

ORIGINAL RESEARCH

GROUP STUDIO CYCLING; AN EFFECTIVE INTERVENTION TO IMPROVE CARDIO-METABOLIC HEALTH IN OVERWEIGHT PHYSICALLY INACTIVE INDIVIDUALS

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ABSTRACT

Introduction: Supervised, laboratory based studies of high intensity interval training (HIIT) is effective at improving health markers in groups at risk of cardiovascular and metabolic disease. Studio cycling, incorporating aerobic and high intensity exercise, may offer a platform for the implementation of HIIT within the wider community.

Methods: Eight, overweight, physically inactive (<1.5 hr·wk⁻¹) but otherwise healthy volunteers completed eight weeks of supervised studio cycling lasting 20-50 minutes 3 times per week. Participants underwent assessment for maximal oxygen uptake (VO_{2max}) body composition, blood lipids, glucose tolerance and insulin resistance before and after the intervention.

Results: Adherence to training was >95%. Mean and peak intensity were equivalent to 83% and 97% of HR_{max}·VO_{2max} increased from 27.1 ± 4.7 mL·kg·min⁻¹ to 30.3 ± 4.3 mL·kg·min⁻¹ (p < 0.0001). Body fat percentage was reduced by 13.6% from 31.8 ± 2.4% to 27.5 ± 4.5% (p < 0.05). Total cholesterol (4.8 ± 1.1 mmol·L⁻¹ to 4.2 ± 1.2 mmol·L⁻¹) and low-density lipoprotein cholesterol (2.6 ± 0.9 mmol·L⁻¹ to 2.0 ± 1.2 mmol·L⁻¹) were reduced (both p < 0.05). There were no significant differences to glucose tolerance or insulin resistance.

Discussion: Group exercise is effective at improving the cardio-metabolic health in previously physically inactive overweight individuals. Coupled with the high adherence rate, studio cycling offers an effective intervention improving cardiovascular health in physically inactive cohorts.

Conclusions: Studio cycling can be implemented as a highly effective high intensity interval training intervention for improving health in overweight, inactive individuals and may promote improved exercise adherence.

Keywords: group exercise, fitness centres, high intensity training, body composition, lifestyle

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INTRODUCTION

In recent decades, the lifestyle of many in the Western-world has become more widely characterised by reduced physical activity and increased sedentary time, potentially due to a reduction in the amount of physically demanding employment and increased technological reliance. This increase in technology dependency for work, transport and leisure has contributed to the current obesity epidemic and increased prevalence of cardiovascular and metabolic diseases. Obesity and type 2 diabetes (T2DM) are widely considered lifestyle diseases and lend themselves to prevention and treatment by lifestyle interventions including altered diet and physical activity.¹ Despite this, the financial burden for the treatment of such diseases in the UK continues to rise, with diabetes expenditure increasing from \$1 billion AUD in 2005/06 to \$1.6 billion AUD in 2013/14.²

Overweight and obesity are characterised by increased visceral and subcutaneous adipose tissue, hypertension and dyslipidaemia, leading to an increased risk of T2DM³ and cardiovascular disease (CVD). A number of studies have demonstrated that cardio-respiratory fitness, as defined by maximal oxygen uptake (VO_{2max}) is a predictor of CVD risk, independent to other risk factors such as obesity.^{4,5} Current exercise guidelines suggest that in order to improve cardiovascular health, >150 minutes of moderate to vigorous activity should be accumulated each week, with additional time dedicated to resistance training.⁶ Sprint interval training (SIT) has been shown to be effective at improving health markers associated with metabolic diseases such as T2DM whilst reducing the overall time commitment to exercise,⁷ however, the extremely high intensity nature of this exercise may not be well tolerated by some and requires moderation. A protocol termed high intensity interval training (HIIT), employing longer duration efforts at a reduced intensity with shorter recovery periods is effective in such groups⁸ and may also increase skeletal muscle mass.^{9,10} There may also be a beneficial effect of the higher intensity component of HIIT in that it appears to be important for targeting reductions in visceral fat.

^{11,12} Therefore, a HIIT intervention is likely to reduce fat mass, whilst increasing both muscle mass and cardiovascular fitness, all of which should be key measurements when establishing the efficacy of an intervention at improving health outcomes.

Despite the growing support for HIITs effectiveness at improving cardio-metabolic health, there is a paucity of studies employing HIIT style protocols outside of the laboratory. Until such studies are conducted, the widespread implementation of HIIT remains difficult. The few studies which do exist are based on solo exercise, but suggest that self-paced HIIT may be effective at improving body composition enjoyment, motivation and adherence.^{13,14,15,16} Therefore, HIIT based around self-selected intensities, may be an effective translation of the current body of scientific research into widespread public practice.

The provision and popularity of group exercise classes has exploded in recent years, with most towns and cities having at least one fitness centre which provides such classes. Many of the activities provided share characteristics of both SIT and continuous aerobic training and, as such offer a platform for implementing a community based, HIIT inspired training intervention that should enhance enjoyment, adherence to exercise and intention to continue with exercise.^{14,17} Therefore, it was the aim of the present investigation to study the effectiveness of an 8 week studio cycling intervention on improving the cardio-metabolic health of previously physically inactive, overweight adults conducted in a group environment. We hypothesised that VO_{2max} , blood lipids, blood pressure, body composition and glycaemic control would be improved following the intervention.

METHODS

Participants and Study outline

Eight overweight, physically inactive (<1.5 h·wk⁻¹ of moderate structured exercise) but otherwise healthy volunteers (2 males, 6 females, table 1) completed 8 weeks of supervised group studio cycling classes on three occasions per week, each lasting up to 50 minutes. Prior to training, all

participants underwent comprehensive medical assessment including resting 12-lead ECG, physical exam and blood pressure measurement (M6 Comfort, Omron-Healthcare, The Netherlands). Abnormal results resulted in exclusion of that individual and referral to their physician. The study protocol was approved by the Loughborough University ethics committee and conformed to the Declaration of Helsinki. Participants provided their written informed consent prior to participation. Measurements indicative of body composition, cardiorespiratory and metabolic health were conducted before the start of the training period and 72–96 h following completion of the final studio cycling session.

Oral glucose tolerance test (OGTT)

Participants reported to the laboratory at 0700–0900 following an overnight fast and having being instructed to refrain from any physical exercise in the preceding 72 h. A cannula was inserted into an antecubital vein and participants remained at rest for 20 minutes before baseline samples for glucose (EDTA, BD Biosciences, UK) and insulin (heparin, BD Biosciences, UK) were obtained. Following baseline sampling, they ingested 75g of dextrose monohydrate dissolved in 300ml of water. Blood samples were obtained at 30, 60, 90 and 120 minutes following glucose ingestion. Glucose concentration was determined in whole blood (YSI Stat2300, Yellow Springs Instruments, USA). Plasma was separated by centrifugation at 4°C 3,500 $r \cdot \text{min}^{-1}$ for 10 minutes and stored at -80°C until subsequent analysis. Plasma insulin was analysed using a commercially available enzyme-linked immunosorbent assay (Mercodia, Sweden) according to the manufacturer's protocol. Absorbance was read at 450nm. Coefficient of variation between duplicate samples was 2.5% and 3.1% between plates. Glucose and insulin area under the curves (AUC) was calculated using the trapezoid rule. The homeostatic model assessment for insulin resistance (HOMA-IR)¹⁸ was calculated to determine insulin resistance.

Blood lipids

Venous blood samples were drawn from an antecubital vein for analysis of fasting glucose (YSI Stat2300, Yellow Springs Instruments, USA), high-density lipoprotein (HDL-C), low-density lipoprotein (LDL-C) triglycerides and total cholesterol using a portable device (CardioCheck, Polymer Technology Systems, USA).

Maximal Oxygen Uptake

The $\text{VO}_{2\text{max}}$ test was conducted on an electronically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands). Participants cycled for 5 minutes against a resistance of 50 W, resistance was then progressively increased by 20 $\text{W} \cdot \text{min}^{-1}$ until the participant reached volitional exhaustion. $\text{VO}_{2\text{max}}$ was determined as the highest value achieved over an 11 breath period.¹⁹

Body composition

Participants' height (Seca, Birmingham, UK) weight (ID1 Multi Range, Sartorius, Goettingen, DE), waist and hip circumferences were recorded. Body composition was estimated using skinfold callipers (Harpندن, HaB Intl Ltd, Warwickshire, UK) and the 7-site skinfold formula for men and women respectively.^{20,21}

Studio Cycling Class

Studio cycling classes (RPM™, Les Mills International Ltd) built up to 50 minutes in length by week 3 and were characterised by periods of low, moderate and high intensity effort. The initial two weeks acted as familiarisation, increasing from 20–35 minutes in duration and participants received instruction on positioning and technique required. In the final 6 weeks, all sessions lasted for 50 minutes and comprised of a warm up, main session and cool down periods. Participants completed 3 sessions a week for 8 weeks, totalling 24 sessions. Heart rate (RS400, Polar, Fi) was recorded to monitor training intensity.

Statistical analysis

All relevant pre and post intervention data were analysed using a paired student's *t*-test. Glucose and insulin data were analysed using a two-way repeated measures ANOVA (time \times training). Where significant main effects were identified, *post-hoc* tests with a Bonferroni correction were conducted. All data are presented as mean \pm SD and calculated using GraphPad Prism (v6.0 GraphPad Software Inc., CA, USA). Statistical significance was accepted at $p < 0.05$.

RESULTS

Attendance and Intensity

RPM™ class attendance was >95% over the eight week period. Average heart rate over the course of the training intervention was $83.4 \pm 4.0\%$ of maximal heart rate, with peak heart rates equivalent to $96.7 \pm 4.2\%$.

Cardiorespiratory response

Relative maximal oxygen uptake increased by 11.8% following the training intervention ($p < 0.0001$; figure 1) and was echoed by an 8.3% increase in absolute oxygen uptake (pre 2.4 ± 0.7 L·min⁻¹; post 2.6 ± 0.7 L·min⁻¹; $p < 0.005$). Systolic blood pressure was also lower when measured after the training period ($p < 0.01$), as was mean arterial pressure (MAP) ($p < 0.05$; table 1). This was coupled with a trend towards lowered diastolic blood pressure ($p = 0.116$).

Anthropometric responses

Body fat percentage was reduced by 13.6% ($p < 0.05$, figure 2). There were concurrent reductions in waist circumference ($p < 0.01$) and waist:hip ($p < 0.01$, table 1). There was a tendency towards an increase in fat free mass (4.4%; $p = 0.146$, table 1). There were no changes to body mass ($p = 0.265$), hip circumference ($p = 0.222$) or body mass index (BMI; $p = 0.250$).

Blood lipids

Following training, total cholesterol was reduced by 13.0% ($p < 0.05$) and LDL-C by 23.3%

($p < 0.05$, table 1). There were no changes to either HDL-C ($p = 0.208$) or triglycerides ($p = 0.322$).

Table 1. Participant characteristics before and after 8-weeks of studio cycling

	Pre	Post
Height (m)	1.69 (0.1)	1.69 (0.1)
VO _{2 max} (mL·kg·min ⁻¹)	27.1 (4.7)	30.3 (4.3)***
Body mass (kg)	86.1 (10.6)	84.5 (10.4)
BMI (kg·m ⁻²)	29.9 (2.3)	29.4 (1.9)
Waist (cm)	93.9 (9.1)	90.9 (8.3)**
Hip (cm)	108.9 (8.1)	107.6 (6.9)
Waist:Hip	0.86 (0.1)	0.85 (0.1)**
Systolic BP (mmHg)	127 (11)	118 (15)**
Diastolic BP (mmHg)	71 (10)	71 (7)
MAP (mmHg)	93 (10)	87 (8)*
Total cholesterol (mmol·L ⁻¹)	4.8 (1.1)	4.2 (1.2)*
LDL-C (mmol·L ⁻¹)	2.6 (0.9)	2.0 (1.2)*
HDL-C (mmol·L ⁻¹)	1.7 (0.4)	1.5 (0.2)
Fasting glucose (mmol·L ⁻¹)	4.9 (0.4)	4.6 (0.3)
HOMA-IR	2.0 (1.0)	1.6 (0.4)
Triglyceride (mmol·L ⁻¹)	1.2 (0.7)	1.6 (0.6)
Fat Free Mass Index (kg·m ⁻²)	20.4 (1.7)	21.3 (2.0)

VO_{2 max} - Maximal oxygen uptake; BMI - Body Mass Index; BP - blood pressure; MAP - Mean Arterial Pressure; LDL-C - Low Density Lipoprotein; HDL-C - High Density Lipoprotein. HOMA-IR - Homeostasis Model of Insulin Resistance. Symbols denote: * different from pre ($p < 0.05$); ** different from pre ($p < 0.01$); *** different from pre ($p < 0.0001$). Data presented as mean (SD)

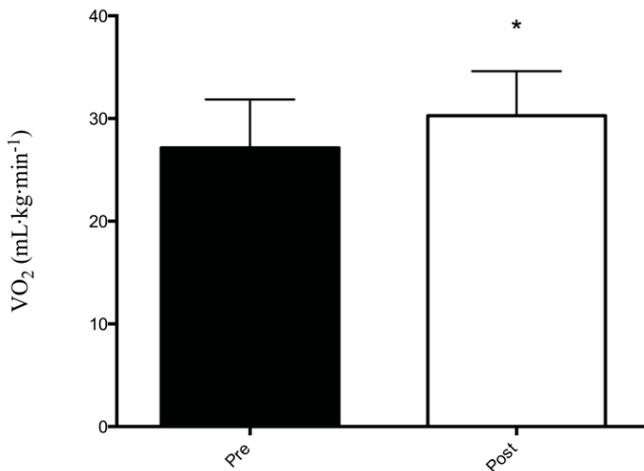


Figure 1. Maximal oxygen uptake was increased by 11.8% following 8 weeks of studio cycling. * denotes significantly different from pre training ($p < 0.0001$). $n = 8$

Glucose response

There was a tendency towards a reduction in fasting glucose ($p = 0.121$; table 1). Due to poor tolerance of the glucose load, pre and post OGTTs were completed in 7 participants. There was a main effect for time ($p < 0.005$) but no effect of training ($p = 0.67$) or interaction between time and training ($p = 0.9$). Blood glucose reached its peak 60 minutes following glucose ingestion in both trials but was not different in response to training (pre = 7.83 ± 2.13 mmol·L⁻¹; post = 7.80 ± 1.31 mmol·L⁻¹). Glucose AUC was unaffected in response to the training period ($p = 0.913$)

Insulin response

Fasting plasma insulin was unaltered in response to the training period ($p = 0.280$). There was a main effect for time during the OGTT ($p < 0.001$) but not for training ($p = 0.327$) and no interaction effect ($p = 0.624$). There was a tendency towards a reduction in HOMA-IR ($p = 0.187$, table 1).

DISCUSSION

The present study demonstrates that 8-weeks of studio cycling completed 3 times per week is effective at improving VO_{2max} and body composition whilst reducing total cholesterol and LDL-C. In addition, the maximal heart rates achieved during the training were equivalent to the 95% of maximal heart rate often used to

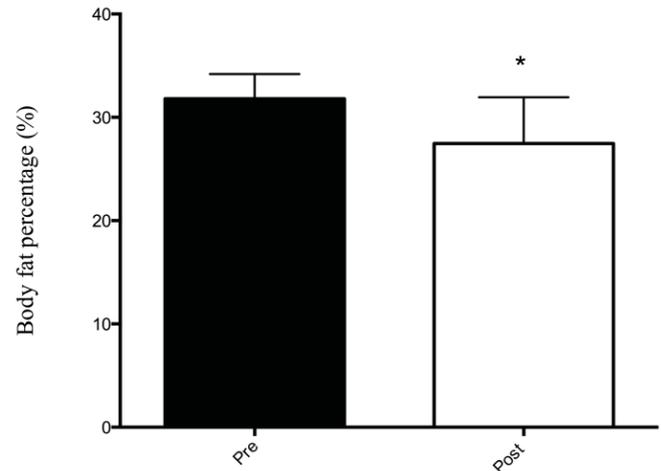


Figure 2. Body fat percentage was reduced by 13.6% following 8 weeks of studio cycling. * denotes significantly different from pre training ($p < 0.05$). $n = 8$

characterise high intensity training, indicating that the protocol, although largely self-paced, did achieve the criteria for HIIT protocols. The data indicate a high adherence rate, beyond that normally associated with group exercise programmes, which may provide an additional motivation for adherence to exercise. The adherence rate of >95% is greater than that reported within the majority of the literature where dropout rates can be as high as ~60-80% among interventions aiming to increase light to moderate physical activity.^{22,23}

Cardiorespiratory fitness

Improvements in VO_{2max} are frequently reported following periods of increased training load in previously physically inactive individuals.^{24,25} Given that VO_{2max} is a powerful predictor of disease risk,⁵ increases in VO_{2max} are an important outcome when establishing the efficacy of an intervention on improving disease risk. Previously, SIT has been suggested to improve VO_{2max} by 4-13% with the increase in VO_{2max} directly linked to exercise duration. Therefore, the longer duration of training in the present study when compared to SIT, coupled with the high average exercise intensity compared to traditional aerobic training is the likely reason for the relatively large, 11.8% increase in VO_{2max} reported here. It has been suggested, that the least fit will benefit the most from HIIT in respect of VO_{2max} improvement²⁶ therefore,

populations with increased disease risk and impaired metabolic health are likely to demonstrate even greater improvements. However, there may be a lower limit to this given the relationship between mitochondrial oxidative capacity and O_2 supply.^{27,28} Patients with sub-optimal mitochondrial function exhibit a particularly low VO_{2max} , with varying degrees of exercise intolerance.²⁹ Therefore, it is possible that in overweight patients with a low VO_{2max} and associated impaired mitochondrial function, there is an inability to sustain ATP re-synthesis due to a build up of non-essential fatty acid (NEFA) overloading the mitochondria.³⁰ This NEFA accumulation leads to protein kinase-C phosphorylation of the insulin receptor substrate-1 (IRS-1) thus limiting insulin signalling, resulting in impaired GLUT4 translocation and glucose uptake.³⁰ The outcome is an inability to maintain the required workload for the duration of a session. In turn, this may manifest itself in a training load that is insufficient to stimulate physiological adaptation, suggesting that a minimal VO_{2max} may be required in order to benefit from interval training.

Blood pressure

Mean arterial pressure was reduced following the training intervention and was largely driven by the 7% reduction in systolic blood pressure, which can be translated into an approximate 20% reduction in the risk of premature death.³¹ Reductions in blood pressure in response to HIIT are rarely reported in interventions lasting less than 12 weeks¹² so the present data is particularly remarkable given the relatively short duration of the training intervention. It is possible that the force of muscular contractions during the high intensity phases of the exercise sessions resulted in an increase in shear stress to the arterial wall and subsequent angiogenesis.^{32,33} Furthermore, although not measured here, there is likely to be an improvement in endothelial function in response to training, which may improve blood pressure profiles³³ and skeletal muscle oxygen delivery.

Body composition

Waist circumference and waist-to-hip ratio were reduced following the intervention, both of which are common features of prolonged interval training programmes.¹² Elevations in waist circumference are closely related to health outcomes, and are associated with higher mortality rates, with the estimated decrease in life expectancy for the highest versus lowest waist circumference being approximately 3 years for males and 5 for females.³⁴ Although BMI was unchanged following the intervention, there was a large reduction in body fat percentage, which is often not reported following SIT and is more consistently reported following continuous aerobic training which results in higher total exercise time and therefore increased energy expenditure.¹² Moreover, it has been shown that when both BMI and waist circumference are compared as predictor variables, only waist circumference is a predictor of a number of comorbidities including the metabolic syndrome.³⁵

Although HIIT causes an increase in exercise energy expenditure, the post exercise increase is transient and relatively minor and results in a reduction in post exercise RER, suggesting a shift towards greater fat oxidation and reduced carbohydrate oxidation.^{36,37} Despite this, it can be speculated from our data that the lack of a difference in BMI and body weight in the face of reduced body fat is due to a tendency towards an increase in lean muscle mass.^{9,10} Indeed, evidence suggests that aerobic training at an intensity equivalent to 70-80% heart rate reserve is capable of stimulating muscle hypertrophy and a 7% increase in muscle mass.^{38,39} Accordingly, it is likely that the present intervention, characterised by periods of very high intensity exercise and of a moderate duration, would result in a comparable, if not larger degree of hypertrophy and increased basal metabolic rate.

Blood lipids

We report a ~13% reduction in total cholesterol following the training intervention, which is driven by the large reduction in LDL-C. A reduction in LDL-C is uncommon following SIT¹² and is most

frequently reported with more traditional continuous endurance training.³³ Therefore, we suggest that the incorporation of some moderate intensity aerobic effort as part of a SIT program is an important factor in the reduction of LDL-C, atherosclerosis and coronary artery disease⁴⁰ and other co-morbidities.

Glucose tolerance

There were no changes in either insulin or glucose control following the training intervention. As the second OGTT occurred 72 h after the final exercise session, it is likely that this data is a true reflection of actual glucose control in that it is not confounded by the insulin sensitising effect of the prior acute exercise bout.³⁷ Moreover, as the present cohort were considered metabolically healthy, it is perhaps unsurprising that we are unable to report any differences. The response of glucose control to an exercise intervention has been shown to be variable due to genetic variation, indeed a small proportion of the population will demonstrate a negative response to exercise in terms of glucose regulation and insulin sensitivity.⁴¹ However, it is not uncommon that exercise training results in an improved insulin profile independently to changes in glucose.²⁴ Again our cohort displayed normal insulin profiles prior to training and the lack of a response likely reflects this. Notwithstanding, such small effects in metabolically healthy individuals may be heightened in those demonstrating impaired glucose tolerance and such interventions as used here may be of additional benefit to groups displaying impaired glucose tolerance.

CONCLUSIONS

The present data show that a group studio cycling intervention led to physiological and metabolic adaptations that are associated with reduced disease risk. The intermittent nature of HIIT is important in maximising skeletal muscle adaptations associated with this form of training⁴² and it is likely that the combination of the physiologically potent stimuli of both aerobic and

high intensity training which yields comprehensive health benefits. It is therefore likely that in certain populations, group exercise involving aerobic training regularly interspersed with near maximal efforts, will elicit a wide range of beneficial physiological and metabolic adaptations that are reflected in the cycling programme assessed in this study. These broad-based health outcomes coupled with the high adherence rate, suggests group studio cycling, offers an effective exercise vehicle for improving cardio-metabolic health in physically inactive cohorts. Further work should aim to elucidate whether the present results can be extended into clinical populations, such as those diagnosed with T2DM and other metabolic diseases, which may benefit from lifestyle interventions.

PRACTICAL APPLICATIONS

Group studio cycling offers an effective exercise vehicle for improving cardio-metabolic health in physically inactive individuals.

Self-paced HIIT appears to be as effective as tightly prescribed laboratory HIIT studies at improving cardiovascular fitness.

Group HIIT exercise may improve exercise adherence that is key to maintaining long-term lifestyle changes.

The prescription of such exercise classes by clinicians may offer a wide scale community health benefit without substantial cost to health care services

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authors and not necessarily those of the NHS, the NIHR or the Department of Health. The authors were fully responsible for conducting the trial and analysing the data.

REFERENCES

1. Hawley, J. A. & Gibala M. J. (2012) What's new since Hippocrates? Preventing type 2 diabetes by physical exercise and diet. *Diabetologia*, 55(3), 535-539.
2. Prescribing and Primary Care, *Health and Social Care Information Centre*. Leeds, UK
3. Roberts, C. K., Hevener A. L., Barnard R. J. (2013) Metabolic syndrome and insulin resistance: underlying causes and modification by exercise training. *Comprehensive Physiology*, 3(1), 1-58.
4. Borodulin, K. et al (2005) Associations between estimated aerobic fitness and cardiovascular risk factors in adults with different levels of abdominal obesity. *European Journal of Cardiovascular Prevention & Rehabilitation*, 12(2), 126-131.
5. Artero, E. G. et al (2014) Longitudinal algorithms to estimate cardiorespiratory fitness: associations with nonfatal cardiovascular disease and disease-specific mortality. *Journal of the American College of Cardiology*, 63(21), 2289-2296.
6. Garber, C. E. et al (2011) American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports and Exercise*, 43(7), 1334-1359.
7. Babraj, J. A. et al (2009) Extremely short duration high intensity interval training substantially improves insulin action in young healthy males. *BMC endocrine disorders*, 93-6823-9-3.
8. Little, J. P. et al (2010) A practical model of low-volume high-intensity interval training induces mitochondrial biogenesis in human skeletal muscle: potential mechanisms. *The Journal of Physiology*, 588(6), 1011-1022.
9. Gillen, J. B. et al (2013) Interval training in the fed or fasted state improves body composition and muscle oxidative capacity in overweight women. *Obesity (Silver Spring, Md.)*, 21(11), 2249-2255.
10. Osawa, Y., et al (2014) Effects of 16-week high-intensity interval training using upper and lower body ergometers on aerobic fitness and morphological changes in healthy men: a preliminary study. *Open Access Journal of Sports Medicine*, 5257-265.
11. Lesser, I. A. et al (2014) The association between physical activity and liver fat after five years of follow-up in a primary prevention multi-ethnic cohort. *Preventive Medicine*, 67(0), 199-203.
12. Kessler, H. S., Sisson S. B., Short K. R. (2012) The potential for high-intensity interval training to reduce cardiometabolic disease risk. *Sports Medicine (Auckland, N.Z.)*, 42(6), 489-509.
13. Thoma, C. et al (2013) High-intensity intermittent exercise therapy reduces liver fat and improves body composition in adults with non-alcoholic fatty liver disease. *Journal of Hepatology*, 58S550-S551.
14. Heinrich, K. M. et al (2014) High-intensity compared to moderate-intensity training for exercise initiation, enjoyment, adherence, and intentions: an intervention study. *BMC Public Health*, 14789-2458-14-789.
15. Tjønnå, A. E. et al (2008) Aerobic Interval Training Versus Continuous Moderate Exercise as a Treatment for the Metabolic Syndrome: A Pilot Study. *Circulation*, 118(4), 346-354.
16. Jung, M. E., Bourne J. E., Little J. P. (2014) Where Does HIT Fit? An Examination of the Affective Response to High-Intensity Intervals in Comparison to Continuous Moderate- and Continuous Vigorous-Intensity Exercise in the Exercise Intensity-Affect Continuum. *PLoS ONE*, 9(12), e114541.
17. Kinnafock, F. et al (2013) High intensity interval and traditional endurance training lead to comparable improvements in motivation and well-being outcomes. European Congress of Sports Science, Annual Meeting, Barcelona, Spain.
18. Matsuda, M. & DeFronzo R. A. (1999) Insulin sensitivity indices obtained from oral glucose tolerance testing: comparison with the euglycemic insulin clamp. *Diabetes Care*, 22(9), 1462-1470.

19. Robergs, R., Dwyer D., Astorino T. (2010) Recommendations for Improved Data Processing from Expired Gas Analysis Indirect Calorimetry. *Sports Medicine*, 40(2), 95-111.
20. Jackson, A. S.& Pollock M. L. (2004) Generalized equations for predicting body density of men. 1978. *The British Journal of Nutrition*, 91(1), 161-168.
21. Jackson, A. S.& Pollock M. L. (1980) Generalised equations for predicting body density of women. *Medicine and Science of Sports and Exercise*, 12:175-182.
22. Xu, K. T.& Ragain R. M. (2005) Effects of weight status on the recommendations of and adherence to lifestyle modifications among hypertensive adults. *Journal of Human Hypertension*, 19(5), 365-371.
23. Marcus, B. H. et al (2006) Physical Activity Intervention Studies: What We Know and What We Need to Know: A Scientific Statement From the American Heart Association Council on Nutrition, Physical Activity, and Metabolism (Subcommittee on Physical Activity); Council on Cardiovascular Disease in the Young; and the Interdisciplinary Working Group on Quality of Care and Outcomes Research. *Circulation*, 114(24), 2739-2752.
24. Dengel, D. R. et al (1996) Distinct effects of aerobic exercise training and weight loss on glucose homeostasis in obese sedentary men. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 81(1), 318-325.
25. Whyte, L. J., Gill J. M. R., Cathcart A. J. (2010) Effect of 2 weeks of sprint interval training on health-related outcomes in sedentary overweight/obese men. *Metabolism*, 59(10), 1421-1428.
26. Weston, M. et al (2014) Effects of Low-Volume High-Intensity Interval Training (HIT) on Fitness in Adults: A Meta-Analysis of Controlled and Non-Controlled Trials. *Sports Medicine*, 44(7), 1005-1017.
27. Hoppeler, H., Hudlicka O., Uhlmann E. (1987) Relationship between mitochondria and oxygen consumption in isolated cat muscles. *The Journal of Physiology*, 385(1), 661-675.
28. Schwerzmann, K. et al (1989) Oxidative capacity of muscle and mitochondria: correlation of physiological, biochemical, and morphometric characteristics. *Proceedings of the National Academy of Sciences*, 86(5), 1583-1587.
29. Tarnopolsky, M. A.& Raha S. (2005) Mitochondrial myopathies: diagnosis, exercise intolerance, and treatment options. *Medicine and science in sports and exercise*, 37(12), 2086-2093.
30. Morino, K., Petersen K. F., Shulman G. I. (2006) Molecular Mechanisms of Insulin Resistance in Humans and Their Potential Links With Mitochondrial Dysfunction. *Diabetes*, 55(Supplement 2), S9-S15.
31. Lewington, S. et al (2002) Age-specific relevance of usual blood pressure to vascular mortality: a meta-analysis of individual data for one million adults in 61 prospective studies. *Lancet*, 360(9349), 1903-1913.
32. Wisløff, U. et al (2007) Superior Cardiovascular Effect of Aerobic Interval Training Versus Moderate Continuous Training in Heart Failure Patients: A Randomized Study. *Circulation*, 115(24), 3086-3094.
33. Schjerve, I. E. et al (2008) Both aerobic endurance and strength training programmes improve cardiovascular health in obese adults. *Clinical Science (London, England : 1979)*, 115(9), 283-293.
34. Cerhan, J. R. et al (2014) A Pooled Analysis of Waist Circumference and Mortality in 650,000 Adults. *Mayo Clinic proceedings*, 89(3), 335-345.
35. Janssen, I., Katzmarzyk P. T., Ross R. (2004) Waist circumference and not body mass index explains obesity-related health risk. *The American Journal of Clinical Nutrition*, 79(3), 379-384.
36. Kelly, B. et al (2013) The impact of high-intensity intermittent exercise on resting metabolic rate in healthy males. *European Journal of Applied Physiology*, 113(12), 3039-3047.
37. Whyte, L. J. et al (2013) Effects of single bout of very high-intensity exercise on metabolic health biomarkers in overweight/obese sedentary men. *Metabolism*, 62(2), 212-219.
38. Konopka, A. R.& Harber M. P. (2014) Skeletal Muscle Hypertrophy After Aerobic Exercise Training. *Exercise and Sport Sciences Reviews*,

42(2), 53-61.

39. Mitchell, C. J. et al (2012) Resistance exercise load does not determine training-mediated hypertrophic gains in young men. *Journal of Applied Physiology*, 113(1), 71-77.

40. Walton, C. et al (1995) Body fat distribution, rather than overall adiposity, influences serum lipids and lipoproteins in healthy men independently of age. *The American Journal of Medicine*, 99(5), 459-464.

41. Boulé, N. G. et al (2005) Effects of Exercise Training on Glucose Homeostasis: The HERITAGE Family Study. *Diabetes care*, 28(1), 108-114.

42. Cochran, A. J. R. et al (2014) Intermittent and continuous high-intensity exercise training induce similar acute but different chronic muscle adaptations. *Experimental Physiology*, 99(5), 782-791.