groups. The dynamic bilateral leg press was a one repetition maximum (1RM) and the only dynamic maximal strength measurement in the study. It is also important to point out that the leg press during training and measurements were similar. The starting knee angle was measured for training and, thus, improvements were estimated. The improvements followed normal trends and similar improvements have been stated in previous studies (Bell et al. 2000; Taipale et al. 2014; Eklund et al. 2015). Interestingly, there was no significant correlation between changes in the dynamic movements of leg press 1RM and changes in CMJ.

6.1.2 Countermovement jump

Countermovement jump. It was during the first five weeks, pre- to mid- measurements, that the greatest increases were achieved for both groups. These findings have at least been found in other research. In an 8-week study, (Vanderka et al. 2016), CMJ and squat jump height were significantly enhanced from pre- to mid-training but no further changes occurred from mid- to post-training.

Strength and plyometric training were somewhat new training modalities for the subjects, therefore, there was some learning effect accompanied with improved motor unit firing rate and synchronization. Other studies that included combined training, (McCarthy et al. 1995 and Taipale et al. 2014), found similar improvements in magnitude.

CMJ allows individual to apply stretch-shortening cycle (SSC) and elastic energy to increase force production. There was a correlation between thigh strength, isometric knee extension, and CMJ among both groups in the pre- mid measurements (Figure 11). This might indicate that the training intervention and knee angles concentrated more on the thigh muscles instead gluteus muscles. It seems that the improved CMJ performance was not only due to improved SSC but also the increased ability to use elastic components of the muscle.

Our findings were similar to other studies. In one study concerning recovery interventions and intermittent-sprint exercise on consecutive days (King and Duffield 2009), the CWI group increased there repeat CMJ performance compared to the passive recovery group. Although, it is important to point out that in that study all participants were female and our study involved no female participants. In another study, (Montgomery et al. 2008) the CWI group increased their 20m sprint performance and CMJ compared to the control group (carbohydrate + stretching) and the CWI group experienced less perceived muscle soreness and fatigue compared to the compression garment group.

6.2 Endurance performance

The subjects from both groups had at least some experience in endurance training. With that said, both groups improved their 3k time-trial performance significantly. Therefore, it seems that the endurance intervention was successful.

Based on the strength measurements the improved running performance could be due to enhanced running economy along with some cardiorespiratory improvements. However, this training program did not primarily concentrate on improving maximal oxygen uptake or running economy. Subjects completed 4x4min endurance training sessions for improving VO_2max (Helgerud et al. 2007) only once a week, and the other endurance session was speed endurance training. Although, other combined strength and endurance studies have presented improvement in VO_{2max} (McCarthy et al 1995 and Paavolainen et al. 1999).

Both groups significantly improved their CMJ performance, which demonstrates power production capabilities. It has been stated in previous studies that rate of force development (RFD) could be the factor that correlates the most with economy of endurance performance (Hoff et al. 2002). This could be one explanation for the improvements in endurance performance in this study. The results from this study suggest that combined strength and endurance training makes for an efficient training modality for improving endurance performance.

6.3 Strengths and limitations of the study

Strengths of the study. The present study was well established and showed similar results to other studies regarding muscular and running performance. The training program was proven to be valuable and there was only one subject drop-out during the 10-week intervention. The training sessions were mostly supervised, except for those who had to travel for work purposes, and data was collected from each training session. In addition, the research staff was experienced and measurement protocols were standardized and valid. All CWI subjects did participate in four CWI's per week, following the four workouts per week.

Limitations of the study. Some of the subjects had never experienced a legitimate strength training program, therefore, some of the training period needed to be used for familiarization of certain movements. Although the number of subjects included was enough for a scientific study, more subjects would have given a more reliable sample. Also, the mid-measurements should have included bilateral dynamic leg press.

The subjects could perform endurance training by themselves, and just deliver the heart rate values of each endurance training session. Also, some strength training sessions could be performed individually at a different location due to personal reasons/ work schedules. Therefore, it is uncertain how these individual training sessions were performed. This was allowed so that the percentage of finished training sessions would be high.

The knee angle during back squat was not measured, and thus not standardized during training. As the training season progressed, and weights increased, so did the knee angle during squats. Therefore, the knee angle during squat may not have been the planned 100 degrees, this most certainly affected the results obtained from strength measurements.

Manpower issues prevented the active recovery group from being monitored during the post-exercise recovery, therefore, this could be problematic because these subjects were on the honor system.

Further considerations. Most literature on CWI and AR recovery primarily examines the short-term responses on recovery of exercise performance. Most of the literature cited in this thesis states that these recovery methods may assist in the acute recovery of performance in the days following high-intensity training, concern still exist as to whether these recovery methods affect chronic adaptation to training. A theory for these recovery methods suggests that CWI and AR, along with other recovery techniques, could assist in acute recovery, therefore allowing athletes to perform repeated bouts of training sessions without negatively affecting subsequent sessions. This in turn would lead to positive chronic adaptations. There is also an opposite theory that suggests CWI and AR, along with other recovery techniques, might disrupt the mechanisms that cause fatigue, therefore they might blunt chronic adaptations to training.

A few CWI studies have examined regular usage over several weeks following training (Yamane et al. 2006; Higgins et al. 2011). In Yamane et al. (2006), the researchers found that regular CWI negatively affected the strength and endurance training effects on muscle performance. However, their study involved post-exercise CWI for both the leg and forearm. It is also important to mention these subjects only immersed a single limb, compared to the seated method performed for this thesis. In addition, Higgins et al. (2011), reported that regular CWI decreased sprint performance for U/20 rugby players compared to the control group (PR). Further research investigating chronic adaptations for exercise performance is needed.

7 CONCLUSION

In conclusion, both groups (AR and CWI) improved their muscular and 3k time-trial performance. Therefore, the present study indicates that combined maximal/ explosive strength and high-intensity endurance training, coupled with different recovery approaches, can be an effective training method to improve muscular and running performance adaptations. The greatest improvements were noticed in the measurements that were similar with the actual training performed during training sessions. There were no statistically significant differences between CWI and AR in muscular adaptations after concluding the 10-weeks of training, however, the AR group reported bigger gains at the mid-measurements compared to the CWI group. This could be due to the unfamiliarity to CWI for the CWI group. With this same logic, it could be possible the AR group reported bigger gains in the beginning due to the similarities with AR and the endurance training. In addition, the AR group may have experienced some level of interference during the latter five weeks due to the combined training, whereas the combined training may not have caused stress for the other group due to the continued familiarity to CWI.

The degree of the adaptations still leaves the question what type of stress, high- or low-, the strength or endurance training should be in order to improve the most from a combined training program. Also, the improvements in the CMJ performance for both groups (AR and CWI) might propose that this type of endurance training does not inhibit the adaptations of RFD. Based on the present study strength training, at some level, should be part of any training program.

Future research should aim to confirm the optimal temperature for CWI. In addition, it is unknown whether full body immersion is more effective than half body immersion, and whether CWI still assists recovery when not performed soon after exercise. The timing of CWI would be of interest to those individuals that do not have access to training pools at their place of training or do not have the time to engage in CWI until the end of the day or the following morning. However, these findings present that combined strength and endurance training followed by either CWI or AR seems to be an effective method of training for recreationally trained subjects.

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