The effects of concurrent training on sprint performance in moderately trained cyclists

Georgy Dias-Johnson

The Swedish School of Sport and Health Science
Graduate Essay Nr 166 : 2011
Master degree Sport Science : 2011
Study supervisor: Kent Sahlin & Niklas Psilander
Examiner Eva Blomstrand
Abstract

Aim: The purpose of the present study was to compare the effects of an 8 week period of combined endurance and resistance training (concurrent training) with that of only endurance training on both maximum strength (1 RM) in the leg press test and performance in the 30 s Anaerobic Wingate Test (WANT) in moderately trained endurance cyclists.

Method: Twenty male moderately trained cyclists were recruited for the investigation and were assigned to either an Endurance training group (E; n=10) or an Endurance Resistance training group (ER; n=10). Subjects underwent 8 weeks (2 training sessions per week, 16 sessions in total) of concurrent training (60 min steady state cycling session followed by 6 sets 12 repetitions of leg press) or cycling only. Furthermore the subjects of the intervention completed both Pre and Post intervention testing in the 1RM leg press and the Wingate 30 s cycle test which was conducted twice (SRM cycle sprint 1 and SRM cycle sprint 2) within each testing session.

Results: The results attained from the intervention were that the ER group demonstrated an increase in concentric leg strength within the one repetition maximum (1 RM) leg press test by 18.7% from pre-test values 339 ± 42 to post test values 402 ± 59 kg. With regard to the Wingate cycle sprints there was significant improvement from pre to post test results in peak power of cycle sprint 1 from 1019 ± 110 watt to 1077 ± 153 watt 5.7% and cycle sprint 2 from 1001 ± 131 to 1054 ± 161 watt, 5.3% (P < 0.05) respectively. The E group showed no significant change in 1 RM or the Wingate cycle sprints after training.

Conclusions: The main findings of the study is that an 8-week concurrent training intervention can lead to significant concentric strength gains in 1 RM leg press development and increased peak power within the Wingate 30 s cycle sprint when conducted by moderately trained cyclists.
# Table of contents

Background ............................................................................................................................ 1
Introduction ............................................................................................................................ 1
Previous research .................................................................................................................... 2
  Concurrent Training ........................................................................................................... 2
  Strength .............................................................................................................................. 5
  Aim and Questions ............................................................................................................. 7
Method ................................................................................................................................... 7
  Pre Participation ................................................................................................................. 7
  Training Intervention ......................................................................................................... 8
  Nutrition ................................................................................................................................ 10
  Test Equipment ................................................................................................................ 10
  Exercise Performance Tests ............................................................................................. 10
  Cycle Ergometer .............................................................................................................. 10
  Leg press 1 RM ................................................................................................................ 11
  Training Sessions ............................................................................................................. 11
  Endurance Protocol ......................................................................................................... 12
  Endurance/Strength Protocol ............................................................................................. 12
  Statistical Analysis .......................................................................................................... 13
  Validity and Reliability ..................................................................................................... 13
Results .................................................................................................................................. 15
  Effects on strength ............................................................................................................. 15
  Effects on Power ............................................................................................................... 16
Discussion ............................................................................................................................. 17
Conclusion ............................................................................................................................ 19
References ............................................................................................................................. 21
Background

Physical training produces specific responses within the body which in turn causes adaption to that stimulus. The combination of training for gains in both endurance and strength within the same session is known as concurrent training (CT). Its methodology can be summarized by the combination of resistance training followed by endurance training (Hakkinen et al., 2003) or endurance training followed by resistance training (Sale et al., 1990) within the same training session or with a respite of several hours between both training modalities (Sale, et al 1990; Chtara et al., 2005, 2008). Thus a logical argument can be made against CT, based upon the training of multiple qualities in tandem. This multiple quality training bewilders the body as to how it should react and adapt to the training stimulus (Interference). Since most sports do not singularly use one energy substrate CT would seem to be a viable training method for improvement in sports that require both elements of endurance and strength for participation. Using road cycling as an example the sport is dependent on great aerobic ability and capacity for the maintenance of speed over great distances with different terrain for inordinate amounts of time. Anaerobic strength and power is also of importance since cycling cadence involves lower body power utilization, specifically with hill climbs and cycle sprints (Tanaka et al 1993). Thus a combination of both aerobic and anaerobic qualities is necessary for success in distance cycling due to the aforementioned specifics of the sport.

Introduction

The general consensus for CT improvement of aerobic endurance and muscular strength within the same session is that it is unproductive for test subjects due to the so called interference phenomena (Dudley et al 1985). There are however investigations that have yielded positive results in the aforementioned combination (Hickson, 1980, McCarthy et al., 1995, Aagaard et al., 2007, 2010). Such as Aagaard et al., (2011), CT intervention conducted upon young elite cyclists the outcome being an increase of 12-20 % in the performance parameters of maximal strength and rate of force development after the 16 week intervention (Aagaard et al., 2011). Very few sports are solely reliant upon a single energy substrate, thus it would seem that concurrent training could be a viable means to improve athletic performance in sports that require both aerobic and anaerobic utilization. It has been
suggested that CT may interfere with strength gains if the endurance portion of CT is too severe in either intensity and or quantity (Dudley et al 1985). More specifically it is the incompatibility of two separate signaling proteins (mTORC1, AMPK) that are linked to either resistance or endurance training. Activation of the mTORC1 enzyme aids in hypertrophy and strength improvement whereas activation of AMPK is an initial stage of the process leading to increases in mitochondrial mass and improved oxidation of fat.

In direct opposition to this is that it has been noted in several CT interventions that concurrent training can improve maximal muscle strength without negative physiological adaptations (Hickson et al., 1988; Bishop et al., 1999; Aagaard et al., 2007, 2010

**Previous research**

**Concurrent Training**

Concurrent training was born out of a theory that physiological training adaptations of endurance and strength could be made within same session training and or alternate day training order. Since the genesis of this idea there have been many forms as well as protocols used in an array of interventions. One of the earliest recorded interventions into concurrent training (CT) by Hickson (1980) in the early eighties was conducted to compare physiological improvements between three training groups consisting of an endurance only group, a resistance only training group and a concurrent group (endurance and resistance) who trained for a period of ten weeks. The subjects of the Hickson intervention were active in sports albeit on a recreational basis. The training sessions were designed to promote strength gains in the lower body and consisted of squats 5 x 5, knee extensions and knee flexions 3 x 5. Upon cessation of the training protocol the CT group showed 30 kg increase in 1 RM squat which was a 30 % improvement above starting values. The CT group had the same strength improvement as the group that resistance trained only, up until the seventh week whereby their strength gains leveled off. The strength group persisted with gains throughout the intervention with a final increase of 42 kg, a 44 % increase above the pre-test values (Hickson, 1980). Hickson (1988) later conducted a further intervention into the potential of strength and endurance to amplify physical performance, the resulting conclusion from that
study was that 10 weeks of CT performed three times per week increased the leg strength of the subjects by an overall 30 % and short term endurance in running and cycling by 11-13 %. The training exercises consisted of parallel squats and leg extensions at 80 % of 1 RM as well as toe raises. The authors summarized that specific endurance can be improved by adding resistance training to an endurance protocol (Hickson et al., 1988). Several later interventions into CT have also reached the same conclusion (McCarthy et al., 1995, Ostrerás, Helgerud and Hoff, 2002, Ronnestad, Hansen and Raastad 2009). Two Meta analyses have been compiled to review the present CT literature; the conclusion reached in the Meta analysis was that there was improved maximal strength within the CT groups with no strength differences when compared against resistance only trained groups within the same study (García-Pallarés & Izquierdo, 2011; Wilson et al., 2011).

Sale et al (1990) intervention consisted of comparing two CT protocols with the aim of accessing if both protocols would have positive increases in the development of strength. Protocol 1 of the Sale (1990) intervention consisted of CT completed on alternating days with Protocol 2 consisting of same session CT. The results for both protocols were positive although mixed Protocol 1 saw an increase of 25 % in leg press strength with CT conducted on alternating days and Protocol 2 saw an increase of 13 % with same session training conducted over 20 weeks (Sale et al., 1990). An interesting facet from the results from of the Sale (1990) intervention is that given the fact that both intervention groups performed the same exercises with accompanying weight increases as well as endurance intensities, there appeared to be the so called interference factor (Docherty and Sporer., 2000). The interference factor pertains to a reduction in improvement of strength due to endurance training intensity and or modality within same session training (Docherty and Sporer., 2000). This was not the case when the subjects completed single session endurance or resistance training only conducted on alternating days. The subjects of the intervention were previously untrained physical education students. Collins et al., (1990) conducted an intervention into CT order, on the possibility of different physiological adaptations in relation to training order. The seven week CT intervention consisting of a control group, resistance/endurance group (RE) and endurance/resistance group (ER). The two CT groups both had positive gains in leg press strength development, with 12 % for the RE and 14 % in the ES. The control group made no significant gains (Collins et al., 1993).
A short six week study on the effects of concurrent training upon performance parameters in well trained cyclist demonstrated an improvement in 1RM leg strength of the squat from 109 to 137 kg with three CT sessions performed per week (Levin et al, 2009). A CT intervention conducted by Ronnestad et al., (2009) consisted of pre and post testing their subjects in 1 RM leg press development and also the Wingate 30 s test (WANT) which is conducted to measure peak anaerobic power (PP) as well as anaerobic capacity of test subjects (Bar-Or, 1987). The resistance training sessions were conducted twice weekly for 12 weeks using four leg exercises completed for 3-4 sets of their 10RM. The results were that the subjects improved their maximal half squat by 21.2 ± 4.9 % and their PP in the Wingate by 9.4 ± 2.9 % (Ronnestad et al, 2009). Ronnestad et al., (2010) next investigation into CT was based on the grouping of high volume endurance training in combination with resistance training performed twice weekly for a period of 12 weeks. The intervention saw a positive increase for both the resistance only training group (R) and the resistance and endurance group (RE) of the intervention with the R group increasing their 1 RM squat ability from 108 ± 3 kg to 159 ± 3 kg and the RE group 109 ± 5 kg to 147 ± 6 kg. The mean increase for R and RE groups in the leg press and half squat were 35 ± 4 % and 25 ± 2 % respectively. The subjects of the study consisted of non-resistance trained men (R group) and well trained cyclist (RE group) with no previous resistance training experience (Ronnestad et al, 2010). A later investigation by the same research group into the positive influence of resistance training on a 5 min all-out cycling test was conducted over 12 weeks (Ronnestad et al, 2011). The 2 session per week protocol of CT consisted of 3- 4 sets 10RM of the half squat and/or endurance only training within heart rate zones (HR training 60-100 % of the HR max). The subjects were well trained cyclists that were tested three days after their last resistance training session in the leg press and on another occasion, tested after cycling continuously for 185 min at 44 % of maximal aerobic power output before being tested in an all-out 5 min cycle test The results were positive in that the CT group increased their 1 RM in the half squat by 26 ± 2 % as well as increasing their mean power (MP) output in the 5 min all out cycle test by 7.2 ± 2 % from pretest results, the endurance only group showed no changes (Ronnestad et al., 2011).

Since most CT interventions are predominantly of short duration an intervention was made to answer if CT could give the same strength improvement under a longer training period as resistance only training and if so would a combination of endurance mixed with explosive strength training yield positive results. Thus an intervention was made for comparative
purposes, which consisted of two groups performing both maximal and explosive type resistance training over the course of 21 weeks. The end result of the study was that both groups had similar gains in leg strength development in the 1 RM squat, with the R group increasing by 21 % and the CT group increasing by 22 % over pre-test values. The CT group also had an increase in maximum activation of the vastus lateralis muscle of 29 % in comparison to the R group rise of 26 % (Hakkinen et al., 2003).

Strength

Strength or resistance training pertains to improving the contractile forces of muscle or muscle groups by the stimulus of training overload which in turn elicits adaption. This is first determined by testing for the subjects 1 repetition maximum (1 RM) (Sale, 1991) which is the most amount of weight a subject can move once. Once the 1 RM is achieved and noted a percentage of 1 RM is used to elicit a training adaption in the desired resistance training exercise. Initial improvement in strength quality can be accounted for by neural adaption and or hypertrophy of cross sectional muscle area in the early stages of resistance training. Neural adaptions take place in the brain and spinal cord and pertain to adaptive changes within the nervous system that lead to improved motor unit recruitment in the trained muscle/muscle group (Sale, 1988). In resistance training neural adaptations dominate the first weeks of strength improvements which precede muscle hypertrophy (Cormie et al., 2011).

Of late it has been documented that beginners to resistance training can make strength gains while resistance training at 60-70 % of their 1 RM (Rhea et al., 2003). According to the American council of Sports medicine (ACSM) novices to resistance training can make initial strength increases of 40 % with moderately trained subjects seeing an increase of 20 % with well trained individuals seeing a 16 % improvement within four weeks to two years of continuous resistance training ACSM (2002). Willoughby (1992) conducted an intervention on periodized resistance training using the squat as the resistance exercise to evaluate three different training protocols conducted over 12 weeks. The first protocol consisted of 3 sets of 10 repetitions which saw a 13 % improvement, the second protocol 3 sets of 6-8 repetitions gave a 26 % improvement over pre/test values, with the final periodized protocol showing a 48 % rise in comparison to pre training results (Willoughby, 1992). A later study on the effects of maximal strength training on 13 competitive cyclists consisting of 10 men and 3
women over 12 weeks revealed a 14.2 % improvement in 1 RM half squat from 155 ± 15.3 kg to 186 ± 21.9 kg. Post test rate of force development in the half squat increased 16.7 %, from 802 ± 141 W to 936 ± 170 W. A Meta analysis on the dose response to resistance training revealed that training at a mean intensity of 85 % 1 RM, two days per week with 8 sets would elicit maximal strength gains for athletes, while a mean intensity of 80 % of 1 RM two days per week with four sets was best for recreational non athletes (Peterson et al., 2004).

Within resistance training rest time between training sets is of utmost importance for the continuation of repetitions of the next prescribed training set. This was the focus for Robinson et al., (1995) study, whereby 33 moderately trained men were divided into three equal training groups and each training group allocated a specific timed rest interval (3 min, 90 s and 30 s) so as to see the rest intervals effect upon resistance training. The subjects trained four days a week for five weeks with 5 sets of 10 repetitions for major muscle groups and 3 sets of 10 repetitions for small muscle groups. The results of the intervention were that the test subjects with the 3 min rest group improved over the 90 s or 30 s rest groups in their 1 RM squat 7 % from 124 kg to 133 kg as well as in their cycle sprint PP from 1016 to 1071 W and cycle sprint MP from 906 to 950 W in cycle PP testing with a significant correlation of Pre 0.62 to Post 0.74 at (P < 0.05) The conclusion of the intervention was that the 3 min respite between training sets was the superior rest length of the intervention (Robinson et al., 1995). A rest time of 3-5 min between sets has also been shown to be adequate recuperation time for the resynthesis of the adenosine triphosphate (ATP) by creatine phosphate (CP) so as to aid with muscular contraction when the goal of training is max strength development (Mirzaei et al., 2008, Miranda, et al., 2007).

It has been well documented that resistance training can improve muscular strength in non-trained to well trained subjects (ACSM, 2002), to this end Hickson et al., (1980) conducted an intervention to assess the effects of resistance training on 1RM. The study involved 9 healthy men who had ceased training regularly for 6 months before the intervention began. The intervention consisted of 10 weeks of resistance training at 80 % of 1 RM, 5 days per week. The focus of the intervention was on lower body strength improvement i.e. squats, leg presses and calf raises etc. The resulting conclusion of the intervention was a 40 % increase in the subjects 1 RM from 104 ± 4.1 kg to 144 ± 6.4 kg (Hickson et al., 1980).
Improvement in strength performance with short term resistance training was the focus of Ronnestad (2004) investigation whereby he compared the performance effects of squats over a 5 week period on recreationally resistance trained men who trained 3 times a week with 3-4 sets of 6-10 RM. The intervention results showed significant increases in 1 RM improvement in the squat exercise from 150.0 ± 15.3 kg to 186.4 ± 21.9 (Ronnestad, 2004). Stowers (1983) 7 week resistance training intervention also assessed short term effects of resistance training conducted using 75 % of 1 RM (Baechle, et al., 2000). The test subjects of the intervention increased their strength by 20 % in the squat with 3 resistance training sessions per week (Stowers, 1983).

**Aim and Questions**

The aim of the present study was to investigate the effects of 8 weeks of concurrent training or endurance training alone on the following performance tests in endurance cyclists.

- Maximum Leg Press Test (1 RM)
- 30 s Anaerobic Wingate Test (WANT)

My hypothesis is that an intervention of concurrent training will yield positive physiological results in moderately trained endurance cyclist in comparison to endurance training performed alone.

**Method**

**Pre Participation**

Before acceptance to the study the subjects were interviewed with the purpose of validating stability in their training routines as well as confirming uninterrupted training due to sickness and or injury. The subjects also participated in an incremental exercise on a cycle ergometer (Monark Ergomedic 893E, Monark Exercise, Varberg, Sweden) on the same day. After cessation of the cycling the subjects then performed a familiarization session in the leg press machine (243 Leg Press 45°, Gymleco, Stockholm, Sweden). The subjects continued their usual training for the following 2-4 weeks and then reported back to the lab for another
familiarization training session consisting of a 40 min time trial (TT) on a SRM ergometer (SRM, Konigskamp, Germany).

**Training Intervention**

Twenty moderately trained cyclists (Table 1) were recruited for the study, whereby a block randomized controlled trial was used to divide the subjects into groups of 10 and placed into either an Endurance training group (E) or an Endurance Resistance group (ER). The two groups were matched for physiological characteristics of strength and endurance as well as training history. The inclusion criteria for the intervention was an exercise quantity of 3-6 workouts or 5-12 hrs weekly of endurance training as well as a \( \text{Vo}_2\text{max} \) of \( >50 \text{ ml/kg-min} \).

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age</th>
<th>Weight</th>
<th>( \text{Vo}_2\text{max} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES</td>
<td>34.1±5.3</td>
<td>79.5±6.0</td>
<td>56±5 ml/min/kg</td>
</tr>
<tr>
<td>E</td>
<td>35.7±5.3</td>
<td>80.2±6.1</td>
<td>55±4 ml/min /kg</td>
</tr>
</tbody>
</table>

*Table 1* Physiological characteristics of the block randomised subjects

The chosen applicants were subjected to a pre-recruitment test on a cycle ergometer, where lactate formation at different workloads was measured and assessed in relation to bodyweight and training background. A further requirement for inclusion was that the applicants should not have trained heavy resistance training up to 6 months before the intervention start date. None of the subjects had any medical conditions or disabilities that hindered their ability to perform the exercises within the intervention. The participants were given a detailed explanation of the aim of the study and a description of what tests would be used and how the training intervention would be conducted before the start of the study. Furthermore the participants were informed that they at any time could withdraw from the study or test without explanation.
The ER training consisted of sixteen 60 minute cycle endurance training sessions followed by circa 25 min of resistance training performed over a period of eight weeks. The E group protocol was that of 60 min cycling followed by 5 min of active cool down with a 10 min respite followed by 3 min of extra cycling (Figure 1). It was determined that the extra 3 min of cycling work corresponded to the energy requirement of the leg press exercise based on their 1 RM.

The inclusion criteria for completion were:

- Completion of pre and post-tests.
- Training participation requirements of 14 of 16 sessions.
- No extra strength training outside of the intervention study.
- Subjects own cycle training should not interfere with the interventions training schedule.

If a subject was absent from a session due to illness and or other complications the training period would be extended so that the subject could meet the requirements for participation of the intervention. One of the subjects in the ER group was unable to meet the participation inclusion criteria and therefore was excluded from the study. Reason for exclusion of the subject was injury. Thus the subject could not complete the last few training sessions as well as the post tests, thus he did not fulfill the inclusion requirements and was excluded from the intervention.
Nutrition

Subjects notated dietary intake throughout the 36 hours that preceded the pre-intervention trial and were instructed to replicate this diet in accordance with the post-intervention trial. The subjects were informed of the necessity of keeping a balanced diet as well as an appropriate intake of carbohydrates. Tests were performed three hours after the last meal with the timing kept at the same time for pre and post testing.

Test Equipment

The equipment used for the leg press exercise was the Gymleco Leg press machine manufactured in Haninge AB, Sweden. Reason for inclusion of this leg press machine was that it activated the leg extensor group of muscles which are predominately used in cycling. The two cycle test ergometers used in the intervention were the SRM test cycle (Figure 2) which was used for the pre and post test data collection and the Monark Ergomedic 893E test cycle (Monark Exercise, Varberg, Sweden) (Figure 3) which was used in the endurance part of the training intervention.

Exercise Performance Tests

Cycle Ergometer

The first day pre-intervention testing consisted of the subjects performing a 40 min Time trial (TT) for the purpose of capturing power output, cadence and heart rate. Upon completion of the TT the subjects cycled unloaded for a further 20 min in preparation for the remaining two 30 s sprint cycle tests which were to be completed 5 min apart from one another for comparative purposes. The SRM test cycle was set to isokinetic mode at 115 rpm and the subjects instructed to pedal “full out” from the start while keeping themselves seated. The test is similar in construction to the exhaustive Wingate 30 s cycle test whereby peak and mean power are ascertained as well as fatigue index within a 30 s bout (Bar-Or, 1987). The result from the test is a measurement of the subject’s ability to produce and maintain high levels of
power within 30 s using the lower body. Test results are divided into six equal periods of 5-s where peak power (PP), in Watts, is the highest power output during any one 5-s period and mean power (MP) is the mean (average) of all six 5-s periods. Power drop (PD) refers to the drop in PP between bouts 1 and 2. The SRM (SRM Training system Version 6.42.06) test protocol was modified to compare mean power decrement from the Pretest score with the Posttest score.

**Leg press 1 RM**

All twenty subjects undertook a preparatory strength test on a leg press machine (243 Leg Press 45°, Gymleco, Stockholm, Sweden). The purpose of the test was to determine each subject’s 1 repetition maximum (1 RM) which is the maximum amount of weight one can lift in a single repetition for a given exercise. All trainees were asked to lower the leg press with an unloaded weight sled eccentrically to an approximated 90 degree angle whereby a tape was placed upon the leg press machine as a visual marker for the turning point of each repetition. Ten repetitions at 100 kg were performed by each subject as a warm up weight in preparation for the 1 RM attempts. The load was then increased by 25-50 kg whereby the subject was asked to perform a single repetition on the newly adjusted weight, three minutes was given as a rest period between each repetition attempt and raising of weight which was individual to each test person. Once the 1 RM was ascertained by the subject the information would then be used as base data for the resistance training portion in the subsequent exercise sessions to commence two weeks later.

**Training Sessions**

Sixteen training sessions were conducted over a period of 8 weeks (twice weekly) set apart by 72 hours. Training sessions were conducted on Monday and Thursdays or Tuesdays and Fridays at the Swedish School of Sport and Health Sciences weight training room. The intervention study was set so that there was adequate rest time for recuperation between the training days. All training sessions were supervised by experienced resistance and cardiovascular training test leaders.
**Endurance Protocol**

Supervised training

The ten subjects of the endurance group (E) protocol commenced their session with a brief warm up of 5 min at a load of 100 W on the Monark cycle ergometer, the cadence was chosen by the cyclists themselves. This was followed by a 60 min steady state session at a load of 90 % of the mean power of the subjects TT test, later to be adjusted to 92, 5 % for sessions 9-12 and 95 % during session 13-16 of the intervention. Cadence was chosen by the subjects themselves and this cadence was used to divide the average peak power of the previous test result giving each subject a specific load on the cycle ergometer. After the 60 min was reached a 5 min cool down at a load 100 W commenced. This was then followed by 10 min of complete rest before the subjects repeated a further cycling session for 3 min, at the same percentage as the previous 60 min cycle setting. This extra 3 min was calculated to be the energy equivalent work of the leg press exercise based on their 1 RM.

**Endurance/Strength Protocol**

Supervised training

The nine subjects who completed the concurrent endurance strength (ES) training protocol of the study commenced their endurance program in exactly the same way as the E group the only difference being the negation of the 3 min extra cycling protocol. Upon completion of the endurance portion of the intervention the ES subjects rested 10 min before commencing with the resistance training protocol. The resistance training protocol commenced with 12 repetitions at 50 % of 1 RM as a standard warm-up on the leg press machine. The exercise protocol consisted of an ascending to descending 6 set pyramid, 65, 70, 75, 75, 70, and 65 % of the subjects 1 RM with 12 repetitions set at each percentage load. The aim of the increase in resistance intensity from 60 % to 75 % was for the ES subjects to reach muscular fatigue (Rhea et al., 2003). The load was calculated from the preparatory 1 RM test. Upon completion of 12 repetitions at 75 % the resistance would be increased by 10-30 kg. Thus the 1 RM was re-estimated to an estimated 1 RM and subsequently increased as the intervention progressed and the subjects increased in strength. The load was lowered slowly for 2-3 s in the eccentric phase and pushed up as fast as possible 1-2 s in the concentric phase. Between each set there
was a respite of 3 min. The strength training component of the intervention took approximately 25 min following the endurance training part of the intervention.

**Statistical Analysis**

All values are reported as mean ± standard deviation (SD). A paired t-test was used to check for statistical significance of gains within groups. An unpaired t-test was used to check between group differences in gains. The level of statistical significance was set to $P < 0.05$.

**Validity and Reliability**

To have any meaning a test must measure what it is purported to measure and be reliable in that measurement (Domholt, 2000). The Intra-class Correlation Coefficient (ICC) is a measure of the reliability (Precision) of measurements. In the case of the leg press the 1 RM test is a valid estimate of maximal strength since it only measures the neuromuscular systems capacity to exert maximal force once until fatigue occurs and the respective weight cannot be lifted. Thus it is indicative means of assessing validity of muscle force ICC $r = 0.99$ (Kraemer et al., 2000). Measurement validity can be summarized by an instrument that appropriately measures that which it is purported to measure (Portney and Watkins, 2000). Technical error of measurement (TEM) refers to the variability of a measurement taken upon an object on different occasions since the values attained will vary due to instrument or human inconsistency with repeated measures. The SRM cycle was calibrated by SRM engineers and is purported to have an error marginal (TEM) of 0.5 % according to the SRM manufacturers. The collection and supervision of the aforementioned tests were completed by experienced physiological test leaders employed by Åstrand Laboratories GIH Stockholm.

Reliability refers to the test-retest theorem whereby a test should yield consistent repeatable scores with little or no change in the measurement results gathered. Although test within the intervention were not repeated for test-retest reliability, all tests were conducted with little or no disparity between subjects due to stringent instrument calibration in tandem with a standardized testing protocol. Scheduling of tests was preceded by a 36 hr abstinence from competition or high intensity training before both the pre and post test results were gathered,
since fatigue from exhaustive training can alter the results collected due to residual fatigue. Post-tests were conducted at the same time of day as the Pre-test.

The word familiarity pertains to knowing something well. With this in mind it was deemed necessary for all subjects to become familiar with the test procedures and the implications of not performing fully. Lack of familiarity to physical tests can give a lower test result, since neuromuscular coordination, motivation and test experience play a pivotal role in test results. Within the scope of this intervention the subjects performed a familiarization training session, before being selected for the intervention, so as to understand and become accustomed to the tests they would be performing. According to Hopkins (2001) physical tests should be repeated so as to yield reliable data. Thus results collected within the intervention had a higher level of reliability since each subject had previously trained and been coached into performing fully within each test.
Results

Effects on strength

The 1 RM leg press post-test results for the ER group showed a positive increase of 63 kg (18.7 %), (P<0.01). Between each training session ER displayed a progressive gain of the estimated 1 RM (averaging 2.2 % per session). The estimated 1 RM was calculated by adding 10-30 kg to the pretest 1 RM weight on completion of 12 repetitions at 75% 1 RM and all successive completions of 75% thereafter (Fig 3). In the in between group comparison the only significantly difference of all measured parameters was the 1 RM (P<0.01).
Effects on Power

At conclusion of the intervention the ER group showed significant positive increase (P < 0.05) on peak power (PP) in both SRM cycle sprints (5.7 % and 5.3 % respectively). The E group showed no significant changes (Fig 4).

Figure 4. Pre and post changes of the first Wingate SRM cycle sprint test.
* P<0.05

Figure 5. Pre and post changes of the second Wingate SRM cycle sprint.
* P<0.05
Discussion

The result of the 1 RM strength development showed a positive increase for the ER group which was significant. The percent increase was 18.7 % at conclusion of the intervention, which when compared to the intervention conducted by Aagaard et al., (2011) on young elite cyclists is comparable 12-20 %.

A comparison of strength development can also be made between the present investigation (18.7 % increase) and that of the Hickson (1980) intervention (30 % increase). The Hickson (1980) intervention had an initial training intensity of 80 % 1RM whereas the present investigations training intensity was conducted between 60-75 % of 1 RM. Thus the Hickson subject’s strength development would be more pronounced than that of the subjects of the present intervention. The lesser strength development of the present investigation could also be due to the proposed interference model of Docherty and Sporer (2000). Which states that concurrent training of maximum aerobic power >95 % and hypertrophy type training within the 10-12 RM repetition range can have an adverse effect on strength development due to the competing biological adaptations of CT on skeletal muscle. Although this intervention used a lower intensity for the endurance protocol 90-95 % of the subject’s average 40 min Time Trial power, it could be argued that there may have been some residual fatigue from the endurance training session which could have impaired the resistance strength development within the subjects of the present intervention.

Both the Hickson (1980) and the Ronnestad (2010) study with its 30 % and 35.4 % strength increase, had far greater development in strength than that of the present intervention. A possible factor could be the training status of the subjects of the intervention, in that the Ronnestad subjects were non trained men and the Hickson subjects were largely active in sport but on a recreational basis. The training status of the subjects is open to interpretation but can be defined as the subjects being novices to resistance and concurrent training of sport, and thus according to ACSM position stand guidelines as it pertains to resistance training, can improve strength qualities by up to 40 % when undertaking resistance training for the first time. The subjects of the present investigation were moderately trained men which according to the ACSM position stand can improve strength development by 20 %.
The present intervention had a strength development of 18.7 % and was conducted for 8 weeks with an average increase of 2.2 % in strength development per session. Ronnestad (1990) and Hakkinen (2003) interventions had an improvement of 21 % and 22 % respectively and were conducted over 12 and 21 weeks. Thus one can suggest it would be possible for the subjects of the present intervention to improve percent strength development results if the present intervention length had been increased. The present intervention also improves on strength development of the previous CT interventions conducted by Collins (1993) 11.9 % and 14 % and Sale et al., (1990) 13 % increases although the latter intervention also showed a CT improvement of 25 %. The 25 % strength improvement in the Sale (1990) intervention could be due to less residual fatigue between the endurance and resistance training sessions due to them being conducted on separate days, thus It is possible that the subjects of the present study could have improved strength development further if CT was also performed on separate days. Also it should be noted that the Sale (1990) intervention was 22 weeks in length with a 3 week rest after 11 weeks which could have added a positive factor towards strength development.

The strength development in the Stowers (1983) and the Willoughby (1992) interventions 20 % and 13 % respectively demonstrate that this intervention 18.7 % had similar and or better strength gains when compared to the aforementioned resistance training only interventions. It should be noted that within week 5 of the present intervention resistance training intensity was not increased over 70 % so as to allow for a period of less intensity for recuperation purposes (Fig 3). On completion of the intervention the ER group showed a 5.7 % significant increase (P < 0.05) in PP from 1019-1077 W for cycle sprint one (Fig 4) and 5.3 % increase from 1001-1054 W, in cycle sprint two (Fig 5).

The increased PP might have been positively influenced by an improvement in contractile strength. Contractile strength pertains to the recruitment and synchronization of motor units and there corresponding muscle fibers. The gains in the present investigation also compare favorably to the results garnered from Ronnestad (2004) intervention whereby the subjects improved their sprint cycle peak power from 1016 to 1071 W after 5 weeks of resistance only squat training.
The Wingate 30 s cycle sprint tests is conducted to assess anaerobic power and capacity, with the contributions of power derived from different energy substrates which in turn have an effect on repeat cycle sprint performance. The energy substrate contribution to the Wingate cycle sprint test has been noted at 38 % from aerobic processes, 45 % from lactic anaerobic processes and 17 % from alactic anaerobic processes (Withers et al., 1991). Peak Power (PP) in cycle sprints 1 and 2 were similar but their respective mean power (MP) was not. A possible explanation could stem from the metabolic process of adenosine triphosphate (ATP) phosphocreatine (PCr) in that PCr is the immediate energy source for high powered intense movement and lasts approximately 8 sec or less with high intensity activity, after which the body must use the next available energy source which is the anaerobic glycolytic system. This system has two distinct phases consisting of the breakdown of glycogen by enzymes to form pyruvic acid which in turns forms lactic acid. The accumulation of lactic acid brings with it a decrease in blood and muscle pH (acidotic state) which hinders muscular contraction (Katz et al., 1986). A five minute respite between the two all-out cycle sprints conducted within the test battery is possibly too short a time to successfully clear all lactic acid from the system, as was the case with Hargreaves et al., (1998) repeat Wingate 30 s cycle sprint protocol which was separated by a 4 min respite between cycle sprint bouts (Hargreaves et al., 1998).

It has also been noted by Bogdanis et al., (1995) that PCr can resynthesize to 85 % of its previous resting value when separated by a 6 min respite between two Wingate 30 s sprints. The subjects of this intervention had a respite of 5 min between cycle sprints 1 and 2 and were able to attain a significant high PP in the second Wingate sprint although full recovery was incomplete.

Conclusion

This study evaluated the effects of an 8-week concurrent training intervention, the results of which show that concurrently training endurance and strength in the same session can lead to positive gains in the expression of 1 RM in the leg press and anaerobic PP in the Wingate cycle sprint test within moderately trained cyclists.
It would have been interesting for comparative purposes to have had a third group consisting of resistance training only and a fourth group consisting of resistance followed by endurance training for their protocol, which I feel could have added another dimension to this intervention as well as generating more hypotheses based not only on CT but resistance and endurance training also.

Further studies could involve power protocols such as plyometric exercises added after the resistance training portion as these have been shown to increase muscular power output which has been used in other CT interventions with positive outcomes. The results of this intervention show a need for a longitudinal examination of CT, since most studies are of short duration generally 6-12 weeks in length. Thus an intervention with a longer duration may also yield positive physiological gains within intervention subjects. In addition higher periodized resistance intensities with accompanying repetition range 3-5 reps in the resistance portion could possibly garner different results. The highest resistance training intensity reached within this investigation by the subjects was 75 % 1 RM which has been noted in previous studies as moderate intensity. Thus a further investigation is warranted with a resistance protocol of >80 % 1 RM since resistance training at these intensities has been shown to increase maximum strength and power within athletes. It has also been documented by Docherty and Sporer, (2000) that training at higher resistance intensities i.e. >80 % 1 RM reduces the risk of interference between endurance and resistance modalities. Consequently a protocol of CT with higher resistance intensity could be the best of both worlds, i.e. enhancement of all qualities strength power and endurance within one protocol. Thus further examination into CT is warranted.
References


Acknowledgement

I would like to take this opportunity to express my sincere appreciation to those who have contributed directly and indirectly to this journey. First and foremost I would like to convey my gratitude to: Kent Sahlin, Niklas Psilander and all the staff connected to Åstrand laboratory and The Swedish school of Sports Science for their time, effort and most important of all their patience. I am thankful for their willingness to assist and provide advice whenever called upon throughout this process. I would also like to recognize the encouragement and patience provided by my family and friends for their unwavering support throughout this journey I call my dissertation. Lastly I would like to acknowledge the test subjects for without whom this dissertation would not have been possible.
Bilaga 1

Litteratsöknings

I bilagan Litteratsöknings ska du återge de sökningar du har gjort för att hitta tidigare forskning inom ditt ämnesområde. Litteratsökningsen ska finnas med som en bilaga i din uppsats.

Syftet med att redovisar litteratsökningsen är att läsaren av ditt arbete ska kunna återskapa dina sökningar och på så sätt kunna hitta intressanta dokument. Redovisningen hjälper också läsaren att kunna bedöma om du sökt på relevanta ämnesord utifrån dina frågeställningar och om du genomfört sökningarna på ett bra sätt.

Använd denna mall när du gör din bilaga. Det gör ingenting om bilagan blir längre än en sida.

**Aim and question:**

The aim of the present study is to verify what improvement in performance if any, can be attained from an intervention of 8 weeks of concurrent training on the following performance tests in endurance cyclists.

- Maximum Leg Press Test (1 RM)
- 30 s Anaerobic Wingate Test (WAT)

**Vilka sökord har du använt?**

Concurrent training
Strength training
Leg Press
Squat in combination with strength training
Leg press in combination with strength training

**Var har du sökt?**

Sports Discus
Google Scholar.
PubMed.

**Sökningar som gav relevant resultat**
**Sport Discus:**
Concurrent training, Squat, Concurrent and Strength,
Strength training and squat, Strength training and leg press.
Google Scholar:
Concurrent training, Strength training,
Hickson, Rhea and strength training,
Wingate test, Strength training Leg Press.

**Kommentarer**
The bulk of my literature was received via my supervisor. Google scholar and Sports Discuss also yielded relevant information that was used in this dissertation. The Pub-med search engine was used to view abstracts that were later viewed in their entirety on sports discuss and google scholar.