Effectiveness of High-Intensity Interval Training (HIT) and Continuous Endurance Training for VO_{2max} improvements: A Systematic review and Meta-Analysis of controlled trials

Heading title: HIT vs Endurance training

Authors: Zoran Milanović[1], Goran Sporiš[2] and Matthew Weston[3]

[1] Faculty of Sport and Physical Education, University of Nis, Nis, Serbia

[2] Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia

[3] Department of Sport and Exercise Sciences, School of Social Sciences, Business and Law, Teesside University, Middlesbrough, UK

Corresponding Author:

Zoran Milanović, PhD

University of Niš, Faculty of Sport and Physical Education

Čarnojevićeva 10a

18000 Niš

tel: 00381 63 7 399 366

e-mail: zoooro_85@yahoo.com

Key points

- When compared to no exercise, endurance training and high-intensity interval training elicit large improvements in maximal oxygen uptake.
- Endurance training and high-intensity interval training elicit additional benefit for individuals with lower pre-training fitness.
- In healthy, young to middle-aged adults, high-intensity interval training improves maximal oxygen uptake to a greater extent than traditional endurance training.

Abstract

Background Enhancing cardiovascular fitness can lead to substantial health benefits. High-intensity interval training (HIT) is an efficient way to develop cardiovascular fitness, yet comparisons between this type of training with traditional endurance training are equivocal.

Objective Our objective was to meta-analyse the effects of endurance training and HIT on the maximal oxygen consumption (VO_{2max}) of healthy, young to middle-aged adults.

Methods Six electronic databases were searched (MEDLINE, PubMed, SPORTDiscus, Web of Science, CINAHL and Google Scholar) for original research articles. A search was conducted and search terms included 'high intensity', 'HIT', 'sprint interval training', 'endurance training', 'peak oxygen uptake', 'VO_{2max}'. Inclusion criteria were controlled trials, healthy adults aged 18-45 y, training duration ≥2 weeks, VO_{2max} assessed pre- and post-training. Twenty-eight studies met the inclusion criteria and were included in the meta-analysis. This resulted in 723 participants with a mean ± SD age and initial fitness of 25.1 ± 5 y and 40.8 ± 7.9 mL•kg^{-1}•min^{-1}, respectively. We made probabilistic magnitude-based inferences for meta-analysed effects based on standardized thresholds for small, moderate and large changes (0.2, 0.6 and 1.2, respectively) derived from between-subject standard deviations (SDs) for baseline VO_{2max}.

Results The meta-analysed effect of endurance training on VO_{2max} was a possibly large beneficial effect (4.9 mL•kg^{-1}•min^{-1}; 95% confidence limits ±1.4 mL•kg^{-1}•min^{-1}), when compared with no exercise controls. A possibly moderate additional increase was observed for typically younger subjects (2.4 mL•kg^{-1}•min^{-1}; ±2.1 mL•kg^{-1}•min^{-1}) and interventions of longer duration (2.2 mL•kg^{-1}•min^{-1}; ±3.0 mL•kg^{-1}•min^{-1}), and a small additional improvement for subjects with lower baseline fitness (1.4 mL•kg^{-1}•min^{-1}; ±2.0 mL•kg^{-1}•min^{-1}). When compared to no exercise controls, there was likely large beneficial effect of HIT (5.5 mL•kg^{-1}•min^{-1}; ±1.2 mL•kg^{-1}•min^{-1}), with a likely moderate greater additional increase for subjects with lower baseline fitness (3.2 mL•kg^{-1}•min^{-1}; ±1.9 mL•kg^{-1}•min^{-1}) and interventions of longer duration (3.0 mL•kg^{-1}•min^{-1}; ±1.9 mL•kg^{-1}•min^{-1}), and a small lesser effect for typically longer HIT repetitions (-1.8 mL•kg^{-1}•min^{-1}; ±2.7 mL•kg^{-1}•min^{-1}). The modifying effects of age (0.8 mL•kg^{-1}•min^{-1}; ±2.1 mL•kg^{-1}•min^{-1}) and work:rest ratio (0.5 mL•kg^{-1}•min^{-1}; ±1.6 mL•kg^{-1}•min^{-1}) were unclear. When compared to endurance training, there was a possibly small beneficial effect for HIT (1.2 mL•kg^{-1}•min^{-1}; ±0.9 mL•kg^{-1}•min^{-1}) with small additional improvements for typically longer HIT repetitions (2.2 mL•kg^{-1}•min^{-1}; ±2.1 mL•kg^{-1}•min^{-1}), older subjects (1.8 mL•kg^{-1}•min^{-1}; ±1.7 mL•kg^{-1}•min^{-1}), interventions of longer duration (1.7 mL•kg^{-1}•min^{-1}; ±1.7 mL•kg^{-1}•min^{-1}), greater work:rest ratio (1.6 mL•kg^{-1}•min^{-1}; ±1.5 mL•kg^{-1}•min^{-1}) and lower baseline fitness (0.8 mL•kg^{-1}•min^{-1}; ±1.3 mL•kg^{-1}•min^{-1}).

Conclusion Endurance training and HIT both elicit large improvements in the VO$_{2max}$ of healthy, young to middle-aged adults with the gains in VO$_{2max}$ being greater following HIT, when compared to endurance training.

1 Introduction

Improving or maintaining cardiovascular fitness can reduce the risk of all-cause and cardiovascular diseases [1]. Indeed, when compared to other well-established risk factors such as hypertension, diabetes, smoking and obesity, cardiovascular fitness is a more powerful predictor of mortality [2, 3]. Fitness training programmes aimed at the improvement of cardiovascular fitness therefore have broad appeal to the general population.

The fitness industry has recently seen a surge of interest in high-intensity interval training (HIT) - a burst-and-recover cycle that is suggested to be a viable alternative to the traditional approach to enhancing aerobic fitness, namely continuous endurance training [4]. However, specifying an optimal training regime for improving fitness in the general community requires knowledge of how these different types of training influence adaptations in physiological parameters [5]. Consequently, there has been a substantial amount of research examining which modality of training, endurance or HIT, is superior for aerobic fitness improvements.

Endurance training and HIT both increase aerobic fitness [6] and thus relate to benefits in cardiovascular risk factors, fitness and all-cause mortality [7]. Some studies, however, have suggested that HIT leads to improvements in both aerobic and anaerobic fitness [8] and improves endurance performance to a greater extent than endurance training alone [9]. For example, Daussin et al. [10] found that maximal oxygen uptake (VO_{2max}) increases were higher for untrained men and women who participated in an 8-week HIT program (15%) than they were for untrained participants undertaking an endurance training programme (9%). High-intensity interval training has also been reported to be more effective than continuous, steady-state exercise training for inducing fat loss in men and women, despite requiring considerably less total energy expenditure during training [11, 12]. Recent studies have demonstrated that the cardiovascular adaptations occurring following HIT are similar, and in some cases superior, to those following endurance training [5, 13] and further beneficial effects of HIT were provided by the Nord-Trøndelag Health Study [13], which indicated that just a single weekly bout of HIT reduced the risk of cardiovascular disease in both men and women (relative risk: 0.61 and 0.49, respectively).

It is therefore not surprising that recent meta-analyses [14-17] have confirmed HIT to be an appropriate training stimulus to improve cardiorespiratory fitness and reduce metabolic risk factors in patient populations. Using similar inclusion criteria to the afore-mentioned reviews, Bacon et al. [18] meta-analysed the effect of HIT on VO_{2max} but only calculated an overall effect size, irrespective of the type of control group (no exercise or endurance training). Consequently, we cannot conclude that HIT is better than endurance training because the effect of HIT is, naturally, much higher in comparison with no exercise control groups than the effect when compared with endurance training controls. A separate analysis (HIT vs endurance training; HIT vs no exercise) is therefore necessary to determine more precise effects of HIT. Gist et al. [19] reported a moderate effect (0.69) of sprint interval training (SIT) - classified as form of HIT at the highest end of the intensity spectrum [20] - on VO_{2max} in comparison with no exercise control groups; yet a trivial effect (0.04) when compared with endurance training controls. However, this meta-analysis [19], as well as the recent meta-analyses performed by Weston et al. [21] and Sloth et al. [20], only addressed the effect of SIT on VO_{2max}. In doing so, these reviews excluded HIT research utilizing longer interval durations and shorter recovery periods. While there have been meta-analyses on longer duration HIT repetitions in patient populations [14-17], to the best of the authors' knowledge there is no systematic review and meta-analysis examining the effect of longer duration HIT repetitions in comparison to either endurance training or no exercise controls. Therefore, our aim was to meta-analyse the effects on VO_{2max} of endurance training and HIT in healthy, young to middle-aged adults, when compared to no exercise controls and also when the two types of training were compared to one another. A further aim was to examine the modifying effects of study and subject characteristics.

2 Methods

2.1 Search strategy

Electronic database searches were performed using MEDLINE, PubMed, SPORTDiscus, Web of Science, CINAHL and Google Scholar using all available records up to 28 February 2014.The search terms covered the areas of high-intensity interval training, continuous endurance training and maximal oxygen uptake (VO_{2max}) using a combinations of the following key words: high-intensity interval training, high-intensity intermittent training, sprint interval training, endurance training, continuous endurance training, aerobic exercises, maximal oxygen uptake, peak oxygen uptake, cardiorespiratory fitness,VO_{2max}, young adults. The literature search, quality assessment and data extraction were conducted independently by two authors (ZM and GS). Papers that were clearly not relevant were removed from the database list before assessing all other titles and abstracts using our pre-determined inclusion and exclusion criteria. Inter-reviewer disagreements were resolved by consensus opinion or arbitration by a third reviewer. Full papers, including reviews, were then collected and when not available the corresponding author was contacted by mail. Reference lists of the selected manuscripts were also examined for any other potentially eligible papers. This systematic review and meta-analysis was undertaken in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [22].

2.2 Inclusion criteria

2.2.1 Type of study

Our meta-analysis included randomised and non-randomised controlled trials, written in English. Uncontrolled and cross-sectional studies were excluded from analysis and only studies published in the last 20 years (after 1995) were included in our review.

2.2.2 Type of participants

The type of participants included in our meta-analysis were healthy, untrained, sedentary, recreational and non-athletic men and women aged between 18 and 45 y, who were not suffering from any kind of acute or chronic diseases. No exclusion criteria were applied to participant baseline fitness; however, studies with overweight and obese participants were excluded from our review due confusion on the proper expression of VO_{2max} data when comparing obese and normal weight individuals.

2.2.3 Type of interventions

To be included in our meta-analysis, training programmes had to last at least a minimum of 2 weeks, with participants allocated to either endurance training, HIT or a no exercise control group. Endurance training intensity was classified as moderate-intensity (60-85% HR_{max}), with HIT intensity classified as either "all-out", "supramaximal", "maximal" or "high (90-95% HR_{max})". Studies involving nutritional interventions were only included if the intervention was used by all participants, and studies were excluded if training was combined with strength training.

2.2.4 Type of outcome measure

The outcome measure for this meta-analysis was maximal oxygen uptake (VO_{2max}).

2.3 Final study selection

Following database examination, 804 potential manuscripts were identified with another 17 selected on the basis of the reference lists of the potential manuscripts (Figure 1). After removal of duplicates and elimination of papers based on title and abstract screening, 84 studies remained. The full texts of the remaining papers were examined in more detail. According to our eligibility criteria, 56 did not meet the inclusion criteria leaving 28 studies that met our inclusion criteria and were therefore included in the meta-analysis (Table 1).

2.4 Data extraction

Cochrane Consumers and Communication Review Group's data extraction protocol was used to extract participant information including age, health status and sex, sample size, description of the intervention (including type of exercises, intensity, duration and frequency), study design and study outcomes. This was undertaken by one author (ZM) while GS checked the extracted data for accuracy and completeness. Disagreements were resolved by consensus or by a third reviewer. Reviewers were not blinded to authors, institutions or manuscript journals. In those studies where the data were shown in figures or graphs, either the corresponding author was contacted to get the numerical data to enable analysis or graph digitizer software was used to extract the necessary data (DigitiZelt, Germany).

2.5 Assessment of Bias

Risk of bias was evaluated according to the PRISMA recommendation [23] and two independent reviewers assessed the risk of bias. Agreement between the two reviewers was assessed using k statistics for full-text screening, and rating of relevance and risk of bias. When there was disagreement about the risk of bias a third reviewer checked the data and took the final decision on it. The k agreement rate between reviewers was k=0.95.

2.6 Statistical analysis

A random effects meta-analysis was conducted to determine the pooled effect size of HIT and endurance training on VO_{2max}, using comprehensive meta-analysis software, version 2 for Windows (Biostat company, Englewood, NJ, USA). We performed separate analyses to determine the pooled effect of the change in VO_{2max} for endurance training vs no exercise, HIT vs no exercise, and HIT vs endurance training. The precision of the pooled effect was reported as 95% confidence limits (CL) and also as probabilities that the true value of the effect was trivial, beneficial or harmful in relation to threshold values for benefit and harm. These probabilities were then used to make a qualitative probabilistic inference about the overall effect [24]. Given that enhanced aerobic functioning has clear clinical applications [21], our meta-analysed effects were assessed via clinical inferences. Here, the effects were considered unclear if the chance of benefit (improved VO_{2max}) was high enough to warrant use of the intervention but with an unacceptable risk of harm (reduced VO_{2max}). An odds ratio of benefit to harm of <66 was used to identify such unclear effects. Inferences were then subsequently based on standardised thresholds for small, moderate and large changes of 0.2, 0.6 and 1.2 standard deviations, respectively [24] and derived by averaging appropriate between-subject variances for baseline VO_{2max}. Magnitude thresholds were 0.8, 2.4 and 4.7 $mL•kg^{-1}•min^{-1}$ (endurance vs no exercise), 0.8, 2.3 and 4.7 $mL•kg^{-1}•min^{-1}$(HIT vs no exercise) and 0.9, 2.6 and 5.3 $mL•kg^{-1}•min^{-1}$ (HIT vs endurance training). The chance of the true effect being trivial, beneficial or harmful was then interpreted using the following scale: 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely [24]. Random variation in the effect from study-to-study was expressed as an SD, with the SD doubled to interpret its magnitude [25]. Publication bias was assessed by examining asymmetry of funnel plots using Egger's test, and a significant publication bias was considered if the P<0.10.

2.7 Meta-regression analysis

Meta-regression analyses were conducted to explore the effect of putative moderator variables on the pooled effect. Here, we selected five moderator variables that could reasonably influence the overall effect of training on VO_{2max} and these were age, baseline fitness, intervention duration, work:rest ratio and HIT repetition duration. The modifying effects of these five variables were calculated as the effect of two SDs (i.e. the difference between a typically low and a typically high value) [24].

Table 1 about here

3 Results

The Egger's test was performed to provide statistical evidence of funnel plot asymmetry (Figure 5) and the results indicated publication bias for all analyses ($P < 0.10$).

3.1 Endurance training vs no exercise controls

The meta-analysed effect of endurance training, when compared to controls, was a possibly large beneficial effect on VO_{2max} (4.9 $mL•kg^{-1}•min^{-1}$; 95% confidence limits ±1.4 $mL•kg^{-1}•min^{-1}$) (Figure 2, Table 2). Meta-regression analysis revealed a greater beneficial effect (possibly moderate) for typically younger vs older subjects and interventions of longer duration, and a greater beneficial improvement (possibly small) for subjects with typically lower baseline fitness. The random variation in the overall pooled effect from study to study, expressed as an SD, was 1.3 $mL•kg^{-1}•min^{-1}$.

3.2 HIT vs no exercise controls

The meta-analysed effect of HIT, when compared to controls, was a likely large beneficial effect on VO_{2max} (5.5 $mL•kg^{-1}•min^{-1}$; ±1.2 $mL•kg^{-1}•min^{-1}$) (Figure 3, Table 3). Meta-regression analysis revealed a likely moderate greater beneficial improvement in VO_{2max} for subjects with typically lower baseline fitness and interventions of longer duration and a likely small lesser effect for longer HIT repetitions. The effects of all other putative modifiers were unclear. Random variation in the effect from study to study was 1.3 $mL•kg^{-1}•min^{-1}$.

3.3HIT vs endurance training

When compared to endurance training, there was a possibly small beneficial effect of HIT on VO_{2max} (1.2 mL•kg^{-1}•min^{-1}; ±0.9 mL•kg^{-1}•min^{-1}) (Figure 4, Table 4). The modifying effects of typically longer HIT repetitions, older and less fit subjects, longer interventions and a greater work:rest ratio were possibly to likely small increased beneficial improvements in VO_{2max}. Random variation in the effect from study to study was 0.8 mL•kg^{-1}•min^{-1}.

4 Discussion

This study presents a quantitative evaluation of HIT and endurance training models for VO_{2max} improvements in healthy adults aged 18 to 45 y. Our results show that when compared to no exercise controls, both types of training elicit large improvements in VO_{2max}. In studies where HIT and endurance were directly compared, there was a small beneficial effect for HIT.

The results of our systematic review and meta-analysis confirm the conclusions of previous studies [11, 27-30, 36, 37, 51] that continuous aerobic endurance training is an effective method for VO_{2max} improvement in young adults. The training effect was greater for less fit adults, which is consistent with previous work demonstrating that aerobic training has an adaptive effect that favours the less fit [21]. Further to this, the beneficial effect of continuous endurance training on VO_{2max} is greater for younger subjects and with interventions of longer duration. Most of the studies in this particular analysis undertook three moderate-intensity sessions per week lasting 40 to 60 minutes, yet the American College of Sports Medicine (ACSM) recommends to undertake moderate-intensity continuous exercises for a minimum 30-min on five days each week or 20-min of vigorous-intensity exercises three days each week, or a combination of the two [52]. As such, it is clear from the findings of this review that substantial gains in aerobic fitness can be obtained with a moderate-intensity training session frequency lower than that currently recommend [2].

When compared to no exercise controls, HIT elicits a likely large substantial improvement in the VO_{2max} of healthy adults. This size of this effect was greater than that reported by Gist et al. [19] who reported a moderate effect (effect size 0.69) for low-volume HIT when compared to no exercise controls, with differences in the overall dose of exercise possibly accounting for these inconsistent results. Irrespective of dose, HIT has a clear beneficial effect on the aerobic fitness of healthy young adults when compared to no exercise. This effect is moderated by initial fitness as the training benefits individuals with lower initial fitness – a finding consistent with low-volume HIT programmes [21]. With regard to HIT programming, a moderating beneficial effect for longer intervention duration is consistent with the subgroup analysis performed by Bacon et al. [18]. Here, the authors reported that the largest increases in VO_{2max} were following longer intervention durations (p=0.004). Additionally, we found an unclear effect on VO_{2max} with an increased work:ratio (e.g. greater recovery in-between HIT repetitions), a finding consistent with that reported by Weston et al. [21]. Future studies are therefore needed to resolve this unclear effect, although the prescription of an ‘optimal’ work:rest ratio is challenging as variables such as age, sex, baseline fitness, training experience may need to be considered when designing HIT programmes. We also found an unclear modifying effect of age on HIT and consistent with previous HIT meta-analyses [18, 19, 21], the demographic of participants in the studies analysed was mainly young adults. As such, we suggest that more HIT studies need to be undertaken in older populations, especially given the recent encouraging findings reported by Adamson et al. [53] and Knowles et al. [54] whereby HIT elicited substantial improvements in VO_{2max} and also measures of functional fitness and quality of life.

When compared to endurance training controls, HIT had a possibly small beneficial effect on VO_{2max}. Previous comparisons between HIT and endurance training yielded either an unclear effect [19, 21] or a significantly higher increase in VO_{2peak} after HIT compared to endurance training (3.03 $mL \cdot kg^{-1} \cdot min^{-1}$; ±2.0 to 4.1 $mL \cdot kg^{-1} \cdot min^{-1}$) [21]. Discrepancies in the overall training dose (e.g. low-volume HIT vs HIT) and study participants (e.g. healthy participants vs patient populations) no doubt account for the inconsistency in these findings. The difference in the training effect between HIT and endurance was enhanced for older and less fit subjects, suggesting HIT to have appeal to those involved in the fitness programming of older adults and patient populations especially given that the safety concerns associated with HIT are unfounded [55, 56]. Our supposition is supported by recent evidence whereby HIT induced substantial improvements in cardiovascular (e.g. VO_{2max}), functional fitness (e.g. sit to stand test) and health-related quality of life/physical functioning following short (3 weeks) [53] and long duration (13 weeks) [54] interventions. Our findings of enhanced beneficial effects for HIT with longer repetitions, greater work:rest ratios and longer training interventions provides valuable information to those involved in the design and implementation of HIT programmes.

While information on the physiological mechanisms subtending the improvements in VO_{2max} following either endurance training or HIT helps to explain changes in VO_{2max}, a discussion of physiological adaptations is beyond the scope of our review. In this instance, we direct readers to the articulate and comprehensive reviews of Jones and Carter [57], Gibala et al. [58] and Sloth et al. [20] for a detailed discussion of the underlying physiological adaptations to endurance training and HIT.

Finally, the observed magnitude of the between-study variation in the mean effect was moderate for endurance training vs control and HIT vs control, and small for HIT vs endurance training. As such, the mean effect, when compared to control, lies typically between 3.6 $mL•kg^{-1}•min^{-1}$ (very likely moderate) and 6.2 $mL•kg^{-1}•min^{-1}$ (very likely large) for endurance training, between 4.2 $mL•kg^{-1}•min^{-1}$ (most likely moderate) and 6.8 $mL•kg^{-1}•min^{-1}$ (very likely large) for HIT, and between -0.4 $mL•kg^{-1}•min^{-1}$ (most likely trivial) and 2.0 $mL•kg^{-1}•min^{-1}$ (likely small) for HIT compared to endurance training.

5 Conclusion

Our meta-analysis confirms that endurance training and HIT both elicit large improvements in the VO_{2max} of healthy, young to middle-aged adults with the effects being greater for the less fit. Furthermore, when comparing the two modes of training the gains in VO_{2max} are greater following HIT. Given the well-established link between aerobic fitness and mortality, further investigations into the manipulations of the HIT dose (e.g. repetition intensity, duration work:rest ratio etc.) are therefore recommended to enhance our understanding of the beneficial effects of HIT.

Compliance with Ethical Standards

No sources of funding were used to assist in the preparation of this review. The authors have no conflicts of interest that are directly relevant to the content of this review.

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