The Effects of Sprint Interval Training on Aerobic Fitness: A Systematic Review

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Appendix
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Abstract

Background: Greater aerobic fitness is associated with improved cardiovascular health. Traditionally high volume (long duration and low intensity) endurance training (ET) has been used to increase aerobic fitness. Sprint interval training (SIT) is a low volume and high intensity form of interval training. Energy for SIT is produced via both the aerobic and anaerobic metabolic pathways. SIT is therefore a potentially efficient and effective means to improve aerobic fitness.

Objectives: Systematically review the effects of SIT on aerobic endurance performance in untrained individuals.

Methods: The following databases were searched up to August 2008: Pubmed, the Cochrane Library, ScienceDirect, and SportsDiscuss. The reference lists of relevant reviews and identified papers were also searched. Included articles were limited to English language, controlled studies, investigating SIT in healthy untrained or recreationally active participants (VO2max < 55ml/kg/min)(1) with an outcome measure of endurance performance (as a measure of aerobic fitness). Studies fulfilling the selection criteria were assessed for methodological quality and relevant outcome data extracted.

Results: A qualitative evaluation of the available evidence demonstrated a consistent association between sprint interval training and improved aerobic performance. SIT produced an improvement of ~ 4% (95%CI -0.2 to 8.7), ~8 to 10% (0.4 to 16), and ~15% (0.8 to 29) after 1, 2 and 6 weeks respectively. These improvements were of the same magnitude as the improvements noted for ET but the training volume required was approximately 90% less.

Conclusions: Short duration SIT is an effective and efficient form of improving aerobic fitness in untrained individuals.

Introduction

Aerobic fitness is associated with reduced cardiovascular disease.(2) Traditional programmes to improve aerobic fitness and thus endurance performance rely upon high-volume training of long duration and low intensity (e.g. 20 to 60 min, 3-5 times a week at 50 to 85% VO2max).(3) Energy production with this type of training is almost exclusively from aerobic metabolic pathways.(3; 4; 1) Interval training where periods of hard exercise (work intervals) are interspersed with periods of rest or lighter work (rest intervals) can also enhance endurance performance of recreationally active individuals.(1) It is suggested that training at or near VO2max is the most effective training intensity to enhance VO2max and endurance performance.(5) This is reflected by the majority of the interval training studies which use exercise intensities at or below VO2max in an attempt to optimise training and thus endurance performance enhancement.(1; 5) This type of training also predominantly relies on aerobic energy pathways but a larger proportion of energy is produced anaerobically.(6)

In contrast to the endurance training protocols above, sprint interval training (SIT) predominantly stresses the anaerobic pathway to produce energy.(7) SIT is an effective means of increasing anaerobic endurance,(8) but has also been found to significantly enhance aerobic performance in untrained individuals.(1; 9) A SIT protocol consists of repeated intervals of short duration at maximal or near maximal intensity, interspersed with recovery periods of rest or low intensity exercise. Due to the high intensity, the intervals do not generally last longer than 60 seconds and most protocols utilise intervals of 30 seconds or less.(1) Muscle hypertrophy is not associated with SIT because unlike resistance training which also employs brief intermittent exercise, SIT is usually performed using activities such as cycling or running which provide lower resistance.(10) The aerobic adaptations following SIT have been observed to be as great as those elicited by endurance training.(9) Further, the adaptations occur rapidly and require a significantly smaller training volume than previously estimated for these adaptations to occur.(9) SIT is therefore a potentially efficient and effective means for recreationally active people to improve aerobic fitness which is associated with improved cardiovascular health.(2)
of one of these reviews(1) and it included uncontrolled studies which only reported surrogate markers of aerobic exercise capacity. The more recent review by Gibala et al(9) reported the results from studies with comparison groups and aerobic performance measures but neither review used a systematic approach to identifying articles or evaluated the quality of studies included in their reviews. These methods do not allow for the impact of bias and confounding factors to be adequately evaluated which could lead to erroneous conclusions. The purpose of this review was to use a systematic methodology to evaluate the effects of SIT on the aerobic energy system. A discussion of study methodology, quality and the possible impact of these factors on the results will also be presented along with suggestions for future research.

Methods

Search strategy
The methods of this review followed the guidelines of the Cochrane Handbook for Systematic Reviews of Interventions.(11) Research articles review were identified in two stages 1) by using freetext searches in electronic databases and 2) by hand searching the reference lists of the included studies and review articles of interval training which included SIT. Included articles were limited to English language, controlled studies, investigating SIT in healthy untrained or recreationally active participants (VO2max < 55ml/kg/min)(1) that included an outcome measure of endurance performance. A free text search strategy was developed using these limitations and their synonyms joined by Boolean operators (appendix 1). The text was then entered into the following databases Pubmed, Sciencedirect, sportsdiscuss, and the Cochrane library. From the list of journal articles produced (appendix 2) potentially relevant papers were then identified by a review of their title and abstract. Fourteen potentially relevant papers were identified from the electronic and hand searches combined. These articles were read in full and appraised using a standardised procedure. Critical appraisal excluded a further 10 articles. The remaining four papers(12-15) met the defined inclusion criteria and were judged of a high enough quality to inform the results of the main review (fig 1).

Analysis of Endurance Performance
Endurance performance data was extracted from the four included papers. To allow the comparison of endurance performance, the data was transformed (where needed) into percentage change in mean power output (using the methods of Hopkins et al(16)). If exact data was not presented, data was obtained by measuring the data points on the presented figures. Effect size and 95% confidence intervals (95% CI) were also calculated for the outcomes to help interpret the clinical as well as the statistical significance of the outcomes. The 95% CI were calculated using a spreadsheet(17) which required the effect statistic and the p value to calculate the upper and lower limits of the confidence interval. To allow an approximate range where the exact p values were not given, the value 0.04 was substituted for a p value of p<0.05 and the value 0.06 was given to p values of p>0.05. These values were chosen as they represent “just significant” and “almost significant” findings. These confidence intervals combined with the magnitude of the effect size should allow the reader to interpret the likely significance of the intervention for themselves. To guard against error data were double entered and cross-checked.

Analysis of secondary outcomes
Data for the secondary outcomes: change in VO2max and change in anaerobic performance (Wingate Peak and mean anaerobic power) were taken from the articles Bergamaster et al(18) and Barnett et al.(19) These papers were judged of high enough quality to be included in the review but did not include a measure of endurance performance so could not be used in the main review. These results are presented along with changes in physiological markers to support the evidence from the endurance performance outcomes. To aid interpretation data is presented as percentage change with 95%CI and effect sizes.

Findings
Quality of published work
All of the studies included in this review have been subjectively rated as having a moderate risk of bias.(20) The use of controlled studies, no drop-outs and objective markers limits the influence of bias in the studies but the lack of adequate randomisation and blinding leave the studies open to the influence of bias and over estimation of outcome measures.(21-24) Small sample sizes leave studies underpowered such that significant effects with large effect sizes are likely to be true results (but may be due to the play of chance). However, small but important effects are likely to be missed as the study is underpowered to detect these changes.(25) The small sample sizes, reliance on the p value to ascertain significance combined with the selective reporting of data can also
be problematic for reviewers. Only reporting significant results in detail does not allow the reader to interpret the changes in results which “just missed” statistical significance. Due to the underpowered studies these results could represent a type II error and not reporting the data for findings which were not statistically significant can lead to reporting bias. The inclusion of data with precision estimates for all measured outcomes will allow for subsequent re-analysis or inclusion in a metaanalysis.

If present the direction of bias in the studies is likely to be away from the null towards a significant finding for the experimental condition. This possibility must be considered when interpreting the results of these studies. The large effect sizes of the main results suggest that these are true results, but their true values may not be as large. The impact of this bias will likely effect secondary measures which have smaller effect sizes thus bias could account for all or most of this apparent effect. To improve future studies greater consideration should be given to reducing the possible influence of bias. This could be achieved by improved implementation and reporting of randomisation and blinding. A justification of sample size should also be included and data summaries presented with effect sizes and precision estimates for each primary and secondary outcome. (26)

Interpreting effects
The use of different intervention durations and performance measures in the included studies prevents the reliable use of meta-analysis to quantify an overall pooled estimate of effect. The consistent results across the studies allow a confident qualitative interpretation of SIT effects on endurance performance. Cautious interpretation of the secondary outcome measures is also presented considering the limitations of the studies outlined above.

Primary Outcome Measures
Endurance Performance following SIT interventions
The homogeneity of the results for enhancement of endurance performance is clear from table 1. Despite small samples and the inherent variability of data from a non-athletic population, significant increases in performance are seen in all of the studies after SIT. (12-15) Due to the imprecision of the data the effect size statistic is only small to moderate and the 95%CI ranges are wide. A dose-response relationship is also evident from the results in table 1 with an approximate 4% (95%CI -0.2 to 8.7) improvement after 1 week increasing to ~8 to 10% (95%CI 0.4 to 16) after 2 weeks training and ~15% (95%CI 0.8 to 29) after six weeks training. In the one study which compared SIT to endurance training (14) the absolute increase in performance following SIT was greater than ET (10.4 v 6.5%), but there was no difference in effect size (both moderate) for these results and considerable overlap between the confidence intervals. This indicates that both forms of training modalities produce rapid adaptations in the aerobic metabolic pathways with no identifiable difference between them. Despite the two interventions producing the same magnitude of effect this result has clinical significance because the volume of exercise used in the SIT protocol was approximately 90% less than the volume of exercise used in the endurance training protocol. This has potential benefits for population health where lack of time is quoted as one of the biggest reasons for adults not committing to regular exercise. (27) However it needs to be established whether the other health benefits associated with ET are also produced through the shorter bouts of exercise associated with SIT.

Recent research has begun to investigate these questions with promising results. High intensity interval training has been found to produce greater reductions in fat mass and insulin resistance in overweight young women compared with steady state endurance training. (28) SIT using the protocol of Bergamaster et al (13) has also been found to improve peripheral vascular structure and function comparable with the changes induced by higher volume ET. (29) Combined these findings suggest that SIT could have a significant impact upon the exercise recommendations for physical fitness and health promotion and deserve further research.

In comparison to the intervention groups the control groups demonstrated no significant changes from baseline. The one exception to this was the control group from Barnett et al (19) which demonstrated a statistically significant increase in VO2max from baseline (table 2). Although Barnett et al (19) did not monitor habitual activity this change was ascribed to natural variations in habitual activity over the eight week duration of the study. This change could also be explained by a Hawthorne effect or an increase in activity because the control subjects were aware that their fitness would be tested again. Whatever the reason for this change, it demonstrates the importance of a control group to help control confounders and the interpretation of the magnitude of the effect that can be ascribed to the intervention.

Secondary Outcome Measures
VO2max Data
The finding of improved endurance performance is supported by the increases in VO2max seen after
training in all but one of the studies (table 2). SIT was found to increase VO2max by between 5.5% (-0.9 to 6.3) to 8.2 (3.9 to 12.0) over a period of two to eight weeks respectively. (15; 18; 19) In the one study that compared improvement in VO2max between SIT and ET the increases in VO2max following ET were smaller in absolute terms after 2 weeks training but greater compared with SIT after 6 weeks (moderate v small effect size), but these findings were not significantly different (table 2). This finding prompted the authors of the study to suggest that differences in the time course for adaptations may be found. To investigate this hypothesis studies with longer follow up durations and larger samples would be needed. Only one study (13) did not find an improvement in VO2peak for either the SIT or ET interventions however the lack of reported data prevented any further interpretation of this result. Support for the changes in endurance performance was also provided by the increased physiological markers of aerobic performance following training which coincided with increased performance. for a comprehensive review of these changes in physiological markers see Gibala et al. (9)

Anaerobic Performance following SIT interventions
The results for anaerobic performance (for which SIT is more traditionally associated) were less consistent than the results for endurance performance (table 4). Mean power in the Wingate anaerobic Test (WAnT) was enhanced in all of the studies. The results of Burgomaster et al (18) suggest that the increase is possibly greater than the improvements seen with ET (table 4) but more research is needed to confirm this. Peak Power results were less consistent. Burgomaster et al (18) found SIT increased PP by 17% (0.9 to 33.0) which was greater than the 7% (0.4 to 14) increase seen with ET and Burgomaster et al (15) reported a 5.4% increase. In contrast Barnett et al (19) found no difference in PP between the SIT group and a control group after 8 weeks of training. Burgomaster et al (15) also reported the fatigue index which was significantly reduced by 20% (4.9% to 82%) after SIT with a moderate effect size. These results are not unexpected because of the design of the studies and use of the specific testing measure. SIT is known to improve repeated sprint endurance (8) but the WAnT is a single 30s test designed to test anaerobic power. As expected mean power over 30s and the fatigue index is improved reflecting an increased ability to generate energy using anaerobic metabolism. Improved aerobic metabolism will also improve these two measures because the aerobic system contributes significantly to the WAnT especially at the end of the test. The inconsistent results seen for the PP are not unexpected because PP measurement is taken over a period of 1s (depending upon the protocol). These short measures of power output are associated with less reliable data because each cycle revolution contributes a greater proportion to the overall score than in longer tests. (30) Individual errors therefore have a greater impact on the measure. This increase in noise makes it less likely to identify changes in small samples where the precision is low. Further, peak power is more closely correlated with maximum strength than endurance capacity. (3) SIT has been shown to cause preferential changes in the aerobic muscle fibres (type IIa and type I fibres) (9) which are likely to have a smaller effect on peak power than interventions such as resistance training or plyometric training which stimulates development in the more anaerobic explosive type IIb fibres and have been found to increase WAnT PP. (31)

Critical Analysis and Suggestions for Improving Future Research
Study Population
The populations used in the included studies were samples of convenience utilising the University students at the researcher’s institutions. Their age, demographics, anthropometric, habitual activity, and thus physical fitness do not represent the healthy recreationally active population as a whole. These limitations restrict the generalisability of the results to recreationally active university students. SIT needs to be tested in the general untrained population and not under strict laboratory conditions so that its effectiveness (as opposed to efficacy) as a method of endurance enhancement can be evaluated. Under these conditions motivation to perform taxing exercise may not be as high, which could lead to a reduction in the effectiveness of the interventions. Further research is also needed on individuals with greater training experience (both sprint trained an endurance trained) to quantify the benefits of this form of exercise for them.

Use of control or comparison groups and sample size
In their earlier review Laursen et al (1) rely almost exclusively upon studies which did not include a control, this leaves outcomes open to the influence of confounding factors. The value of only including controlled studies is demonstrated by the example of Barnett et al (19) where a significant improvement in performance was seen in the control group who did not complete a training intervention. This improvement
was explained by Barnett et al (19) as seasonal improvements associated with changing levels of habitual fitness in active individuals. This highlights a potential problem with working with recreationally active individuals as small fluctuations in training volume represent a much greater proportional increase in training volume for them than moderately trained or elite athletes. Combined with their lower baseline of physical fitness these small changes could lead to dramatic improvements in physical ability. Indirect evidence for this is seen in the findings of a metanalysis investigating the reliability of power output data from endurance performance tests. (30) Non-athletes were 1.3 times less reliable than athletes and in addition non-athletic females produced less reliable data than non-athletic men (1.4x). This is a potential source of confounding factors especially as one of the studies (Bergomaster et al (13)) included 2 females in the SIT group but the control group was all men. To adequately control for these fluctuations future studies should include sample size calculations and equal comparison groups.

Reliability and validity

Reliable and valid measures of endurance capacity are also needed and the data should be presented with enough information to allow transformation into other forms to allow future comparisons and/or metanalysis. This suggestion is supported by the observation that the performance enhancement in one paper (13) was substantially greater in absolute terms than the other papers (12; 14; 15). In their review of SIT Gibala et al (9) noted this difference in performance change but because they only reported on the outcome data as it was presented in the individual papers they did not adequately explain this outlying result. The inclusion of untrained female data in the SIT group only and the unblinded protocol in Burgomaster et al (13) is likely to have contributed to this finding. The greatest contributor to this disparity was the use of incomparable outcome measures. Burgomaster et al (13) measured the change in endurance capacity using a constant power test until volitional fatigue, the other papers (12; 14; 15) used constant work tests (time trials). These two types of tests both produce reliable results demonstrated by low average coefficients of variations (30) but a small change in endurance capacity will cause a substantially larger improvement in performance in the constant power test. (30) This difference accounts for the substantial difference in absolute performance change between this paper and other papers using similar protocols (96.6% (13) vs ~10% (12; 14; 15)). However, by transforming the outcome data into the same form (change in mean power) direct comparisons can be made and the results are in agreement with the other papers (table 1).

The use of both performance tests and physiological measures in combination improved the confidence of the findings. Studies which only rely upon surrogate measures do so based on assumptions which rely upon current understanding linking them to outcome of interest. Understanding is constantly evolving and such assumptions can be misleading if our understanding is incomplete. (32) Surrogate markers should not be relied upon when the outcome of interest can be readily measured. Performance data is therefore the main outcome measure of interest but surrogate markers of aerobic performance can increase the confidence in positive findings in unblinded studies such as these. If an increase in performance is found in conjunction with increases in these markers then the increase in physical performance is unlikely to be completely due to a placebo effect. (16) Further, using criteria such as the Hill (33) criteria the strength of association for cause and effect can be evaluated and evidence for mechanisms of improvements in performance can be elicited. The important questions for researchers to focus on in the future are if the physiological adaptations from SIT that lead to improved endurance capacity are due to the same physiological adaptations that occur with endurance training in both the short-term and the long-term. The time course of the adaptations should also be investigated along with any additive effects of a combination of both low and high intensity training verses either type of training alone.

Randomisation

The main strength of randomisation is in the explanation of cause and effect. (34) Only one of the included studies (1) reported using matching and randomisation to allocate participants to the intervention groups, but the reporting was inadequate to ascertain if the methods were rigorous enough to prevent subversion and bias. Each stage of randomisation (allocation concealment, randomisation, and implementation) should be adequately described in the methods of a study so that the likelihood of bias in group allocation can be evaluated. (26) Without adequate allocation concealment even random, unpredictable allocations can be corrupted. (21; 26) Well meaning or not, such tampering undermines the validity of a trial. Strong empirical evidence has been reported that the lack of adequate randomisation is associated with overestimates of treatment effects. (21; 22; 24) These findings support the use of
randomisation in studies and as a criterion in critical appraisal. It is therefore important that appropriate methods of randomisation are used and how it was implemented is adequately described so that the overall quality of the study and its conclusions can be evaluated with confidence.(26)

Blinding
Knowledge, experiences, and beliefs can all influence physical and psychological responses to an intervention.(35) This is an important consideration for interventions like the ones in this review because physical performance relies upon a multitude of variables, including motivation of the subjects and knowledge of intervention allocation is associated with larger estimates of treatment effects.(23) Blinding (concealing the intervention from the participant, investigator, or both) can be utilised to avoid participants’ or investigators’ expectations impacting upon the results. Unfortunately none of the studies included in this review reported using blinding in their methods. It is accepted that blinding is more difficult in non-pharmacological interventions(36) but blinding of some form can still be implemented (e.g. blinding the statistical analysts). In an attempt to increase and improve the use of blinding, descriptions of blinding methods have been published for non-pharmacological interventions(36) and guidelines have been written for the correct reporting of blinding.(26)

All studies have limitations but good study design reduces the potential for bias and combined with the good reporting increases our confidence in the conclusions of a trial. The lack of randomisation and blinding does not automatically indicate a methodologically unsound trial as the design may prevent bias in other ways.(35; 23) The studies included in this review all used objective measures of physiological markers to support their findings. This increases our confidence in the validity of the findings. Attrition bias was also not a problem as there were no reported drop outs. This indicates that the motivation of the subjects was high (as the training was strenuous) which increases the confidence in the reliability of the performance test which can be influenced by fluctuating motivation. The inclusion of familiarisation trials and the use of reliable performance tests in all of the included papers also increases the reliability of the performance data.(30) Furthermore unlike randomisation which has string empirical evidence for its inclusion the influence of blinding on reducing bias has yet to be fully ascertained. Studies are required to assess its influence on preventing bias because its actual impact may be considerably different to its theoretical influence.(37)

Review

Strengths & Weaknesses of the Review
The systematic methodology is the main strength of this review compared with other reviews.(1; 9) The exclusion of uncontrolled trials and critical appraisal of studies reduces the influence of bias and confounding and produces more accurate and reliable conclusions. Limitations of the methods are its restriction to the English language and published articles which may result in publication bias. The measurement of data from graphs where primary data was not presented in the original articles could have also introduced error to the results as could the assumptions used to transform data. These limitations together with the limitations of the included studies outlined above need to be considered when interpreting the results and should be addressed in future research and reviews of SIT for endurance performance.

Suggested Further Research
Studies with improved research designs are required to allow more precision to investigate the speed of adaptations seen with SIT compared with endurance training. Longer studies investigating the long term adaptations to SIT compared with endurance training will also provide evidence for the efficacy of this training modality to enhance aerobic fitness and provide health benefits as the fitness of the participant’s changes.

Conclusion

SIT protocols using short bouts of high intensity exercise can produce significant improvements in aerobic fitness and thus endurance performance in as little as two weeks in active adults. The improvements in endurance performance increase for up to six weeks but longitudinal studies are needed to quantify the improvements beyond this time. The magnitude of these changes is equivalent to the changes seen with endurance training but the volume of training is ~90% less with SIT. Mean anaerobic power is also improved concurrently with this type of training, possibly to a greater extent than with ET but further research is needed to confirm this finding. These results could have a significant impact upon physical activity recommendations for health and fitness if further studies can confirm the health benefits associated with longer duration ET also occur with brief SIT.
interventions.

References

25. Hopkins WG. Estimating Sample Size for
Magnitude-Based Inferences. Sportscience. 2006;1063-70.


Illustrations

Illustration 1

Study Selection process

Potentially relevant studies identified (n = 1284)

Articles retrieved for detailed evaluation (n = 14)

Studios excluded after screening titles and abstracts (n = 1270)

Articles excluded (n = 10)
- No control (n = 2)
- No SIT intervention (n = 2)
- Trained participants (n = 1)
- No relevant data (n = 3)
- Confounding factors (n = 2)

Articles included in systematic review (n = 4)
Illustration 2

Table 1

Summary of Endurance Performance as change in Mean Power

<table>
<thead>
<tr>
<th>Study Description</th>
<th>Exercise Protocol</th>
<th>Endurance Performance Measures &amp; Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>Condition</td>
<td>n</td>
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<tr>
<td>Burgomaster et al 2007</td>
<td>SIT 8 M</td>
<td>3</td>
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<td></td>
<td>CON 8 M</td>
<td>0</td>
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<tr>
<td>Burgomaster et al 2005</td>
<td>SIT (6M &amp; 2W)</td>
<td>3</td>
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<td></td>
<td>CON (8M)</td>
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<td>Gibala et al 2006</td>
<td>SIT 8 (8M)</td>
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SIT = Sprint Interval Training intervention; CON = Comparison intervention; CP80%; Constant power test at 80% VO2max until voluntary exhaustion; 750kJ = 50-60min work; 50kJ = 2min exercise; 250kJ = 16 to 20 min exercise. Effect size += Trivial (<0.2); + = Small (0.2 to 0.6); ++ = Moderate (0.6 to 1.2); +++ = Large (1.2 to 2.0); ++++ = Very Large (>2.0). Arrows indicate result when no data given ? = improved performance; ? = no change; ? = decreased performance. * indicates statistical significance; ? = unknown/unable to calculate.
Illustration 3

Table 2

### Summary of change in VO2peak

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<td>CON 8 M</td>
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Illustration 4

Table 3

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