ORIGINAL RESEARCH PAPER

PEAK OXYGEN UPTAKE AND MUSCLE POWER CAN BE SIMULTANEOUSLY IMPROVED WITH HYBRID TRAINING

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Abstract

The purpose was to investigate the effects of simultaneous endurance and strength training repeatedly performed in the same training sessions (hybrid training). Twenty-six habitually active female physical-education students took part in the study. They were assigned to a hybrid training group (HT) or one of two control groups (CON1; only endurance training and CON2; maintained their normal training regimen). In a pre- and post-test training design all the subjects were tested before and after the intervention period concerning peak oxygen uptake while pedalling on a cycle ergometer and power output in a progressive cycle ergometer pedalling power/strength test. The HT intervention group and the CON1 group trained three times per week for five weeks, while the CON2 group did not change their normal training regimen. The HT group used a pre-programmed cycle ergometer to pedal at a mean oxygen uptake of 70-75% VO_{2peak} for 30 minutes, but the training time was divided into 60 intermittent work periods (6 seconds) at a very high relative intensity (approximately 190 % of VO_{2peak}) interspersed with low-intensity work periods (24 seconds) at about 45% of VO_{2peak}. The CON1 group trained at the same mean oxygen uptake level as the HT group but during 30 minutes continuous training. The HT group significantly increased VO_{2peak} and muscle power performance. The CON1 group increased VO_{2peak} significantly but not power/strength. The CON2 group did not change significantly in the parameters studied. Thus, it can be concluded that in-session hybrid training allows simultaneous significant improvements of both VO_{2peak} and muscle power performance during cycle ergometer pedalling.

Key words: *Aerobic power, muscle power, concurrent training, cycle ergometer*

Introduction

There has been great scientific interest in concurrent strength-and-endurance training for over thirty years and numerous studies have addressed this issue (e.g. Balabinis et al., 2003; Bell et al., 1991; Dudley & Djamil, 1985; Hickson et al., 1980; Hickson, 1980; Kraemer et al., 1995; Leveritt et al., 2003; Shaw et al., 2009). The interest may relate to the fact that performance in many sports relies on both strength and endurance; and also perhaps to the puzzling issue of how strength and endurance can be trained in combination as they largely represent two different energy systems. Physiologically this is no trivial matter. In strength training, energy from anaerobic (alactacid and lactacid) energy processes is used, while aerobic processes dominate during endurance training. The difference in energy domain relates to a number of training responses. Strength training can result in muscular hypertrophy (Wernblom et al., 2007), but this is not expected as a main result of endurance training. The repeated low-frequency fibre recruitment that occurs during endurance training might interact negatively to explosive strength development, which requires high-frequency recruitment of fast type II muscle fibres (Widrick et al., 1996A; Widrick et al., 1996B). This may be associated with the reduced jumping ability seen after endurance training (Costill, 1967). Strength training shows a small reduction in mitochondrial density in contrast to endurance training which shows an increase here (MacDougall et al. 1979). Aerobic energy production may be hampered by a reduction in mitochondrial density, which may in turn decrease endurance performance level. The above examples indicate possible sites of interference in physiological adaptation during training in these energy systems, at least if maximal performance is sought in both capacities. However, recent studies (Wang et al., 2009; Psilander et al., 2010; Wang et al., 2011) on PGC-1α, a key regulator of mitochondrial biogenesis, shows an increased expression as a result of sprint-like interval training, which may indicate possibilities of concomitant adaptations on micro-cellular level to a given training stimulus. Studies focusing on physiology- and performance-related responses in concurrent strength and endurance training have shown that strength training does not reduce maximum oxygen uptake (Chromiak & Mulvaney, 1990). Some studies indicate an increase in maximum oxygen uptake (Hickson, 1980; Hunter et al., 1987; Sale et al., 1990), some have shown increased performance in endurance tests after concurrent endurance and strength training (e.g. Hickson, 1980; Hortobagyi et al., 1991). Studies on the effect of concurrent training on strength show contradictory results, both a decrease in strength (e.g. Dudley & Djamil, 1985; IzQuierdo et al., 2005) and an increase (e.g. Bell et al., 1991; Hortobagyi et al., 1991; McCarthy et al., 2002; Shaw et al., 2009). Together these results provide strong indications that combined strength and endurance training in separate training sessions under certain circumstances can increase performance in both capacities.

To our knowledge no-one has studied concurrent training when strength and endurance have been trained in the same exercise of high-volume and in consecutive sessions. In the present training study we were interested to do this. We call the mixed training of the two capacities “hybrid training” (Nilsson, 1998). The reason for this research interest is that two or several capacities are relevant for performance and are utilized simultaneously in many sports. In line with this strength and endurance are important and are used simultaneously in such different sports as soccer, cross-country skiing and middle-distance running. Typical of these sports is that neither strength nor endurance seems to be maximally used: instead there appears to be a balance in development between the two capacities for optimal performance.

The experimental approach in this study of hybrid training has a pre- and post-test design. Strength and endurance are blended into the same exercise in repeated, hybrid interval-training sessions with a combination of work and “rest” periods. This results in an average oxygen uptake level which is expected to allow an increase in maximum oxygen uptake and thereby an improvement in aerobic endurance. Work is performed at very high intensity (>100% VO_{2peak}) in short time intervals and with high resistance. This highly activates the target musculature so as to stimulate muscle power and strength adaptation. Two control groups performing only continuous endurance training or a constant quantity and intensity of training is tested before and after the intervention period to check for training cross-talk and changes in performance that could be related to the test design, respectively.

Thus, the aim of this intervention study was to design hybrid training that improved endurance (here represented by an increase in VO_{2peak}) and muscle power i.e. to overcome a larger braking force of a cycle ergometer at a given pedal rate, which is also an expression of increase in strength. The research hypothesis was that hybrid training in this form can sufficiently stimulate the development of both VO_{2peak} and muscle power. If this is the case, both will increase significantly after five weeks of hybrid training.

Materials and Methods

Participants. Twenty-six habitually active female physical-education students volunteered to participate. Their informed consent was obtained and the study procedures were approved by the regional ethics committee. The participants were assigned to one of three groups, a hybrid strength and endurance training group (HT) and two control groups (CON1 and CON2). The participants were assigned to a hybrid training group (HT) or one of two control groups (CON1 or CON2). The inclusion criteria were:

- Female gender, habitually active at an average of about three training sessions per week.
- No history of systematic and extensive strength or aerobic training several times per week during a long period more recently than three months prior to the study.

In addition the participants in the HT and CON1 groups should be willing to train hybrid training or continuous endurance training three times per week for five weeks, i.e. as their main training during the intervention period. They had to agree to avoid other heavy-resistance and high-intensity endurance training at or above the HT training intensity during the intervention period. The participants in the CON2 group were to maintain their normal training routines. There were no significant differences between the groups in age, height, body mass, peak oxygen uptake or maximal pedalling power before the intervention period. One participant withdraws from the study due to illness.

Table 1

Mean (±sd) anthropometric and other data on participants in the intervention group and the control group (BMI – body mass index)

	N	Age (yrs)	Height (m)	Body mass (kg)	VO_{2peak} ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$)	BMI
Hybrid training group (HT)	12	26.2±5.3	1.68±0.05	62 ± 6	44 ± 4	22.1±1.4
Control group 1 (CON1)	9	25.6±4.7	1.69±0.06	65±7	44±5	22.7±1.7
Control group 2 (CON2)	5	27.8±7.6	1.68±0.03	61 ± 6	45 ± 7	21.7±1.8

Apparatus and experimental design

A pre-and post-training test design was used in which peak oxygen uptake and progressive peak power/force production at a constant cadence on a cycle ergometer were determined. Between the pre- and post-tests the participants were randomly assign to five weeks of hybrid training (HT), or control groups performing continuous endurance training (CON1) or continue with their normal training (CON2).

Before the pre- and post-test the participants were instructed not to train on the test day, eat a heavy meal or smoke later than two hours before testing.

Peak oxygen uptake was determined for all participants while they pedalled on a cycle ergometer (Monark 839E, Monark AB, Vansbro, Sweden) pre-programmed to start at 100 W and to increase power by 10 W each 30 s. The participants were instructed to maintain the cadence at 90 rpm through the whole test to exhaustion or as long as possible. The participants were allowed to stand up pedalling on the cycle ergometer in the end of the test.

Oxygen uptake was recorded online with an automatic ergo-spirometric device (Oxycon Pro, Jaeger GmbH, Hoechberg, Germany). Respired air was sampled from a mixing chamber for measurement of PO_2 and PCO_2. Ventilation was measured with a low-inertia, low resistance, bi-directional rotating turbine flow sensor. Precision gas mixtures (± 0.5% error variability) were used for calibrating the gas analysers. The turbine flow sensors were automatically calibrated. The time delay between the ventilation and gas-concentration signals was measured and compensated for. In a method study by Foss & Hallén (2005) the validity and stability of the Oxycon Pro system was validated against the Douglas bag method over a large range of ventilation, drift during short (25 minutes) time trials as well as long test periods (approximately three months). The results from the validation study (n=18) showed an overall average oxygen uptake 0.8% lower with Oxycon Pro than with the Douglas bag method. During the short-time trial the oxygen uptake recorded with Oxycon Pro gradually changed from 0.5% to1.0% lower than with the Douglas bag method. Over the long test period the difference in average oxygen uptake changed from 1.1-0.5% lower oxygen uptake with Oxycon Pro. The authors concluded that the Oxycon Pro was accurate for measuring oxygen uptake over a large range of ventilations and during short and long test periods.

Heart rate was recorded with a heart-rate monitor (Accurex, Polar Electro OY, Kampele, Finland) together with the rating of perceived exertion on a rating scale (Borg, 1982) during test of VO_{2peak} and by the HT group during training. It was calibrated using lactate standards before each test.

Criteria for reaching VO_{2peak} were: "leveling off" in oxygen uptake and/or respiratory exchange ratio (RER) > 1.1, perceived exertion according to the rated perceived exertion scale (Borg, 1982) higher than or equal to "very hard" and rate of increase in ventilation.

Power output in a progressive pedalling power and strength test was performed on the Monark 839E cycle ergometer, pre-programmed to start at 100 W and to increase power output by 100 W stepwise every tenth second. The participants were instructed to remain seated and to pedalling at 90 rpm with increasing power output (i.e. increasing braking force) for as long as possible. The mean duration was designed to be maximally approximately 40 seconds with a relatively low power output the first 20 seconds (100-300W). As the subjects kept a constant pedalling rate the progressively increasing power output in the test will be proportional to an increase in force output. In a *post hoc* method study eight female, habitually active physical-education students performed a test and re-test of the progressive pedalling power and strength test as described above. The average relative difference was less than 0.5%. A paired *t* test (95% confidence interval) revealed no significant difference ($p=0.645$). The correlation coefficient between the test and re-test results was 0.984.

The training period lasted for five weeks with three sessions per week. Each session consisted of a five-minute sub-maximal warming up period on a cycle ergometer for all subjects in the intervention group. In each training session the CON1 group pedalled on a pre-programmed cycle ergometer (Monark 839E, Monark, Vansbro, Sweden) at 70-75% of VO_{2peak} continuously for 30 minutes. In each training session the HT group pedalled on a pre-programmed cycle ergometer (Monark 839E, Monark, Vansbro, Sweden) at a mean oxygen uptake of (70-75% of VO_{2peak}) for 30 minutes, but the training time was divided into 60 intermittent, six-second work periods at a very high relative intensity (approximately 190% of VO_{2peak}) interspersed with low-intensity work periods (24 seconds) at about 45% VO_{2peak}.

The calculation of work load during hybrid training was based on the linear relationship between oxygen uptake and power during pedalling on a Monark cycle ergometer (Åstrand & Rodahl, 1986). Power with respect to each mL oxygen uptake was calculated to 0.070579 W. The maximum oxygen uptake for each participant in the HT group was recalculated in watts at 45, 190 and 70-75% of VO_{2peak}.

To check that the relative muscular activation level was high enough during the hybrid training, a control study was performed on one participant. In this study the myo-electrical activity in m. vastus lateralis on the right leg was recorded with surface EMG (Type SX230, Biometrics Ltd, Gwent, UK). An electrogoniometer was taped over the right knee to serve as a kinematic reference to the muscular activation. This allowed the mean EMG activation level during the concentric contraction phase of the right m. vastus lateralis to be determined in each pedalling cycle. Mean EMG was obtained during the high-intensity "strength training" phase (6 s) in the hybrid training (190% VO_{2peak}), during continuous cycling (75% VO_{2peak}) as well as during the maximal power test on the cycle ergometer. In addition, EMG was obtained during squat 1RM as well as 60, 70, 80% 1RM and maximal counter-movement jumps with arm swing (CMJa). This control study indicated that the high-intensity phase in hybrid training activated m. vastus lateralis to a large relative extent (87%) with respect to the squat 1RM. The progressive power test at peak power and CMJa with respect to squat 1RM was 77 and 85 %, respectively. The mean EMG activation level during continuous pedalling at 75% of VO_{2peak} was 62% of squat 1RM activation. The activation level at 60, 70 and 80% of squat 1RM corresponded to 65, 70 and 78% EMG activation level compared to squat 1RM (100%).

After each training session the participants in the intervention group continued to pedal at a low power level for five minutes to cool down. In each training session they recorded power output, heart rate and perceived exertion in ventilation effort and in leg muscles. Every participant also documented training performed in addition to the study and this was checked by the experimenters with no remarks.

Statistics

Conventional statistical methods were used to calculate means, ranges and standard deviations (sd). Differences between the training group and the control group concerning peak oxygen uptake and pedalling power were tested with ANOVA for repeated measures using an alpha level of 0.05 to assume statistical significance. Post hoc comparisons were made using the Tukey procedure. To test differences in peak oxygen uptake and power performance within the HT and Con group pre and post training, a dependent *t* test was used. The threshold for keeping overall risk of type I error equal to 0.05 for two comparisons was here set at 0.03. Effect size (ES) was calculated (Cohen, 1969) for the intervention and control groups by dividing the difference between pre-and post-training period means by the standard deviation (pooled standard deviation). ES >0.8, 0.5 and 0.2 were considered as large, moderate and small, respectively.

Results

There was no significant difference between the HT, CON1 and CON2 groups in peak oxygen uptake or maximal power after the pre-test, i.e. before the training period.

Peak oxygen uptake increased by 7.8 and 10.7% in the HT and CON1 groups, respectively. The increase was significant ($p<0.03$). The CON2 group showed somewhat lower but not significantly different values at the post-test (-2.9 %) compared to the pre-test. Power output in the progressive pedalling power/strength test in the HT and CON1 groups increased by 6.0% and 4.3%, respectively. The increase was significant ($p<0.03$) for the HT group, but not for the CON1 group. The CON2 group showed somewhat lower values at the post-test (-1.5 %) but they were not significantly different from the pre-test (Figure 1).

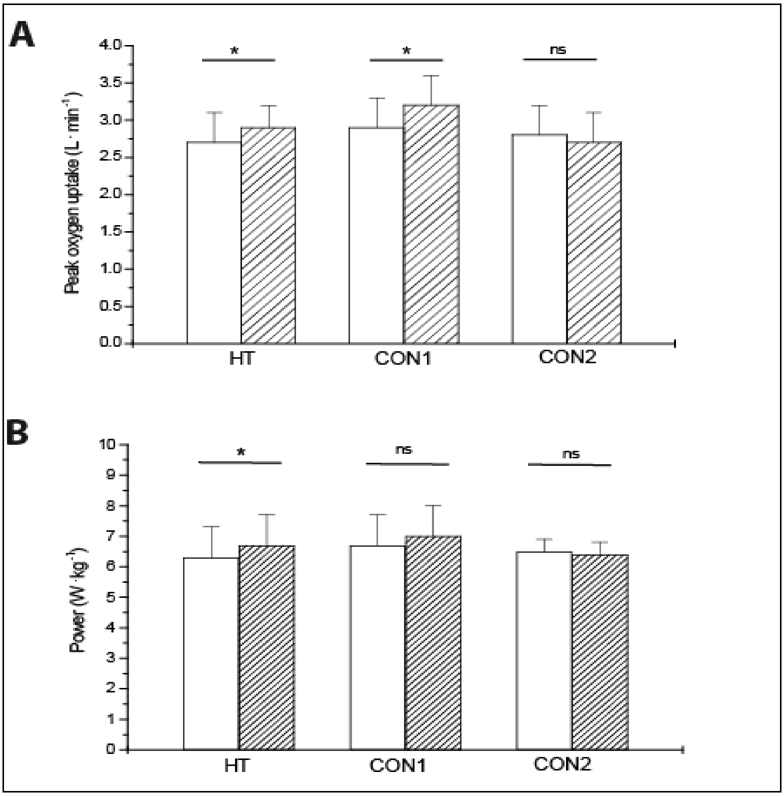

Figure 1. Mean (+sd) peak oxygen uptake (A) and power output in the progressive power/strength test (B) for the hybrid (HT) and control groups CON1 and CON2. White bars denote pre-test and hatched bars denote post training (post-test) values. * and ns denote significant ($P<0.03$) and non-significant differences, respectively.

The effect size for HT group concerning pre-and post-test peak oxygen uptake were 0.6. The effect size for the CON1 and CON2 was 0.8 and -0.3, respectively. The effect size for HT concerning power output in the progressive power pre and post-test was 0.4. The effect size for the CON1 and CON2 group was 0.3 and -0.3, respectively.

Discussion

The novelty in the present results is that muscle power and peak oxygen uptake can improve significantly in the same exercise and training session repeated three times per week for five weeks, which confirm the research hypothesis. Thus, hybrid training allows, at least, two capacities representing essentially two different energy systems to improve significantly as a result of training in the same training exercise in repeated training sessions at least in the present population.

Thus, we conclude that systems that stimulate the development of muscle power and oxygen uptake (aerobic power) can function in parallel over time, which is supported by previous results from concurrent training (e.g. Bell et al., 1991; Hickson, 1980; Hortobagyi et al.. 1991; Hunter et al., 1987; McCarthy et al., 2002; Sale et al., 1990; Shaw et al., 2009).

The populations (HT, CON1 and CON2) in this study consisted of habitually active females with a peak oxygen uptake at about $45mLO_2·kg^{-1}·min^{-1}$. This is a somewhat higher average peak oxygen uptake than the average woman of the same age has, which is about $40mLO_2·kg^{-1}·min^{-1}$ (Wilmore & Costill, 1994). However, the average maximal oxygen uptake among elite female athletes in endurance sports is about $60mLO_2·kg^{-1}·min^{-1}$ (Ibid.), which indicates that the present population more resembled the average woman than the elite endurance female athlete with respect to peak oxygen uptake. No comparison of power performance is available. While the present results show that hybrid training was performed successfully in the present population, it is reasonable to assume that relative training intensity level and training quantity must be specifically adjusted to the fitness level of the population. Future research is needed to further clarify these issues.

Stimuli for improving peak oxygen uptake and strength were obviously present in the hybrid training. The mean relative level of oxygen uptake during training was increased progressively from 70 – 75% during the training period, as controlled and verified by the experimenters. The activation of the leg extensor muscles during short but high-intensity work bouts (6s) in the hybrid training group was obviously high enough to stimulate improvement in muscle power. The control study on one participant showed that the mean EMG activation level of m. vastus lateralis during the high-intensity work bouts (6s) was 87% of that during 1RM squats. This relative activation level is higher than we found in the control study for the relative loads in squats of approximately 70% of 1RM required for strength development suggested by McDonagh & Davies (1984). This also supports the impression of high relative muscle activation and tension during high-intensity pedalling in the hybrid training group.

The hybrid training with repeated short work bouts of very high intensity may induce fatigue in the quadriceps muscles. Rooney and co-workers (1994) proposed that fatigue contributes as a strength-training stimulus. The ratio between high-intensity work bouts and intensity level with respect to periods of lower work intensity may be adjusted to further boost the development of strength. The results that show an increased expression in the key regulator of mitochondrial biogenesis PGC-1α (Wang et al., 2009; Psilander et al., 2010; Wang et al., 2011) support the results obtained in the present study. Thus, there can be stimulation factors for adaptation that are shared in the hybrid training concept. However, the optimal combination of intensity and duration in training prescription are still under debate and should be in focus for future research (Bishop et al., 2014).

It is thus obvious that the main issue during hybrid training is not how to maximize load to develop a single capacity but to find an exercise and training intensity level that simultaneously stimulates the development of two or more physical capacities i.e. to find intensity and activation levels that allow mutual simultaneous adaptation to training. The ultimate development of two very different capacities like oxygen uptake and power/strength will each contradict the other's function due to built-in morphological and physiological conflicts. One example of this is muscle mass versus mitochondrial density and oxygen diffusion (MacDougall et al., 1979; Wernblom et al., 2007). The objective of maximizing both strength through neural adaptation and hypertrophy and aerobic endurance in terms of maximum oxygen uptake will, at a certain point of large training volumes, inevitably lead to a conflict in training time and time for recovery. In addition, the attempt to maximize strength and endurance simultaneously may be questioned. This is because strength in association with hypertrophied muscles and endurance is not an optimal combination for performance – at least not in endurance sports where the body mass has to be carried by the athlete. This means that there are built-in limitations and conflicts in attempts to maximize these two different capacities for a given athlete during a given period. A critical question about hybrid training is why one should mix the training of two or more physical capacities in a hybrid training session with the risk of intensity reduction in the stimulation of a single capacity. There are at least three answers to this question. First, hybrid training allows the athlete to gain time. Parts of an endurance training session can be performed at such high intensity and muscular tension/activation that they also allow a strength or power gain. Secondly, an additional adjustment of work intensity and duration, causing a certain muscle fatigue, may further boost the strength gain (Rooney et al., 1994) without decreasing the quantity of endurance training. Thirdly, in numerous sports strength and endurance are used simultaneously during performance of a specific technique, which fits well with the hybrid training concept.

The single capacity conventional training can be combined with hybrid training in separate training sessions. This allows athletes during a training period to mix training sessions focusing on very high intensity levels for single capacities with sessions of hybrid training in which two or more capacities are trained simultaneously but at a somewhat lower average intensity level. In certain training periods, different combinations of training design can be used, emphasizing different types and periodization of training. In the present investigation a training period of only five weeks hybrid training was tested with significant results of improvement. This information can be used by the coach and athlete when designing training in certain sports where at least two physical capacities contribute simultaneously to the end result. Thus, the main focus in hybrid training is to find the right balance in training intensity level in the physical capacities being simultaneously trained, allowing them to reach a relative intensity level that stimulates an increase in development. This is a different view with respect to conventional training that tries to optimize every single capacity in separate sessions.

Conclusions

The results from the present investigation show that peak oxygen uptake and muscle power/strength can be trained successfully with hybrid training. Hybrid training is suitable in complex training forms specific to the target sports, and also allows e.g. maximal oxygen uptake and strength to be trained simultaneously with the sport-specific technique. The combined training of several physical capacities simultaneously allows a considerable gain in training time and thus time for recovery.

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Submitted: March 23, 2015
Accepted: June 12, 2015