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# A Review on effects of High intensity Training on performance and Physiological Fortitude on Athletes

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## ABSTRACT

Athletes are fortitude to use high-intensity training to prepare for competitions. They uses their entire stamina for their practice to show their better performances in various competitions. In this current review we would like to illustrate the probable effects lead by the high-intensity interval and resistance training on endurance performance and their related physiological measures of competitive endurance in athletes. A total number of 22 relevant training studies were taken in the present study. The training classification was based as per intervals (supramaximal, maximal, submaximal) and resistance (including explosive, plyometrics, and weights). All effects were converted on performance into percent changes by mean power and included physiological effects on measures that impact fortitude performance. The Endurance performance of the longest durations were enhanced mostly by the intervals of maximal and supramaximal intensities (~6%), but resistance training had smaller effects (~2%). Interval training achieved its effects through improvements of maximum oxygen consumption, anaerobic threshold and economy, whereas resistance training had benefits mainly on economy. Effects of some forms of high-intensity training on performance or physiology were unclear. All but one study was performed in non-competitive phases of the athletes' programs, when there was a little or no high-intensity training. Endurance performance of the shortest durations was enhanced most by supramaximal intervals (~4%) and explosive sport-specific resistance training (4-8%). The present study concludes that addition of explosive resistance and high-intensity interval training to a generally low-intensity training program will produce substantial gains in performance.

**Keywords**: aerobic, anaerobic threshold, economy, plyometrics, resistance, strength.

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# INTRODUCTION

Athletic training is practiced by athletic trainers, health care professionals who collaborate with physicians to optimize activity and participation of patients and clients. Athletic training encompasses the prevention, diagnosis, and intervention of emergency, acute and chronic medical conditions involving impairment, functional limitations and disabilities. Peak athletic performance has improved dramatically in the past 100 years, although the age at which peak performance is achieved in Olympic track and field (athletics), swimming, baseball, tennis and golf has remained constant over the period. Endurance in relation to athletic performance has been defined in various ways. In this article we have reviewed effects of high-intensity training not only on athletic endurance performance but also on underlying changes in the aerobic energy system. Endurance for our purposes therefore refers to sustained high-intensity events powered mainly by aerobic metabolism. Such events last ~30 s or more[1]. Although the physiological mechanisms regulating endurance performance are quite complex, the main factors limiting prolonged exercise have a straightforward interpretation. To continue exercise for extended durations, sustained muscle contraction must be maintained and is dependent on the continuous provision of both oxygen and fuel. Although each of the physiological factors limiting performance is modifiable through endurance training, it is important to recognize that genetic factors play a tremendous role in determining capacity and trainability. Therefore, when designing training programs to improve your clients' endurance exercise capacity, it is critical to recognize all the physiological components that contribute to—and limit—performance. Training for endurance athletes generally emphasizes participation in long-duration low- or moderate-intensity exercise during the base or preparation phase of the season, with the inclusion of shorter-duration high-intensity efforts as the competitive phase approaches. The effects of low- to moderate-intensity endurance training on aerobic fitness are well documented [2], but reviews of high-intensity training on endurance performance have focused only on describing the effects of resistance training [3], the effects of resistance training with runners[4], and the different types of interval training used by athletes [5] and studied by researchers [6]. Furthermore, previous reviews have included the effects of high-intensity training on untrained or recreationally active subjects, so findings may not be applicable to competitive athletes. The purpose of this review was therefore to describe the effects of high-intensity training on performance and relevant physiological characteristics of endurance athletes.

# MATERIALS AND METHOD

**Selection of Studies**

We identified most relevant publications through previous reviews and our own reference collections. We found 22 original-research peer-reviewed articles that identified competitive endurance athletes as the subjects in a study of effects of high-intensity training on performance or related physiology. We excluded studies of recreationally active subjects or of subjects whose characteristics were not consistent with those of competitive athletes[7-11]. We did not perform a systematic search of Sport Discus or Medline databases for theses or for non-English articles, and we did not include data from chapters in books.

# RESULT AND DISCUSSION

**Analysis of Training**

We assigned the training to two categories Resistance training: sets of explosive sport-specific movements against added resistance, usual or traditional weight training (slow repeated movements of weights), explosive weight training, or plyometrics and other explosive movements resisted only by body mass (Table 1).Interval training: single or repeated intervals of sport-specific exercise with no additional resistance (Table 2). Classification of some resistance-training studies was difficult, owing to the mix of exercises or lack of detail. In particular, all the studies we classified under explosive sport-specific resisted movements probably included some non-explosive resisted movements and some plyometrics. We classified the duration and intensity of intervals in Table 2 as follows: supramaximal (<2 min), maximal (2-10 min) and submaximal (>10 min), where "maximal" refers to the intensity corresponding to maximum oxygen consumption ($VO_2max$). The supramaximal intervals will have been performed at or near all-out effort; the maximal intervals will have started at less than maximum effort, but effort will have approached maximum by the end of each interval; the submaximal intervals can be considered as being close to anaerobic threshold pace (a pace that can be sustained for ~45 min), and effort will have risen to near maximum by the end of each interval. TA major concern with all but one of the studies we reviewed is that the high-intensity training interventions were performed in the non-competitive phases of the athletes' season, when there was otherwise little or no intense training. Authors who have monitored endurance athletes throughout a season have reported substantial improvements in performance and changes in related physiological measures as athletes progress from the base training to competitive phases [12-14]. Indeed, our own unpublished observations show that well-trained cyclists ordinarily make improvements in power output of ~8% in laboratory time trials as they progress from base through competitive phases of their season. The large improvement in performance as the competitive phase approaches occurs because athletes normally include higher intensity endurance training as part of a periodized program. It therefore seems unlikely that the large improvements reported in studies performed during a non-competitive phase would be of the same magnitude if the studies were performed in the competitive phase, when the athletes ordinarily include higher intensity training in their program. Indeed, in the only training study we could find performed during the competitive phase of a season, Toussaint and Vervoorn[15] found that 10 weeks of sport-specific resistance training improved race performance time in national level competitive swimmers by ~1%. Though such improvements appear small, they are important for elite swimmers [16], and the estimated change in power of ~3% is certainly greater than the ~0.5% that is considered important in other high-level sports [17].

**Table 1: Experimental and control training in studies of the effects of high-intensity resistance training on endurance performance in competitive athletes.**

| Study | Experimental training | Control training[a] |
|---|---|---|
| **Explosive sport-specific resisted movements** | | |
| Hoff et al. (1999) | Skiing-specific, 3x 6RM, 7%; general strength, 2%; endurance, 70%; total 8.5 $h.wk^{-1}$ | Endurance, 72%; general strength, 13%; total 9.2 $h.wk^{-1}$ in basic preparation phase |
| Hoff et al. (2002) | Skiing-specific, 3x 6RM, 7.5%, plus endurance; total 9.6 $h.wk^{-1}$ | Mainly endurance with strength endurance; total 10.1 $h.wk^{-1}$ in pre-season phase |
| Osteras et al. (2002) | Skiing-specific, 3x 6RM, 5% of total of 15 $h.wk^{-1}$ | Endurance + strength-endurance weights, total 15 $h.wk^{-1}$ in pre-competition phase |
| Paavolainen et al. (1991) | Skiing-specific, 34-42%; endurance, 66-58%; total 6-9 sessions $wk^{-1}$ in base preparation phase | Endurance running & roller skiing (83%) + strength-endurance weights (17%); total 6-9 sessions $wk^{-1}$ in base preparation phase |
| Paavolainen et al. (1999) | Running-specific, 32%; endurance and circuit, 68%; 2-3 $session.wk^{-1}$; total 9.2 $h.wk^{-1}$ | Endurance running and circuit, 97%; running-specific explosive strength, 3%; total 9.2 $h.wk^{-1}$ in post-competition phase |
| **Sport-specific resisted movements** | | |

| | | |
|---|---|---|
| Toussaint and Vervoorn (1990) | Swimming sprints against resistance for 30 min, 3 $wk^{-1}$ for 10 wk in competition phase, plus usual (?) swim training | Same as experimental group but without additional resistance during sprint training |
| **Explosive non-sport-specific weight training** | | |
| Bastiaans et al. (2001) | 4x sets of 30 reps each of squats, leg presses, single-leg step ups for 3.3 $h.wk^{-1}$, plus 5.5 $h.wk^{-1}$ of control endurance cycling | 8.9 $h.wk^{-1}$ endurance cycling in pre-competition phase |
| **Plyometrics** | | |
| Spurrs et al. (2003) | 2x 10 reps of 3-4 jumps, bounding and hops, plus 60-80 km. $wk^{-1}$ endurance running | 60-80 km. $wk^{-1}$ endurance running; training phase not stated |
| Turner et al. (2003) | 6 sets of jumps, 3 $wk^{-1}$ for 6 wk, plus usual low-intensity endurance running | Minimum 3 sessions and 16 $km.wk^{-1}$ running; unspecified intensity and training phase |
| **Usual weight training** | | |
| Bishop et al. (1999) | 3-5 sets of 2-8RM squats, plus usual endurance cycling | Endurance cycling in off-season, unspecified weekly duration |
| Johnston et al. (1997) | 2-3 sets of 6-20RM, plus 32-48 $km.wk^{-1}$ endurance running | 32-48 $km.wk^{-1}$ endurance running in pre-competition phase |
| Millet et al. (2002) | 3-5 sets of 3-5RM of 6 lower-limb exercises, 2 $wk^{-1}$ for 14 wk, plus control endurance training | 20 $h.wk^{-1}$ endurance running, cycling, swimming at <70 $\%VO_2max$ in winter non-competition phase |
| RM, repetitions maximum. [a]"Endurance training" is presumably long sessions below submaximal intensity (below anaerobic threshold). | | |

**Analysis of Performance**

Measures of performance in real or staged competitions are best for evaluating the effects of training interventions on competitive athletes [15, 17] were the only researchers to use competitive performance in a study of high-intensity training. The others have opted instead for laboratory-based ergometer tests or solo field tests, which may not reproduce the motivating effect of competition. Reviews summarizes the effects from sport-specific time trials and constant-power tests, sorted into the same three intensity/duration categories as the interval training and the effects on maximum power in incremental tests. To permit comparison of effects, we have converted outcomes in the various performance tests into percent changes in mean or maximum power, using the methods of [18].

**Analysis of Physiological effects**

The remaining tables show the effects of high-intensity training on physiological measures related to endurance performance: maximum oxygen consumption ($VO_2$max), anaerobic threshold, exercise economy and body mass. Most endurance events are performed at a nearly constant pace, and for those performed at an intensity below $VO_2$max mean performance power or speed is the product of $VO_2$max, the fraction of $VO_2$max sustained, and aerobic energy economy [19]. Provided they can be measured with sufficient precision, percent changes in each of these components are therefore worth documenting, because they translate directly into percent changes in endurance power. Of course, training is likely to change more than one of these components, so researchers serious about identifying the mechanism of a change in performance should assess all three. Most authors of the studies we reviewed measured $VO_2$max, usually in an incremental test. Some also measured economy (work done per liter of oxygen consumed) from $VO_2$ measurement either in middle stages of the incremental test or at a fixed work rate in a separate test. Where necessary, we re-expressed percent changes in $VO_2$max and economy for $VO_2$ measured in units of $L.min^{-1}$, to avoid difficulties in interpretation arising from changes in mass when $VO_2$ is expressed as $ml.min^{-1}.kg^{-1}$. No authors measured the fraction of $VO_2$max sustained in the endurance test itself (requiring measurement of $VO_2$ throughout the test), but some measured the anaerobic threshold, usually from an analysis of blood lactate concentration during an incremental test. Depending in its method of measurement, the anaerobic threshold occurs at ~85% of $VO_2$max, an intensity that an athlete can sustain for ~30-60 min. One can therefore assume that percent changes in the anaerobic threshold will translate directly into percent changes in fractional utilization of $VO_2$max in a sub-$VO_2$maximal event. Authors in two studies provided the anaerobic threshold as a power rather than a percent of $VO_2$max; in this form the measure is effectively already a net measure of submaximal endurance performance, with contributions from $VO_2$max, fractional utilization of $VO_2$max, and economy. We therefore included these measures in the subgroup of submaximal tests. The relevance of changes in anaerobic threshold to changes in endurance performance at maximal and supramaximal intensities is unclear, but for such events (lasting up to ~10 min) anaerobic capacity makes a substantial contribution to performance. None of the studies we reviewed included critical-power or other modeling of performance to estimate the contribution of changes in anaerobic capacity resulting from high-intensity training. However, a practical and much more reliable measure of anaerobic capacity is performance in sprints lasting ~30 s, which we have included as supramaximal tests. Body mass is an important determinant of performance in running and presumably in most other high-intensity endurance sports, depending amongst other things on the distribution of the change in mass between the active limbs and the rest of the body, the power required to continually accelerate and decelerate the limbs, and the power required to move the rest of the body against gravity with each cycle of limb movement and over any undulating terrain or hills. The relationship between changes in body mass and performance is therefore difficult to predict, but it has not been studied empirically for any sport. We have nevertheless included in the percent changes in body mass from those studies where mass was reported before and after resistance training, because this form of training could increase body mass substantially by increasing muscle mass. None of the studies of interval training provided enough data to estimate changes in body mass, presumably because there were either no substantial changes or the authors did not consider changes in body mass to be an issue with this kind of training.

**Table 2: Experimental and control training in studies of the effects of high-intensity interval training on endurance performance in competitive athletes**

| Study | Experimental training | Prior and/or control training[a] |
|---|---|---|
| **Submaximal intervals** | | |
| Sjodin et al. (1982) | Running at anaerobic threshold, 1x 20 min, 1 session.wk$^{-1}$ for 14 wk, plus usual training | No control; usual winter training, ~6.5 h.wk$^{-1}$ |
| **Maximal intervals** | | |
| Acevedo and Goldfarb (1989) | Running, ?x ? min, 1 session.wk$^{-1}$, plus Fartlek (presumably mainly max) sessions (8-19 km, 2 session.wk$^{-1}$ for 8 wk | No control; endurance training runs (8-19km) for 3-4 session.wk$^{-1}$ |
| Billat et al. (1999)[b] | Running, 5x 3 min, 1 session.wk$^{-1}$, plus 2x 20 min (submax), 1 session.wk$^{-1}$ replacing usual training | No control; low-intensity base phase training, unspecified weekly duration |
| Laursen et al. (2002)[b] | Cycling, 8x 2.4 min with 4.8-min recoveries, 2 session.wk$^{-1}$, plus usual training? | ~10 h.wk$^{-1}$ of endurance training in off and pre-competition phases |
| | Cycling, 8x 2.4 min with 2- to 3-min recoveries, 2 session.wk$^{-1}$, plus usual training? | |
| Lindsay et al. (1996) | Cycling, 6-8x 5 min with 1 min recoveries, 1-2 session.wk$^{-1}$ replacing ~15% of usual training | No control; usual base-phase endurance training, ~300km.wk$^{-1}$ |
| Smith et al. (1999) | Running, 5-6x 2-3 min, 2 session.wk$^{-1}$ for 4 wk plus 1x 30 min.wk$^{-1}$ at 60% of $VO_2$max | No control; prior training unclear |
| Stepto et al. (1999)[c] | Cycling, 4x 8 min, 8x 4 min, or 12x 2 min with 1- to 3-min recoveries, 2 session.wk$^{-1}$, | No control; usual endurance training, unspecified training |

| | | |
|---|---|---|
| | plus usual training | phase, 230 km.wk$^{-1}$ |
| Westgarth-Taylor et al. (1997) | Cycling, 6-9x 5 min with 1 min recoveries, 2 session.wk$^{-1}$ replacing 15% of usual training | No control; usual base-phase endurance training, unspecified weekly duration |
| Weston et al. (1997) | Cycling, 6-8x 5 min with 1 min recoveries, 1-2 session.wk$^{-1}$ replacing 5% of usual training | No control; usual base-phase endurance training, ~290 km.wk$^{-1}$ |
| **Supramaximal intervals** | | |
| Creer et al. (2004) | Cycling, 4-10x 30-s, 2 session.wk$^{-1}$ for 4 wk plus 5 h.wk$^{-1}$ endurance training | 8 h.wk$^{-1}$ endurance training |
| Laursen et al. (2002)[a] | Cycling, 12-19x 1 min, 2 session.wk$^{1}$ plus 8 h.wk$^{-1}$ base training | Low intensity in base phase, ~10 h.wk$^{-1}$ |
| Laursen et al. (2002)[b] | Cycling, 12x 30 s with 4.5-min recoveries, 2 session.wk$^{-1}$ plus usual training? | ~10 h.wk$^{-1}$ of endurance training in off and pre-competition phases |
| Stepto et al. (1999)[b] | Cycling, 12x 30 s with 4.5-min recoveries or 12x 1 min with 4-min recoveries, 2 session.wk$^{-1}$ plus usual training | No control; usual endurance training, unspecified training phase, 230 km.wk$^{-1}$ |

[a]"Endurance" training is presumably long sessions below submaximal intensity (below anaerobic threshold).
[b]Shown in Appendices 2-4 as submax and max intervals.
[c]The five training groups in this study were merged into two groups for this review.

**Table 3: Summary of effects of high-intensity interval and resistance training on performance and physiology of endurance athletes in a non-competitive (low intensity) phase of training.**

| | Interval training | | | Resistance training[a] | | | |
|---|---|---|---|---|---|---|---|
| | **Sub-maximal** | **Maximal** | **Supra-maximal** | **Explosive sport-specific** | **Explosive non-sport specific** | **Plyo-metrics** | **Usual weights** |
| **Performance power** | | | | | | | |
| Submaximal-endurance | | +++ | +++ | + | + | | +/– |
| Maximal endurance | | + | | ++ | | + | |
| Supramaximal-endurance | | 0 | ++ | ++ | ++++ | | |
| Maximum incremental | | +++ | ++ | ++ | + | | 0 |
| **Physiology** | | | | | | | |
| Maximum oxygen uptake | + | ++ | + | +/– | | – | – |
| Anaerobic threshold | + | +++ | | ++/– | | | 0 |
| Economy | + | +++ | | ++++ | ++ | +++ | + |
| Body mass | | | | + | + | 0 | + |

**Key to effects:** ++++, 8% or more; +++, 6% (5 to 7%); ++, 4% (3 to 5%); +, 2% (1 to 3%); 0, 0% (-1 to 1%); –, -2% (-1 to -3%).

[a]The study by Toussaint and Vervoorn (1990) of effects of non-explosive resisted movements on swimmers in the competitive phase of training is not included in this summary.

Our interpretation of the appendices was cautious and tentative, because the various kinds of performance and physiological tests are disproportionately represented by the different kinds of training. For example, there has been only one study of purely submaximal interval training, and it did not include a measure of performance power or maximal power in an incremental test [20]. Further, a submaximal performance test was generally included in studies of interval training but not in studies of resistance training, whereas tests of economy are more likely to have been included in studies of resistance training. The reasons for such bias in the use or reporting of tests are unclear. Authors might have been more likely to include a test or measure that had already been shown to produce a big change. Also, some authors may have chosen not to report non-significant effects, or they may have been instructed to remove them from the manuscript by a misguided reviewer or editor. A formal quantitative meta-analysis can partially improve the interpretation when there are such biases, but we decided against a meta-analysis when we discovered that all but one of the published studies were performed with athletes in the base phase of training. A meta-analysis would not address the real issue for athletes: how does each kind of high-intensity training contribute to performance against a background of other high-intensity training? This review can provide only suggestive evidence.

**Endurance Performance**

A study by Westgarth shows that maximal and supramaximal intervals produced equally impressive gains (3.0-8.3%) on performance at submaximal intensities. The magnitude of the largest improvement [21] is likely to be due to either sampling variation or a computational error, because it is not consistent with the smaller gains (4.6 and 8.3%) in two similar studies by the same group [22, 23]. Explosive resistance training was less effective (0.3 and 1.0%) over the same time frame as the interval training studies (~4 wk), and even after 9 wk the gains were still not as great (2.9 and 4.0%) as with interval training. In the only study of the effect of usual weight training on submaximal endurance, there were opposing effects on anaerobic threshold power (2.6%) and time-trial power (-1.8%) in the same subjects after 12 wk. The authors suggested that the non-specific movement and speed of the weight training accounted for its failure to enhance time-trial performance [24]. Explosive sport-specific movements produced the greatest gains in maximal endurance tests (1.9-5.2%) after 8-9 wk. Maximum intervals were less effective (2.8%), although the duration of training was only 4 wk. Plyometric jumps were less beneficial (1.2%). Not surprisingly, the highest-intensity training produced the greatest enhancements in the supramaximal tests. The very large gain with explosive weights (11%) was more than twice that with supramaximal intervals and explosive sport-specific resistance (3.0-4.6%). Maximal intervals had little effect (0.4%). There was only one study of the effects of submaximal intervals[20], and it did not include measures of performance power. The effects on $VO_2$max, anaerobic threshold, and economy in that study, if they were additive, would be consistent with ~6% enhancement of submaximal endurance and possibly 2-4% on supramaximal and maximal endurance respectively.

**Maximum Incremental Power**

Maximum-intensity intervals appear to be the most effective form of high-intensity training for improving maximum incremental power (by 2.5-7.0%). Gains appear to be smaller with explosive sport-specific resistance training (2.3% and 6.0%) and supramaximal intervals (1.0-4.7%), and possibly smaller still with explosive weights (2.0%). Remarkably, a gain of 4.7% was achieved in only four sessions of supramaximal intervals [25]. These improvements will transfer to time-trial performance to some extent, because maximum power achieved in an incremental test correlates well with time-trial performance [27-29]. Exactly how they will transfer might depend on the duration of the time trial. Most of an incremental test is performed at submaximal intensities, but the last minute or two is maximal and supramaximal. Performance in the test will therefore be determined by a mix of $VO_2$max, anaerobic threshold, economy, and anaerobic capacity. If the mix does not reproduce that of the time trial, enhancements of one or more components of the mix will produce changes in maximum incremental power that differ from those in time-trial performance.

**Maximum Oxygen Consumption**

It is evident from that the largest improvements in $VO_2$max occurred with maximal-intensity interval training (gains of 2.3-7.1%). Supramaximal intervals were probably less effective (impairment of 0.6% in one study, enhancements of 2.2% and 3.5% in two others). The changes can occur rapidly:[26] recorded an increase of 3.5% after a total of only four supramaximal sessions in two weeks. Explosive weight training can produce smaller gains (up to 2.0%), but the various forms of resistance training had a predominantly negative effect on $VO_2$max. Improvements in other physiological measures can offset this effect and result in net improvements in endurance performance following resistance training.

**Anaerobic Threshold**

One cannot draw a firm conclusion about the effect of explosive resistance training on the anaerobic threshold in, given that there were major enhancements in three studies (5.0-7.1%) and substantial impairments in two others (2.0 and 2.1%). In the only study of presumably maximal intervals, the gain was ~5.0%, whereas the gain was less (1.5%) in the only study of submaximal intervals.

**Economy**

Although the claim of 39% increase in economy from explosive sport-specific resistance training in is almost certainly erroneous, it is clear from the other studies in the table that explosive resistance training in general produced spectacular beneficial effects (3.5-18%) on this endurance parameter. Plyometrics may be only a little less effective (3.1-8.6%). The effects of interval training were least for submaximal (2.8%) and greater for a mixture of submaximal and maximal (6.5%).

**Body Mass**

It is reasonably clear from that explosive resistance training increased body mass by ~1%, presumably via an increase in muscle mass. Any direct harmful effects of this increase in mass on performance were inconsequential, given the large enhancements that this form of training produced in power output of all durations. Usual weight training may produce increases in body mass that are greater (2.8% in one study) and therefore more likely to impair performance in some sports.

## CONCLUSION

On the basis of the existing research one can tentatively recommend adding or increasing explosive resistance training for an athlete with a poor economy and/or poor anaerobic capacity, and adding or increasing maximal intervals for an athlete with a poor $VO_2$max. We need more research aimed at filling voids in the matrix of different kinds of training vs effects on performance and physiological effects of non-specific resistance training (especially plyometrics and usual weights) on performance and the effects of supramaximal intervals on anaerobic threshold and economy need more research.

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