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**Department of Clinical Sciences and Nutrition**

**MSc In Exercise & Nutrition Science - Dublin**

***High intensity interval training, the best HIIT FITT: Literature review, systematic review and comparative analysis***

**“Dissertation submitted in accordance with the requirements of the University of Chester for the degree of Master of Science”**

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**September 2016**

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**(4096 words)**

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**Acknowledgements**

I would like to acknowledge and thank Dr. Stephen Fallows and Dr. Mike Morris for their help and guidance in the preparation of this dissertation.

Chomh maith le sin ba mhian liom buíochas a ghabháil le mo chlann agus mo chairde as an dtacaíocht agus an ngrá a dtugann said dom i gconaí. Ar deireadh, chaithfidh mé adhmháil nach mbeadh mé in ann é seo go léir a chur le chéile gan Al agus an foighne a thaispeáin se agus a thaispeánann se dom gach lá, na mílte cupan tae a rinne sé dom, agus an tacaíocht agus grá a fhaighim lá i ndiaidh lae uaidh. Go raibh maith agaibh go léir.

**Abstract**

**Background** - High-intensity interval training (HIIT) may be a viable approach to improving the health of the general population. The objective of this literature review was to investigate the current research available on HIIT, examining its evolution, and health benefits as well as the barriers that exist to this type of training.

**Conclusions** - HIIT is a feasible and time-efficient approach for improving overall health indicators in the general adult population.

**Keywords: Health, exercise, benefits, barriers.**

**Intended Journal and rationale for selection:** *British Journal of Sports Medicine*

The aim of this review is to help establish the current and emerging protocols involved in high intensity interval training for adults and to place them in context of the ACSM recommendation of 75 minutes of intense exercise per week. It will also look at health benefits and barriers of HIIT. BJSM is a leading clinical journal and the relevance of the chosen topic lies in the aim to help clarify exercise protocols and guidelines. The topic of HIIT is a current one with broad scope for interpretation. Further clarification of intense exercise may help to encourage the increased participation of the general population.

**Declaration**

"This work is original and has not been submitted previously in support of a degree qualification or other course.”

**Signed:**

**Dated:**

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**List of Abbreviations**

|  |  |
| --- | --- |
| **HIIT** | High intensity interval training or high intensity intermitent training |
| **FITT** | Frequency intensity time type |
| **BJSM** | British Journal of Sports Medicine |
| **ACSM** | American College of Sports Medicine |
| **CMO** | Chief Medical Officer |
| **NCD** | Non-communicable diseases |
| **CVD** | Cardiovascular disease |
| **SSE** | Steady state exercise |
| **MIET** | Moderate intensity endurance training |
| **MICT** | Moderate intenisty continuous training |
| **CV** | Cardiovascular |
| **HVIT** | High volume interval training |
| **VIIT** | Varied intenisty interval training |
| **REHIT** | Reduced exertion high intensity training |
| **RPE** | Rating of perceived exertion |
| **PACES** | Physical activity enjoyment scale |
| **TDEE** | Total daily energy expenditure |
| **ET** | Endurance training |

***High intensity interval training, the best HIIT FITT: Literature Review***

* 1. **Introduction**

High intensity interval exercise (HIIE) or high intensity interval training (HIIT) is a form of exercise training that aims to work the body, at close to maximum capacity, repeatedly, for short bursts of time ranging from 8 seconds to several minutes, interspersed with periods of rest or active recovery (Gibala, 2008; Weston, Taylor, Batterham & Hopkins, 2014). The primary goal is to repeatedly pressurize the physiological systems beyond the level required in actual performance. For non-athletes this equates to exercising for short, intermittent periods of time, at a much higher intensity than would be considered normal i.e. 90% v 70% V̇*O2max* (Bartlett et al. 2011). The basic rationale behind this type of exercise currently focuses on information from studies, which will be reported discussed throughout this review, including Billat (2001); Gibala (2008); Laurent, Vervaecke, Kutz and Green (2014) and Laursen and Jenkins (2002) that demonstrate how HIIT can produce similar training benefits to steady state exercise (SSE) in a much shorter timeframe particularly for untrained persons. From a physiological perspective, as Gibala and Ballantyne (2007) and Billat (2001) outline, this type of exercise results in the depletion of muscle glycogen reserves and causes an increase in lactate production as well as a reduction in muscle PH. The rest interval then allows a partial or full recovery before the beginning of the next interval. As the number of intervals increases, the recovery time becomes insufficient for homeostasis to be achieved resulting in physiological adaptations to the workload. However, the capacity to sustain intense workloads that rely heavily upon anaerobic pathways is limited (Burgomaster et al. 2008). Intervals in excess of 2-3 minutes rely more upon the aerobic system and require lower intensities. By working at high intensities and permitting the systems to replenish during recovery intervals, exercisers can continue to stress the physiological systems during the workout, resulting in quicker adaptations than are commonly seen from continuous steady state exercise (SSE) at lower intensities (Gaesser & Angadi, 2011).

Current exercise guidelines published by the ACSM (2011), CMO (2011) state that the general population should include 30 - 75 minutes of intense exercise or 150 minutes of moderate intensity exercise in their lives each week. To date, researchers (Laursen & Jenkins, 2002; Buchheit & Laursen, 2013; Hatle et al., 2014) have outlined the various health benefits attainable through the inclusion of HIIT programmes for a variety of populations ranging from rehabilitation patients to elite athletes. In the existing body of research on HIIT the ratio of work intervals vary greatly from just seconds to several minutes with rest times and ratios ranging just as widely, as well as intensities of up to 95% of maximum heart rate (HRmax) (Laursen & Jenkins, 2002).

Perceptions and understanding of exercise parameters influence behaviour (Sniehotta, Scholz & Schwarzer, 2005). By clearly outlining HIIT protocols that have been shown to be effective, exercisers may be more inclined to participate in and to adhere to recommended regimes. With a plethora information available, it may not be clear how to begin incorporating HIIT, therefore the primary aim of this systematic review is to try to outline the FITT principals (frequency, intensity, time and type) appropriate for the general adult population to incorporate HIIT into an exercise regime.

**2.1 Physiological Adaptations**

The World Health Organization’s fact sheet from January 2015 stated that non-communicable diseases (NCD) kill 38 million people each year with cardiovascular diseases (CVD) accounting for most NCD deaths, or 17.5 million people annually. Cancers, respiratory diseases and diabetes are also noted as worldwide killers. Bearing this in mind, it is worth considering the potential role HIIT can play in fighting the battle against NCDs. The primary endorsement of HIIT is that it offers similar health benefits to SSE but in a shorter timeframe. HIIT has been shown to illicit numerous, significant physiological adaptations including but not limited to, increases in V̇*O2max*, insulin sensitivity and weight-loss (Kessler, Sisson & Short, 2012; Gibala, 2008; Laursen & Jenkins, 2002) (see Table 1.1)which are all directly related to protection from and treatment of NCDs (Earnest, 2009).

**Table 1.1 Health benefits of HIIT and deaths from non-communicable diseases.**

|  |  |  |
| --- | --- | --- |
| Deaths from NCDs  (million per annum) | Health Benefits of HIIT | |
| **Increases** | **Decreases** |
| CVD 17.5m | ↑V̇O2peak (9.1%\*) & V̇O2max (15%\*) | ↓Risk of CVD Death (0.61 M and 0.49 F) |
| Cancers 8.2m | ↑Endothelial Function (9%\*) | ↓ Metabolic Syndrome Risk Factors (5.9) |
| Respiratory diseases 4m | ↑ Fat Loss (~14%) | ↓Central Body Fat (~4%) |
| Diabetes 1.5m | ↑ Insulin sensitivity (~35%) | ↓Fasting Plasma Insulin (31%) |

Figures from WHO (2015) and averaged results from Boutcher and Boutcher (2010); Weston et al. (2014), Wisløff et al. (2006); Tjønna et al. (2008); Trapp et al. (2007)

*\* denotes a significant improvement.*

NCD (non-communicable diseases), CVD (cardiovascular disease), M (male), F (female)

As previously outlined, the adaptations are similar to those seen following long-term SSE. The primary difference being HIIT may provoke these adaptations in a much shorter timeframe with clinical results being achieved in as little as 4-6 sessions in previously untrained as well as trained participants (Kubukeli, Noakes & Dennis, 2002; Laursen & Jenkins, 2002; Weston et al., 2014). One of the main problems with this research is the transfer of protocols to real-life situations. It is difficult to tell whether the general population is well enough equipped to effectively convert extreme clinical practices into everyday exercise routines. With the potential benefits on offer from HIIT, it is worth finding out.

**2.2 History**

Dr. Woldemar Gerschler and Dr. Herbert Reindel successfully pioneered interval training for performance enhancement, based on clinically examined physiological and psychological responses. In 1996, Tabata, et al. continued the exploration of HIIT on performance indicators when they compared the effects of moderate-intensity endurance training (MIET) to HIIT on anaerobic capacity, V̇*O2max* and energy release. It was concluded that MIET that improved maximal aerobic power did not change anaerobic capacity but that sufficient HIIT may have resulted in significant improvements (*P* < 0.01) in V̇*O2max* and anaerobic capacity of 7 ml.kg-1.min-1 and 28% respectively. These adaptations resulted from imposing intensive stimuli on both anaerobic and aerobic energy supplying systems (Figure 1.1).

Figure 1.1 Comparison % increase between Moderate Intensity Endurance Training (MIET) & High Intensity Interval Training (HIIT) (Tabata et al., 1996)

This study indicated that HIIT could improve anaerobic and aerobic systems significantly more than MIET, over a shorter period of time. While this was a small study of just 14 men, similar results have been repeated in many studies since and there is now widespread clinical acceptance of the power of HIIT to positively impact V̇*O2max* in non-elite populations.

More recent studies investigated the potential for HIIT to improve other general health and fitness markers. As a number of meta-analyses (Gist, Fedewa, Dishman, & Cureton, 2014; Milanović, Sporiš & Weston, 2015; Weston, Wisløff & Coombes, 2014) point out, neither HIIT protocols, control nor comparison groups are standardized across studies and this makes comparing results challenging, however, a sample of study results is summarized in Table 1.2 and Figures 1.2 and 1.3.

**2.3 HIIT for Health**

**Table 1.2 HIIT Comparison of HIIT and MICT in non-patient populations**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Author & Year | Study Duration | Population (N size) | Intensity | Effect on Health |
| Burgomaster et. al, (2008) | Wingate, 6 wks, 3/wk | 20 young M & F | All-out | Compared to endurance training, training volume and time ~90% & 66% , with similar metabolic responses. |
| Gibala and McGee, (2008) summary | Wingate,  2 wks,  6 sessions | Healthy college-aged M&F | All-out | Skeletal muscle oxidative capacity 15-35%.  Endurance performance ~doubled |
| Hood et al., 2011 | 2 wks,  6 sessions | 7 SED middle aged M&F | 60% peak power | Muscle oxidative capacity  ∼35%,  Glucose transporter protein content ∼260%, insulin sensitivity  ∼35% |
| Tabata et al., (1996) | 6 wks, 5 d/wk | 7 healthy young M | 170% V̇*O2max* | V̇*O2max*  14.5% (7 ml.kg-1.min-1)  Anaerobic capacity by 28% |
| Trapp, et al., (2007) | 15 wks, 20 mins | 16 F (trained & untrained) | 70% V̇*O2peak* | Lactate production  from baseline to 4-8 mmol/L |

All studies used cycle ergometers. M= male, F = female, SED = sedentary

Figure 1.2 Health Benefits of HIIT

Muscle Oxidative Capacity (MOC)

Figure 1.3 % Time and Training Volume of HIIT saved compared to SSE

Results vary across the range of physiological adaptations but in general significant gains have been found in V̇*O2max* (~10%, *P* < 0.01), muscle oxidative capacity (∼35%, *P* < 0.01) and insulin sensitivity (+1.66 ± 0.61 mg kg−1 min−1, *P*= 0.04) following HIIT with much lower training time and volume, as low as 2 to 10 minutes of intense exercise. Gains were reported across sexes, levels of activity and ages. It is noteworthy that the HIIT protocols that produced results not significantly different from the SSE groups still reported much lower training time and volume. These studies still had relatively low numbers of participants but produced consistent results across a range of health indicators and populations.

**2.4 HIIT and the Patient Population**

While there has been a focus on studies examining the impact of HIIT to improve performance, there is also a growing body of research on the potential role of HIIT to aid clinical populations. Weston et al. (2014) summarized their findings of HIIT compared to MICT in a meta-analysis involving cardiac patients (Figure 1.4) and showed an overwhelming favouring of the capacity of HIIT to improve health markers.

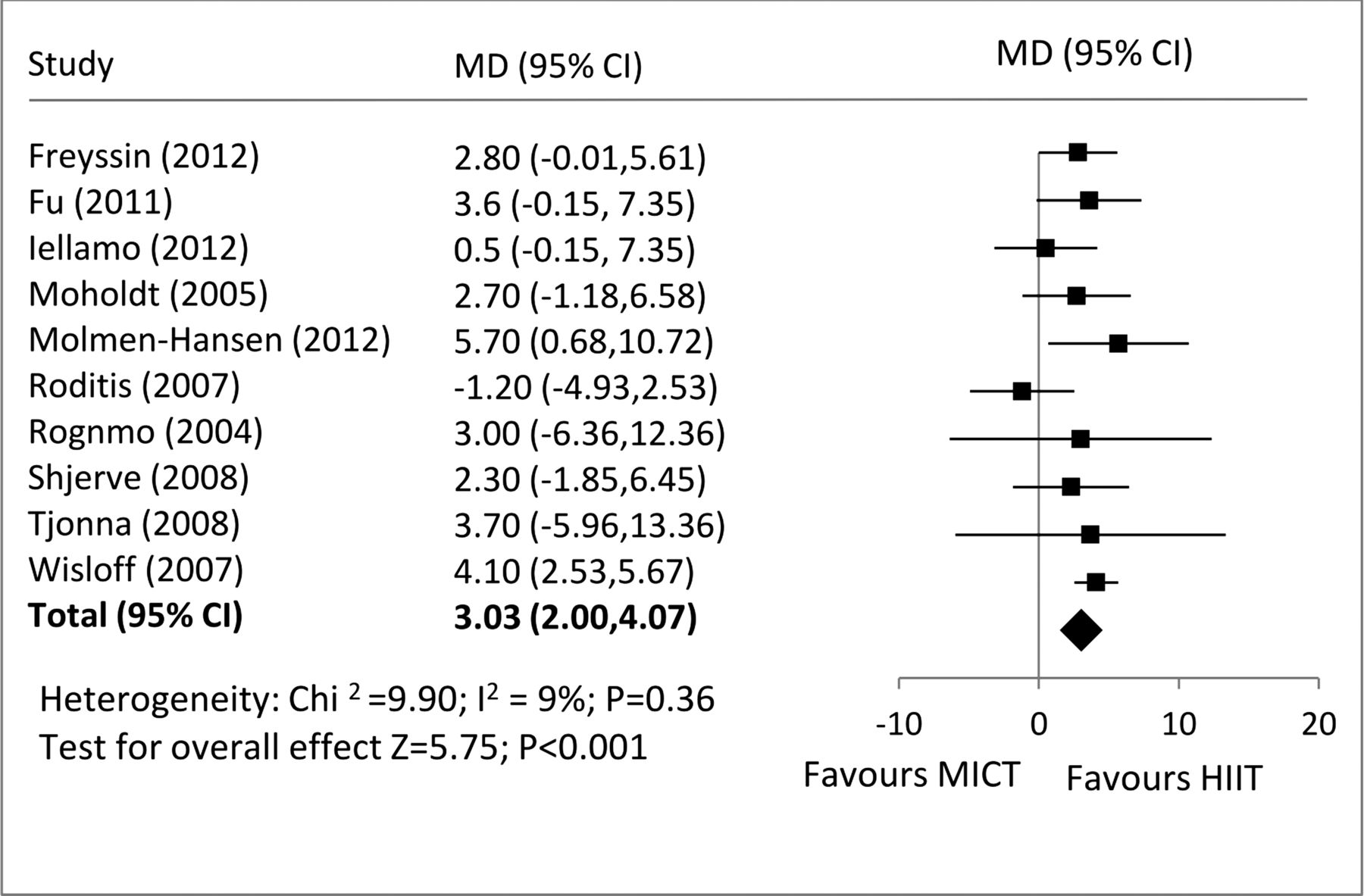
**

Figure 1.4 Weston, Wisløff & Coombes (2014) HIIT v MICT for health markers in patients with life-style induced cardio-metabolic disease.

They inferred that HIIT significantly increased (9.1%, p<0.001) cardio respiratory fitness (CRF) in patients with lifestyle-induced chronic diseases by almost double that of MICT, and that HIIT was significantly better for improving endothelial function, reducing central body fat and fasting plasma insulin, and improving V̇*O2*max, again, advocating the use of HIIT as a means of improving general health across a range of populations, in a shorter time-frame.

**2.4.1 Cardiac, Diabetes and Metabolic Syndrome**

Other clinical populations also stand to benefit from the inclusion of HIIT as a treatment as outlined in Table 1.3. In the comprehensive HUNT study of 27,143 men and 28,929 women Wisløff et al. (2006) demonstrated that a single weekly bout of HIIT reduced the risk of cardiovascular death, both in men [relative risk (RR) 0.61, 95% confidence interval (CI) 0.49-0.75], and women (RR 0.49, 95% CI 0.27-0.89), compared with no activity. They found that the risk reduction related to exercise increased with increasing age in men, but not in women and noted that there was no additional benefit from increasing the duration or the number of exercise sessions per week. It was concluded that the observation that exercise training reduces cardiovascular mortality was robust and consistent. The nature of this study and the volume of participants is noteworthy, as is the support it offers for the potential role of HIIT in an area like CV health.

HIIT has also been shown to offer protective health benefits to patients of diabetes and the metabolic syndrome.Gaesser and Angadi (2011) and Little, Safdar, Bishop, Tarnopolsky and Gibala (2011) found that HIIT could improve glucose control and markers of skeletal muscle metabolism in patients with Type 2 Diabetes (T2D). Tjønna et al. (2008) investigated patients of metabolic syndrome and compared effects of MICT and HIIT in the form of aerobic interval training (AIT). It was found that HIIT was more effective at removing metabolic syndrome risk factors including endothelial function, insulin action, and lipogenesis, than MICT. However both were equally effective at lowering mean arterial blood pressure and reducing body weight and fat (Table 1.3).

**2.5 Summary**

Overall the most common and most significant adaptation from HIIT appears to be the improvement in V̇*O2max*, which is directly related to enhanced protection from CVD (Boutcher & Boutcher, 2010). Of similar importance are the dramatic effects HIIT has on insulin sensitivity. There is also the impact on visceral fat and subcutaneous fat-loss which, while not always significant when compared to SSE, is still encouraging. HIIT has the added benefit of stimulating these results in a shorter timeframe with optimistic reactions regarding enjoyment and perceived exertion levels, which will be discussed further in the next section.

**Table 1.3 Summary of studies investigating health benefits of HIIT**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Author & Year | Study Design | Population (N size) | Intensity | Work to Rest Intervals | Health Benefit |
| Weston, et al., (2014) | Meta-analysis  10 studies, majority cycle erg, treadmill | N = 273  CVD, MetS, Obesity | 75-95% MHR  averages from meta - analysis | Ranging from 1.3:1 to 1:2. | VO2peak  by 19.4%  Systolic and diastolic blood pressure by 10mmHg and 6mmHg respectively  CRF  by almost double that of MICT |
| Wisløff et al., (2006) | HUNT study, exercise and CV mortality | 27,143 M, 28,929 F | 45 min at 80% of maximal oxygen uptake | 1 bout of high intensity exercise | One weekly bout of HIIT risk of CVD death, in men [relative risk (RR) 0.61, 95% confidence interval (CI) 0.49-0.75], and women (RR 0.49, 95% CI 0.27-0.89), versus no activity. |
| Little et al., (2011) | Over 2 wk, 6 sessions | 8 subjects | 6 HIIT ~ 90% maximal heart rate (HRmax) | 10 x 60-s cycle ergometer interspersed with 60 s of rest. 1:1 | Blood glucose by 13% - 30%.  Muscle mitochondrial proteins  by 20–70%, GLUT4 protein levels  by 369%. |
| Tjønna et al., (2008) | (AIT) 3 times a week for 16 weeks | 32 MetS patients | Interval=90% HRmax  Recovery=70% HRmax | 4 x 4-minute intervals with 3-minute active recovery | V̇O2max  by 35% and risk factors of MetS (from 5.9 before to 4.0 after), enhanced endothelial function (9%). |

MetS = metabolic syndrome, CV = cardiovascular, CVD = cardiovascular disease, AIT = aerobic interval training, MHR = maximum heart rate

**3.1 Variations and Programming**

While widespread agreement on the benefits of HIIT dominates the literature and research, (Bartlett et al. 2011; Kessler et al. 2012 and Milanović et al. 2015) the question of specificity is still open for debate. Numerous HIIT protocols are referenced within the existing body of research offering a variety of frequencies, intensities, methods and work to rest ratios. These protocols include high intensity interval training (HIIT), high-volume interval training (HVIT), variable-intensity interval training (VIIT), reduced-exertion HIT (REHIT) constant-load low-volume HIT and “extreme” HIIT. Results vary but are generally positive for all and are outlined below. The issue is ascertaining the most appropriate protocol to recommend for the general population to follow with clear guidelines on frequency, intensity, time and type (FITT).

**3.2 Finding the FITT**

The beneficial role HIIT can play in treating diabetes has been noted previously, but Metcalfe, Babraj, Fawkner and Vollaard (2011) trialed a novel REHIT exercise intervention. While the results were not conclusively significant across the study, it was found that REHIT could significantly increase insulin sensitivity by 28% in men, but not in women, despite relatively low ratings of perceived exertion (RPE) with a maximum of 14 on the Borg scale, (Borg 1970) compared to control groups and still yielded increases in aerobic capacity of 15% and 12% in men and women respectively. The 10-minute REHIT session used in this study represented the smallest volume of exercise that has been shown to induce positive health benefits. It used ‘all-out’ sprints on a cycle ergometer as the mode of exercise, which is a common mode across the research. The conclusion was that the programme could improve metabolic health and aerobic capacity in a genuinely time-efficient alternative to SSE. From a FITT perspective for the general population, this may be a good starting point to work from.

In addition to this after Gibala and McGee (2008) initially introduced an “extreme” version of HIIT, using 4–6 “all-out” Wingate tests as the exercise stressor they subsequently modified the protocol to a less intense 10-60-s interval. This new protocol elicited ratings of perceived exertion (RPE) of 4–8 on a 10-point scale, suggesting that this HIIT paradigm had clinical and non-clinical utility due to the relatively low exertion levels recorded. Seiler and Sjursen (2004) found that under self-paced conditions, well-trained runners performed HIIT at an RPE of approximately 17, independent of interval duration. It was found in the few investigations that addressed the issue of intensity, that subjects appeared to not only tolerate the higher exercise intensity but to actually prefer HIIT to the more traditional SSE (Bartlett et al. 2011; Jung, Zelt, Bourne & Gurd 2014). These results warrant further investigation to assess the implications of intensity and RPE for HIIT prescription for non-athletes and sedentary individuals, but it can be assumed that ‘all-out’ cycle sprints could be a viable option. If ‘all-out’ sprints become the starting point for exercise programming, the next step would be to assess how far below this exertion level HIIT can be adjusted and still be practical and worthwhile.

**3.3 Enjoyment and RPE**

In young healthy males, Bartlett et al. (2011) reported that ratings of perceived “enjoyment” were higher for HIIT than for SSE on the PACES scale (88 v 61), despite RPE being higher for HIIT than SSE (14 v 13). Similarly, patients with heart failure found HIIT more motivating than traditional steady-state exercise, which was perceived as “quite boring”. On the other hand, there appears to also be a case for moderating the exercise intensity and still availing of beneficial results. Boyd, Simpson, Jung and Gurd (2013) carried out a study on lower intensity interval training using a comparison of 9 sessions of interval training with a 1-min on, 1-min off protocol on a cycle ergometer between either 70% (low) or 100% (high) peak work rate. Exercise performance improved by 8.6 ± 7.6% in the low group and 14.1 ± 4.3% in the high group. There were no differences in perceived enjoyment or self-efficacy between groups despite significantly lower affect (enjoyment) scores during training in the HI group. When the comparisons are drawn it would appear that the lower intensity group has clinical viability. Overall, however, no clear conclusions have been drawn regarding the most effective intensity for a HIIT session. This is probably related to the number of variables in question from mode of exercise, to interval duration, work to rest ratio and type of recovery between work intervals.

**Table 1.4 Studies investigating the role of interval timings**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Study | Protocol | Time & Intensity | Results | Recommended |
| Edge et al., (2013) | HIIT 1 min v 3 min rest intervals | 6-10 x 2min intervals 3/wk  140% LTDmax, + 10% / wk | 181 ± 10 bpm and 94% of HRmax v 175 ± 9 bpm and 91% of HRmax | No preference |
| Price & Halabi, (2005) | HIIT 1, 2, 4 min recovery | 40 min HIIT treadmill  Repeated sprints at 120% of the speed at V̇*O2max*  Passive recovery | long and medium work – rest durations > short work – rest duration. Greater physiological strain and carbohydrate utilization. | Longer |
| Seiler & Hetlelid, (2005) | HIIT 1, 2, 4 min recovery | HIIT readmill 5% incline. 6x 4-min work 1-, 2-, or 4-m recovery  Highest possible avg running speed for the work intervals | V̇*O2max* higher @ 2-min rest.  Blood La similar (6.2 +/- 2.6, 6.8 +/- 2.9, 6.2 +/- 2.6 mmol.L(-1))  Running velocity increased (14.7 +/- 0.7 vs 14.4 +/- 0.8 km.h(-1), P = 0.02) from 1 to 2 min rest | Longer |
| Price & Moss (2007) | HIIT  1:1.5 work:rest ratio short (6:9 s),  long (24:36 s) | 20 mins | HR, *O2* consumption, RER, blood glucose all similar across trials.  Blood La greater during the long  RPE greater for long v short (16.6 and 15.1 respectively) | Longer |

**3.4 Interval Manipulation**

While some studies examined intensities others investigated the role of interval timings (Table 1.4). Edge et al. (2013) concluded that manipulation of the rest period during intense interval training did not affect changes in muscle Na+,K+-ATPase content, PCr resynthesis or V̇*O2peak* and that using short rest periods during HIIT did not offer any advantage over the use of longer rest intervals when training intensity and volume were matched. This was attributed to the similar muscle adaptations induced by both programmes. Similar results were reported by Price and Halabi (2005); Seiler and Hetelid (2005) and Price and Moss (2007) all concluding that using intervals with longer rest durations offered similar or improved results to shorter ones.

Figure 1.5 Comparison of short and long interval durations in HIIT. Results are presented as percentage differences adapted from studies by Price and Moss (2007); Price and Halabi (2005); Seiler and Sjursen (2004).

Seiler and Hetlelid (2005); Price and Halabi (2005) and Price and Moss (2005) all found that varying rest duration had limited impact on performance and that HIIT involving longer work-rest durations elicited greater increases % HRmax, RPE and % V̇*O2max* than the same amount of exercise undertaken with a shorter work-rest duration (Figure 1.5). Overall these studies seem to indicate that longer work-to-rest interval durations are more beneficial yet the range of interval times is still very broad; from 24 seconds to 5 minutes. This suggestion of slightly longer work-rest intervals, counteract one of the prime benefits of HIIT, namely, the shorter workout times compared to SSE. Overall, however, HIIT would still require less time than SSE training.

**3.5 Sex Differences**

In an interesting study on sex-specific responses to HIIT Laurent et al. (2014) found that that men self-selected higher % velocity V̇*O2peak* (84.5 vs. 80.7%), whereas women produced higher %HRmax (96.9 vs. 92.1%) and % V̇*O2peak* (89.6 vs. 86.1%) with no difference in lactate or RPE. These findings suggested that women demonstrated improved recovery during HIIT, as they self-selected intensities to suit work/rest intervals that result in greater cardiovascular strain. While there is no overwhelming support of an exact sex difference with respect to HIIT evidence indicates that sex-specific training considerations could be included in programme design.

**3.6 Summary**

There are few findings that can be used to generate definitive guidelines for choosing specific HIIT protocols as the ranges involved vary greatly from study to study. Those mentioned above contribute to the idea that the principles of specificity and overload should be applied appropriately by controlling variables such as intensity and interval timings while also taking gender and mode of training into consideration. These studies suggest that alternating the load in HIIT training offers the potential for significant health benefits and risk-reductions but while clinically viable, it remains to be seen which protocol could be most effectively implemented in a real world setting across a variety of populations. There is supporting evidence that HIIT intensity levels can be manipulated downward while work-to-rest durations can vary, but longer intervals appear to be more beneficial, allowing for maximization of health benefits and enjoyment.

**4.1 Barriers and Benefits**

Time-constrained exercisers will naturally want to know how little they need to do to still reap benefits. Gaesser and Angadi (2011) noted that with a large percentage of the US population failing to meet minimum physical activity guidelines HIIT offers the potential to assist sedentary or less active individuals to overcome this significant time-barrier to maintaining a physically active lifestyle.As has been outlined, HIIT offers a wealth of health benefits, but a number of concerns regarding this type of training and exercise have also been outlined.

**4.2 Benefits**

Time is often cited as one of the primary barriers to exercise by the general population. How often and for how long HIIT should be included in an exercise regime is still open for debate. Studies have demonstrated that as little as one session of HIIT per week can offer significant health benefits when compared to SSE (Roxburgh, Nolan, Weatherwax & Dalleck, 2014). Studies by Wisløff et al., (2006) and Sevits et al. (2013) indicated that just a single weekly bout of high-intensity exercise was found to reduce the risk of cardiovascular disease in both men and women (relative risk: 0.61 and 0.49, respectively) while increasing TDEE (total daily energy expenditure) in every research participant (n=15 and 12) (9169 ± 243 vs. 10,111 ± 260 kJ/day; P < 0.0001); with an increase of 946 ± 62 kJ/day (∼10%).

Interestingly, increasing the duration or number of exercise sessions appeared to offer no additional benefits. To put this into context Sevits et al. (2013) estimated that an increase in total daily energy expenditure of approximately 200–600 kJ with no change in dietary intake was sufficient to prevent weight gain in ~90% of adults living in industrialized countries (Figure 1.6). In a similar studySmith-Ryan, Melvin and Wingfield (2015) concluded that HIIT offered minimal time demands (i.e. 20 minutes of total work, 3 times per week, split into either 10x1 min or 5x2min intervals) and was well tolerated by participants, with no adverse events reported and 100% compliance (N=25 men). Similarly Burgomaster et al., (2008) found that just 3 sessions of HIIT per week (approx. 30 minutes) was a time-efficient strategy to increase skeletal muscle oxidative capacity and induce specific metabolic adaptations during exercise that are comparable to traditional endurance training (ET).

Figure 1.6 The positive impact of one HIIT session per week.

TDEE = total daily energy expenditure. TDEE A = the % increase required to prevent weight gain in adults. TDEE B = the % acquired by HIIT. CVD is average % of risk reduction from HIIT for adults.

Talanian, Galloway, Heigenhauser, Bonen and Spriet (2007) also concluded that for untrained populations seven sessions of HIIT over a 2 week period offered a short-duration stimulus to improve whole body fat oxidation and the capacity for skeletal muscle to oxidize fat. They noted that HIIT could be used by untrained individuals to improve initial fitness by training for 3 hours per week for 2 weeks. However, the HIIT protocol used was very intense (10 x 4 min work at 90% V̇*O2peak* with 2 min rest) and unlikely to be sustainable outside of a clinical situation.

These studies reported interesting and positive physiological and psychological results but considering the FITT principals involved in each study varied widely from just one twenty minute session per week to five sessions per week it is evident that programming for HIIT is far from conclusive or immediately transferrable to a real-world setting.

Figure 1.7 Comparison of Interval Running (IR) to Continuous Running (CR)

For rating of perceived enjoyment, exertion and maximum heart rate

**4.3 RPE**

Bartlett et al. (2011) in their study of interval running (IR) compared to continuous running (CR) (see Figure 1.7) found that ratings of perceived enjoyment after exercise were higher (P < 0.05) following IR compared with CR (88 ± 6 vs. 61 ± 12) despite higher (P < 0.05) RPE (14 ± 1 vs. 13 ± 1). Interestingly, no differences were recorded in average heart rate, total V̇*O2max* or energy expenditure. These results indicated that the greater enjoyment associated with high-intensity interval running may be relevant for improving exercise adherence, since running is a low-cost exercise intervention requiring no exercise equipment and similar relative exercise intensities have previously induced health benefits in multiple populations. However, it would be important for exercisers to have a clear method of gauging the intensity of intervals using RPE scales, machine monitors or similar.

**Table 1.5 Pros and Cons of HIIT**

|  |  |
| --- | --- |
| *Pros* | *Cons* |
| *↑*V̇*O2peak and* V̇*O2max* | **Adaptive response to training is limited** |
| *↑Endothelial Function* | **Non-adherence is an issue** |
| *↑ Insulin sensitivity* | **Some HIIT protocols disregard current standards for developing muscular fitness.** |
| *↑ Fat Loss* | **Can be difficult to select and monitor appropriate intensity** |
| *↓Central Body Fat* | **Insufficient recoveries can results in injury, strain or overtraining.** |
| *↓Fasting Plasma Insulin* |  |
| *↓Risk of Cardiovascular Death* |  |
| *↓Metabolic Syndrome Risk Factors* |  |

**4.4 Barriers**

While it may appear to be the more enjoyable mode of exercise, Zavorsky, Saul, Decker and Ruiz (2007) discovered during their meta-analysis on pulmonary oedema (PO) caused by exercise protocols that the chance of triggering PO from exhaustive max effort exercise was 4 times greater (65% v 16% P  0.01) than SSE. They also noted that the likelihood of triggering pulmonary oedema was likely independent of lung size, sex, moderate levels of hypoxia, and aerobic fitness. This could have serious implications for HIIT given the intensities required by certain protocols and further research is needed.

Lunt et al. (2014) used a community based feasibility study to expand on the findings of previous studies by showing that it was possible to improve CRF in overweight, inactive participants and at the same time reduce the duration of the exercise sessions, compared to walking. It was noted that the overall change in V̇*O2max* was less than the changes observed in earlier more structured research settings. They considered non-adherence to the programme within the real world setting of their study to be the primary cause for the lesser, observed changes in V̇*O2max*. Bergeron et al (2011) highlighted the concern that many characteristics of HIIT workouts disregard current standards for developing muscular fitness. They noted that repetitive, timed, maximal or near-maximal efforts using short or insufficient recoveries, could predispose individuals to injury, strain or overtraining, elevating oxidative stress and cellular damage beyond the body’s natural ability to recover, also suppressing immune responses and negatively impacting technique. Other barriers related to HIIT in a real-world setting include how to gauge the appropriate intensities for work and recovery. A summary of the pros and cons of HIIT can be found in Table 1.5. The majority of studies in this paper focus on clinical trials and there are indications of complications with the effective transfer of HIIT protocols to a real-world setting.

**5.1 Conclusion**

HIIT has been clinically proven to be a time efficient method of reaping the health benefits offered by traditional endurance style exercise. Trained, untrained and clinical populations stand to benefit from it. Research into precise work to rest ratios, interval durations, effective intensities and modes of training and the full health implications of HIIT is still ongoing. Clinical settings allow patients and untrained participants to be closely guided and monitored, but outside this setting, effective HIIT will require the use of heart rate monitors, accurate use of the RPE scale or knowledge of HRmax and V̇*O2max*. There is evidence that exercisers from a variety of populations can withstand the high intensities of ‘all-out’ sprinting and that work/rest intervals can be relatively long, but definitive intensities and ratios have yet to be established. If HIIT is to be promoted as an effective means for the average person to meet health goals, clear guidelines and precautions need to be established and outlined in order for HIIT to be integrated successfully into exercise practices. With the potential health benefits available through HIIT it would appear to be in the interest of health agencies to pursue this line of research to clarify a public stance and recommendations on HIIT. The accompanying systematic review and comparative analysis attempts to synthesize results from existing research in order to establish optimum guidelines for FITT principles of HIIT for the general population.

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**Department of Clinical Sciences and Nutrition**

**MSc In Exercise & Nutrition Science - Dublin**

***High intensity interval training, the best HIIT FITT: a systematic review and comparative analysis***

**“Dissertation submitted in accordance with the requirements of the University of Chester for the degree of Master of Science”**

**(3796 words)**

**Nicola O’Loughlin**

**September 2016**

**Abstract  
Background** - High-intensity interval training (HIIT) has been shown to be a time-efficient, effective method of exercise offering numerous health benefits to the general population. The objective of this systematic review was to evaluate the FITT principles 9frequency, intensity, time and type) of HIIT to enable the composition of a clear set of guidelines for the general population to follow. Current guidelines recommend 150 minutes of moderate exercise or 75 minutes of vigorous exercise per week with limited elaboration.

**Methods** - A structured electronic search of all publication years from January 1996 to June 2016 using PubMed, CINAHL Complete, MEDLINE Complete, SPORTDiscus with Full Text, Psychology and Behavioural Sciences Collection and Cochrane was conducted using these string searches: (high intensity interval training OR high intensity intermittent training OR high intensity training) AND (adult) NOT (patient OR adolescent OR trained). The results were limited to peer-reviewed publications written in English. A comparative-analysis was undertaken to determine the most effective FITT principles of HIIT protocols for the general adult population.

**Results** - 16 trials, including 500 participants, met the eligibility criteria and were included in the report. Based on findings, the FITT principles of HIIT recommendations to elicit significant positive effect on V̇*O2max* were outlined as follows; Frequency- 3 sessions per week, Intensity – 85-95% HRmax, Time – 20 minutes, Type of work to rest intervals - 2:1.

**Conclusions** - HIIT is a feasible, safe and time-efficient approach for improving cardiorespiratory fitness in adult populations. Recommendations for HIIT based on FITT to balance health benefits with time constraints are; 3 times per week at an intensity of 85-95%HRmax for 20 minutes at a 2:1 work to rest ratio and most forms of cardiovascular activity will suffice.

**Keywords: duration, recovery, V̇*O2max*, benefits.**

**Intended Journal and rationale for selection:** *British Journal of Sports Medicine*

The aim of this systematic review is to determine the optimal FITT requirements of HIIT for adults and compare them to the recommendations of 75 minutes of intense exercise per week. It will also look at health outcomes of HIIT and primarily its impact on V̇*O2max.* BJSM is a leading clinical journal and the topic chosen has relevance to clinicians, given that the primary aim is to help clarify exercise guidelines. The area of HIIT is a growing, contemporary one with broad scope for interpretation. Further simplification of recommendations for intense exercise may help to encourage increased participation of the general population.

**5 multiple choice questions for BJSM**

1. What was the average difference in time taken to complete HIIT workouts compared to SSE workouts?

|  |  |  |  |
| --- | --- | --- | --- |
|  | HIIT mins | V | SSE mins |
| A | 22 | V | 45 |
| B\* | 28 | V | 47 |
| C | 20 | V | 35 |
| D | 28 | V | 50 |

1. Select the general reported benefits of HIIT.

|  |  |  |  |
| --- | --- | --- | --- |
| Benefits | | | |
| A | Multiple varieties | Takes less time | Cost effective |
| B | Significant weight loss | Minimal equipment | multiple varieties |
| C | Takes less time | Significant weight loss | Cost effective |
| D\* | Takes less time | Minimal equipment | Significantly Increases o2max |

1. On average what is the difference in intensity of HIIT workouts compared to SSE workouts?

|  |  |  |  |
| --- | --- | --- | --- |
|  | HIIT %HRmax | V | SSE %HRmax |
| A | 80-90 | V | 60-70 |
| B\* | 85-95 | V | 60-70 |
| C | 95< | V | 50> |
| D | 75 | V | 70< |

1. By how much more, on average, did the %o2max increase due to HIIT compared to control groups?

|  |  |  |  |
| --- | --- | --- | --- |
|  | HIIT % | V | Control % |
| A | **15.1** | **V** | **8.8** |
| B | **19.5** | **V** | **22.0** |
| C\* | **12.8** | **V** | **10.4** |
| D | **22.2** | **v** | **16.1** |

1. What were the overall ultimate FITT recommendations for HIIT protocols?

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | A\* | B | C | D |
| Frequency  (Times per week) | **3** | **3** | **3** | **2** |
| Intensity (%HRmax) | **85-95** | **70-80** | **85-95** | **80-90** |
| Time  (Mins per session) | **14-20** | **10-15** | **30** | **25** |
| Type (Interval ratio) | **2:1** | **1:1** | **1:2** | **3:1** |

(\*Denotes the correct answer)

|  |  |  |  |
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**List of Abbreviations**

|  |  |
| --- | --- |
| **HIIT HIIE** | High intensity interval training or high intensity interval exercise |
| **FITT** | Frequency intensity time type |
| **ACSM** | American College of Sports Medicine |
| **CMO** | Chief Medical Officer |
| **NCD** | Non-communicable diseases |
| **CVD** | Cardiovascular disease |
| **SSE** | Steady state exercise |
| **MIET** | Moderate intensity endurance training |
| **MICT** | Moderate intenisty continuous training |
| **CV** | Cardiovascular |
| **HVIT** | High volume interval training |
| **VIIT** | Varied intenisty interval training |
| **REHIT** | Reduced exertion high intensity training |
| **RPE** | Rating of perceived exertion |
| **PACES** | Physical activity enjoyment scale |
| **TDEE** | Total daily energy expenditure |
| **ET** | Endurance training |
| **PICO** | Population, Intervention, Comparison, Outcomes |
| **PEDro** | Physiotherapy Evidence Database |
| **MET** | Metabolic equivalent |
| **% V̇*O2max*** | Percentage of maximum volume consumption |
| **%HRmax** | Percentage maximum heartrate |
| **%Hfmax** | Percentage maximum heart frequency |
| **V̇*O2max*** | Peak volume of oxygen consumption |
| **%PPO** | Percentage peak power output |
| **%1RM** | Percentage one rep max |
| **HR@AT** | Heart rate at anaerobic threshold |
| **PO@VT** | Power output at ventilatory threshold |
| **MHR** | Maximum heart rate |

***High intensity interval training, the best HIIT FITT: a systematic review and comparative analysis***

1. **Introduction**

The health benefits of physical activity are extensive. Current physical activity guidelines recommend that adults partake in 150 minutes of moderate or 75 minutes of intense exercise per week (to achieve a total energy expenditure of ≥500-1000 MET/min/wk), in addition to participating in muscle and bone strengthening activities at least three times per week. While the benefits of physical activity are well established (Warburton, Nicol, & Bredin, 2006), physical inactivity is prevalent with one in five adults around the world physically inactive (Dumith, Hallal, Reis, & Kohl III, 2011). There is a need to develop strategies to engage adults in sufficient physical activity to maintain and improve their general health. High intensity interval training (HIIT) has emerged as one possible strategy. HIIT generally consists of short, intense bouts of exercise punctuated by brief rest periods. The fact that an effective HIIT session can be accomplished in a short period of time, requiring minimal equipment with physiological adaptations comparable to endurance training (Burgomaster et al., 2008) makes it a viable protocol worthy of in-depth consideration.

Other systematic reviews and meta-analyses investigating the effects of HIIT with adults concluded that it is safe, efficient and effective (Bacon, Carter, Ogle, & Joyner, 2013; Weston, Wisløff, & Coombes, 2014; Milanović, Sporiš, & Weston, 2015.) Considering that lack of time and access to facilities are commonly cited barriers to participation in physical activity (Reichert, Barros, Domingues, & Hallal, 2007), HIIT can be deemed a viable approach to overcome these obstacles for a wide population. Current recommendations for intense exercise can be considered somewhat vague therefore this review aims to further investigate the FITT (frequency, intensity, time and type) principles of HIIT for adults in order to determine the most effective protocols for recommendation to this population.

**2.0 Methods**

**2.1 Protocol and Data management**

The aim of this review focused on using a clearly identified reproducible methodology, a systematic search and assessment strategy and synthesizing and presenting findings in a systematic way in line with the Centre for Reviews and Dissemination, (2009). This systematic review was conducted in fulfillment of an MSc dissertation therefore all review processes were conducted by a single reviewer. The review was developed and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher, Liberati, Tetzlaff, Altman, & Prisma Group, 2009).A completed PRISMA 21 item checklist of the systematic review reporting items is provided in Appendix 1 and a PRISMA progress flowchart is available in Figure 1.1.

Zotero citation management software (Zotero, 2013) was used to document the search process. All records located by the search strategy were exported, or entered manually, into Zotero where records were merged and duplicates removed.

**PRISMA 2009**

Additional records identified through other sources  
(n = 83)

Zetoc = 66

Other = 17

Records identified through database searching  
(n = 1713)

Science Direct = 807

NCBI = 276

EBSCO = 567

Cochrane = 63

Records identified  
(n = 1796)

## Identification

## Screening

Records not meeting initial eligibility criteria  
(n = 1582)

Records left after duplicates removed and abstracts screened  
(n = 214)

Full-text articles excluded, with reasons  
(n = 198)

**Abstract only = 102**

**Dissertation/thesis = 8**

**Non-human = 5**

**Adolescents = 6**

**No control group = 10**

**Patient populations = 42**

**Elite populations = 7**

**Meta-analyses = 6**

**Not exercise only interventions = 12**

## Eligibility

Full-text articles assessed for eligibility  
(n = 214)

## Included

Studies included in quantitative synthesis (comparative-analysis)  
(n = 16 )

Figure 1.1 PRISMA flowchart of study selection process

**2.2 Study Selection Criteria**

A structured electronic search of all publication years from 1996 to 2016 using PubMed, CINAHL Complete and EBSCO (MEDLINE Complete, SPORTDiscus with Full Text, Psychology and Behavioural Sciences Collection and CINHAL) and Cochrane was conducted. The following search strings were used: “*high intensity interval training* OR *high intensity intermittent training* OR *high intensity interval exercise* OR *high intensity training* OR *high intensity exercise* OR HIIT OR HIT OR HIIE ‘AND’ *adult* ‘NOT’ *patient, trained, adolescent, disease*”. These strings were further limited to peer-reviewed publications written in English. First, title and abstracts of articles identified in the search process were assessed for suitability. Second, full-text articles were retrieved and assessed for inclusion. Reference lists from retrieved full-text articles were searched and finally a citation search was carried out. Basic eligibility criteria, based on the PICOS criteria evaluation questions (found in Table 1.1) were initially used to screen titles and abstracts of records to help determine their inclusion in this review. This was followed by a screening of full-text articles for full eligibility criteria outlined in Table 1.2. Refer to the PICOS data extraction tool, attached in Appendix 2, for full definitions of inclusion or exclusion criteria terms.

**Table 1.1 Initial eligibility screening criteria**

|  |  |
| --- | --- |
| PICOS concept area Inclusion / exclusion criteria | |
| Study Design | Was this study primary research? |
| Population | Did this study include human subjects?  Did this study include adult subjects? (>18 years)  Did this study include non-patient populations? |
| Intervention | Did the intervention include HIIT?  Did the intervention have a control or other exercise comparison group? |

**Table 1.2 Eligibility Criteria**

|  |
| --- |
| Screened for the following; |
| * All variations of HIIT |
| * English Language |
| * Non-patient population |
| * Full-Text version |
| * Adult population |
| * FITT principles |
| * Control or Other-Intensity group |

**2.3 Methodology of Quality Assessment**

Even though HIIT may be considered a relatively new phenomenon, it has sparked interest across a range of research disciplines therefore it was necessary to search a range of specialist databases to locate significant literature. Initial literature searches revealed that the earliest published study investigating the effects of HIIT on the human body was conducted in 1996 (Tabata et al., 1996) therefore databases were searched for studies from 1996 onwards. Searches were performed up to June 2016. To improve the precision of the searches and reduce the number of unrelated studies returned, wherever possible, searches were limited by species (humans), population (non-patient) and age (adults 18+ years). Full details of the electronic bibliographical search strategy used, and the number of records returned, are provided in Table 1.3. The inclusion of grey literature in a systematic review may help to overcome some of the problems of publication bias (Hopewell, McDonald, Clarke, & Egger, 2007). The source of grey literature used in this review was the ZETOC database (details included in Table 1.3).

**Table 1.3 Results of search of electronic bibliographical databases**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Databases/  Search Terms | Science Direct | NCBI (PubMed) | EBSCO\* | Cochrane | Zetoc |
| HIIT  (1779) | 807 | 276 | 567 | 63 | 66 |
| HIIT ‘AND’ adult  ‘NOT’ patient/trained/ disease adolescent (214) | 57 | 94 | 28 | 21 | 14 |
| Final list: duplicates and non- eligible studies removed | 16 studies remaining **(see PRISMA flowchart Figure 1.1)** | | | | |

\*Medline, Psychology & Behavioural Sciences Collection, CINHAL, SPORTDiscus with Full Text. Full outline of screening can be found in Appendix 4.

Due to feasibility issues relating to translation, non-English language reports were excluded. All studies that the met the full eligibility criteria were included in the final review and the quality of methods reported in each included study was evaluated, using a modified PEDro Scale (Sherrington, Herbert, Maher, & Moseley, 2000) of 8 criteria (removed #3 ‘allocation was concealed, #5 blinding of all subjects, #6 blinding of all assessors - generally not possible in these studies) (Table 1.4). A PEDro score of at least 5 was required for inclusion in this study to limit analytical bias of this review. Studies were considered eligible if they: (1) examined adults; (2) included a control or moderate intensity comparison group; and (3) used a high intensity activity as defined by Weston et al., (2014). Conference abstracts, dissertations, theses and articles published in non-peer-reviewed journals were not included for review. The results of the PEDro analysis can be found in Table 1.4.

**Table 1.4 PEDro - Methodological quality of HIIT studies**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *Author / Item* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *Total* |
| 1. BÆKKERUD et al (2016) | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| 1. Cheema et al (2015) | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| 1. Dunham & Harms (2011) | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| 1. Edge et al (2012) | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 6 |
| 1. Foster et al (2015) | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 6 |
| 1. Helgerud et al (2007) | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| 1. Keating et al (2014) | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| 1. Knowles et al (2015) | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 5 |
| 1. Mangine et al (2015) | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| 1. Nybo et al (2010) | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 6 |
| 1. Scharf et al (2015) | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| 1. Scribbans et al (2014) | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 6 |
| 1. Sculthorpe et al (2015) | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| 1. Tjønna et al (2008) \*\*\* | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| 1. Willoughby et al (2016) | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 5 |
| 1. Ziemann et al (2011) | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |

**PEDro criteria: Modified to 9 points, score of 5 required for eligibility.**

1. Eligibility criteria were specified.

2. Participants were randomly allocated to groups, (allocation was not concealed).

3. The groups were similar at baseline regarding the most important prognostic indicators.

4. There was blinding of all assessors who measured the primary outcome.

5. Measures of at least one key outcome were obtained from more than 85% of the participants initially allocated to groups.

6. All participants for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome were analysed by ‘intention to treat’.

7. The results of between-group statistical comparisons are reported for the primary outcome.

8. The study provides the point measures and measures of variability for at least one key outcome.

**2.4 Data Extraction**

Key study characteristics were extracted, including: size and source of study population, study design, age, gender, study duration, HIIT dose and health outcomes. In order to minimize bias a data extraction tool was used allowing objective-specific, relevant data to be obtained. A data extraction tool was developed that focused on the specific elements of PICO that were relevant to the review questions (Table 1.5).

Different studies were likely to present their findings in slightly different ways

(e.g. mean change or percentage change) therefore the percentage change (from pre- to post-intervention) for the control and exercise groups was recorded (or calculated if unavailable). This allowed for some standardization of data collection and comparisons of the effect of different HIIT protocols on participants. It was not possible to provide standard deviations or 95% CIs, as this level of data was not reported by all studies.

The data extraction tool was applied to all studies that met the full inclusion criteria. A blank copy and an example of a completed data extraction form are attached in Appendix 3. Where a study had two or more groups, data extraction was performed, and results were presented, for each group.

**Table 1.5 PICO data extraction tool**

|  |  |  |
| --- | --- | --- |
| PICO | Keyword | Synonym |
| Population | Adult | Grown-up |
| Indicator | Frequency  Intensity  Time  Type | Regularity  Volume/Load/Exhertion  Duration  Mode/Method |
| Control | Placebo, control and/or other intensity group | AIT, SIT, HIT, MICT, MIET |
| Outcome | Health Benefit | V̇*O2max* |

See appendix 2 for a copy of the full data extraction tool.

**2.5 Duplicate publications**

In order to try to identify duplicate publications; the names of the authors, the countries and situations, the specific elements of the interventions, the numbers and population of participants, as well as the dates and durations of all studies meeting the full eligibility criteria were compared (Higgins & Deeks, 2011). All identified duplicate publications were treated as one individual study, with references being made to all publications in the final review (Centre for Reviews and Dissemination, 2009).

**3.0 Results**

**3.1 Study Characteristics**

The following data points were extracted from the studies reviewed and can be found in Table 1.6; Author, date, country, number of subjects, study duration, HIIT protocol, control protocol, health outcomes.

**3.2 Synthesis of Results**

**3.2.1 Study and Participant Characteristics**

Studies took place in the USA, Australia, Norway, Denmark, UK, Germany, Canada and Poland between 2007 and 2016. Five hundred and twenty three adults (382 males and 141 females) participated in the sixteen studies. Ages ranged from college-aged (19 years approximately) participants to 63 years, with an overall average age of 31.6 years. Study duration ranged from 4 to 16 weeks. The range of total HIIT workout times was from 4 to 95 minutes and the frequency ranged from once every 5 days to 4 days per week.

**Table 1.6 Final studies included for analysis.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Study | Age / Population / Health status | Duration, Frequency, HIIT Mode | Work : Rest  Ratio | Intensity | Control Group | Health Outcomes and Conclusions |
| BÆKKERUD et al (2016)  Norway | N= 30 adult | 3/wk, total 18 sessions  Treadmill | 4HIIT  4:3  1HIIT  1:1 | 85–95% HRmax,  90% HRmax | 45 min of steady-state running/walking at 70% HRmax | 4HIIT  V·O2max to a greater extent than 1HIIT and MICT. 4HIIT  TTE more than MICT. |
| Cheema et al (2015)  Australia | N = 12 adult | 12 weeks, 4/week  Boxing | 2:1  3 x 5 exercises (total HIIT = 30 mins) | RPE of 15-17/20  Or  75% HRmax | Walking 4 x 50-min sessions of brisk walking/wk | Boxing significantly BF%, resting SBP, AIx and  absolute o2max. It showed trends toward reduced RHR, DBP and relative o2max. No adaptations in WALK |
| Dunham & Harms (2011)  USA | N = 15 untrained, active, healthy | 4 weeks, 3 days per week  Cycle erg | 1:3min  x5 reps | 90% of their o2max final workload | ET exercised at 60–70% o2max  (45 mins) | Both  inspiratory muscle strength with HIT offering a time-efficient alternative in improving aerobic capacity and performance. |
| 1. Edge et al   (2012)  Australia | N = 12 women | 5 weeks 3 days/week  Cycle erg | 6-10 x 2 mins  2:1 (1:0.5)  or  2:3 | Initially 140% LTDmax, inc by 10%/wk | Short (1 min) or Long (3 min) rest period | High intensity interval training resulted in marked  in muscle Na+,K+-ATPase content, PCr resynthesis and o2peak. Rest period manipulation did not affect these changes |
| Foster et al (2015)  USA | N = 55 untrained college subjects | N = 55  3 groups  3/wk, total 24 sessions | 2:1  Tabata  1:2  Meyer | 170 % o2max  100% P o2max  max | SSE cycle erg  20 minutes at 90% of (VT) | The results suggest that although HIIT protocols are time efficient, they are not superior to conventional exercise training in sedentary young adults. |
| Helgerud et al. (2007)  Norway | N = 40 healthy, mod trained males | 3 d·wk-1 for 8 wk.  Treadmill | Interval Run  1:1  Interval Run  4:3 | 90-95% HRmax  90-95% HRmax | 1)long slow distance (70% HRmax);  2)LT (85% HRmax) | HIIT more effective than same total work at lactate threshold or 70% HRmax, in  o2max. The changes in o2max correspond with changes in SV. |
| Keating et al  (2014)  Australia | N =38 inactive overweight adults | 3sessions/week for 12 weeks of regular HIIT  cycle erg | Weeks 1-4=30–45 secs at 120% o2peak: 120–180 seconds at low intensity  Weeks 5-12 = 60 : 120 seconds  1:4 and 1:2 | 120% of  o2peak | continuous moderate intensity exercise (CONT), or placebo exercise (PLA) intervention | Continuous aerobic exercise, not HIIT, total body fat and android fat in previously inactive, overweight adults. HIIT significantly  work capacity in previously inactive and overweight adults |
| * Knowles et al   (2015)  UK | N = 44 | 6 weeks  1/5days  9 sessions  *cycle erg* | *6 × 30 s sprints 3-min active recovery*  *1:6* | *40 % of PPO* | 6 wks (150 min /wk,≥30 min /day ≥5days /wk) mod ex. avg HR reserve (HRR) of 65 % by final 2 wks | HIIT appears to enhance HRQL and exercise motives (especially appearance/weight management) in otherwise healthy sedentary ageing males |
| Mangine et al (2015)  USA | N = 33 physically active, resistance-trained men | 8 wks 4/wk  Resistance training | 4 sets at 3–5 repetitions with 90% of their 1RM, with 3-min rest/set | 90% 1RM | VOL = 4 x 10–12 reps @ 70% 1RM, with a 1-min between sets. | High-intensity Training resulted in significantly  1RM bench press and lean arm mass gains compared to a moderate intensity, high-volume program. |
| Nybo et al. (2010)  Denmark | N = 36 untrained men | 12 weeks  Treadmill | 5 x 2mins run, 2 min recovery  1:1 | HR < 95% HRmax at the end of 2mins | Strength (ST), prolonged running (PR) and control | HIT effective for improving CRF, glucose tol, but less effective for hyperlipidemia and obesity, than PR. HIT had no impact on muscle mass or skeletal health compared to ST |
| Scharf et al (2015)  Germany | N = 84 untrained, sedentary or inactive | 16 wks inc 2/wk 1st month, 2- 3/wk 2nd month, 3-4 /wk 3rd+4th months.  Treadmill | HIIT = (range, 90 s–12 mins)= 80%–90% HRmax;  active recovery (1–3 minutes jog/walk)  3:1 | 95%–105% of HR at AT | No exercise / inactive | 16 weeks of HI(I)T led to measurable changes in cardiac atrial and ventricular morphology and function in previously untrained men. This correlates with improvements in parameters of endurance capacity. |
| Scribbans et al (2014)  USA | N = 21 adults | 6 weeks  Cycle erg | 8x 20s intervals with 10 seconds of rest; 2:1 | ∼170% of o2peak | END: 30 minutes at ∼65% of o2peak | Training-induced adaptations resulting for these protocols, and other HIT and END protocols are strikingly similar |
| Sculthorpe et al (2015)  UK | N = 33 men | 6 weeks of HIIT once every 5 days  cycle erg | 30 s effort 3 min recovery  1:6 | 50% of peak power | (n=11) non-exercise control group | PPO  significantly more in HIIT group |
| Tjønna et al., (2008)  Norway | N = 32 Met Syn patients | 3 x week for 16 weeks  treadmill | 4x4-min intervals 3-min active recovery  4:3 | 90% of Hfmax | CME 70% of Hfmax  Cont group | V̇O2max  more after AIT than CME and AIT removed more risk factors than CME |
| Willoughby et al (2016)  Canada | N = 28 | 4 weeks 3/wk interval running  treadmill | 30 s “all-out” efforts + 4 min act rec  1:8 | All out sprints | Middle aged group, same procedures | SIT programmes are equally effective at  aerobic and anaerobic fitness in younger and middle-aged adults. |
| Ziemann et al (2011)  Poland | N = 21 Recreationally active male volunteers | 3 sessions per wk, for 6 wks  cycle erg | 6x 90-s (180-second rest)  1:2 | 80% of o2max (80% p o2max) | normal routine for the 6-week period (active men) | HIT was a sufficient stimulus to significantly  markers of anaerobic and aerobic performance in recreationally active college-aged men. |

**3.2.2 Total duration**

|  |  |
| --- | --- |
| 1 | Baekkerud |
| 2 | Cheema |
| 3 | Dunham |
| 4 | Edge |
| 5 | Foster |
| 6 | Helgrud |
| 7 | Keating |
| 8 | Knowles |
| 9 | Mangine |
| 10 | Nybo |
| 11 | Scharf |
| 12 | Scribbans |
| 13 | Sculthorpe |
| 14 | Tioanna |
| 15 | Willoughby |
| 16 | Ziemann |

Minimum total HIIT duration was 4 minutes; maximum was 95 minutes, averaging 32 minutes per HIIT session across the 16 studies. Minimum total control duration was 30 minutes; maximum was 68 minutes, averaging 46.7 minutes per session see Figures 1.2 and 1.3.

Figure 1.2 Total workout duration for HIIT protocols Study name

|  |  |
| --- | --- |
| 1 | Baekkerud |
| 2 | Cheema |
| 3 | Dunham |
| 5 | Foster |
| 6 | Helgrud |
| 7 | Keating |
| 9 | Mangine |
| 10 | Nybo |
| 12 | Scribbans |
| 14 | Tioanna |

Figure 1.3 Total workout duration for control protocols Study name

**3.2.3 Intensity and Recovery**

Intensities were set based on baseline maximal/peak testing data. Intensity measurements included %HRmax (6), % V̇*O2max* (2), %Hfmax (1), &LTDmax (1), %%o2peak (1), %PPO (2), %1RM (1), HR@AT (1) and ‘all-out’ sprints (1) see figure 1.4.

Figure 1.4 Comparison of intensity of workout to the work intervals used

**3.2.4 Mode**

8 of the studies used a cycle ergometer as the mode of exercise, 5 used treadmills, one used a self-propelled treadmill, one employed a boxing regime and one used resistance training in a high intensity format.

**3.2.5 Intervals**

A multitude of timings and work to rest ratios were included throughout the studies; 4:3(3), 1:1 (1), 1:6 (2), and 1:3, 1:4, 3:1, 2:3 and 1:8 (all 1), but the most common work to rest ratio used was 2:1 (4). Rest also came in a variety of manners and intensities from active rest to completely passive rest. The other intervals ranged from 20 seconds to 12 minutes across the studies.

**3.2.6 V̇*O2max***

There were significant improvements in % V̇*O2max* for all 15 HIIT groups across the studies where V̇*O2max* was measured. Of the 10 control or other non- high- intensity groups, significant increases in % V̇*O2max* were reported in 4 groups. These increases ranged from 3.1% to 35% depending on the population and protocol involved. The average increase for HIIT groups was 12.8% versus 10.4% across the control and other training groups (Figure 1.5)

Figure 1.5 Comparison of percentage increase in o2max between HIIT and control groups.

**3.2.7 Weight Loss**

Five studies reported on weight loss, or percentage body fat loss. One found no significant changes in any group, one reported a significant change of 13.2% body fat for HIIT with no change for control group, one reported a significant reduction in average body mass of 2.3kgs for the MICT group but not for the HIIT group, another reported a significant reduction in body fat of 2.6% for the MICT group, one reported HIIT and MICT to be equally effective for weight loss with significant reductions of 2.6 and 4.1% respectively.

**3.3 Comparative Analyses**

Analyses were conducted to determine the relationship between HIIT and increases in % V̇*O2max.* Post-test mean values or change scores were used in the analyses. Statistical analysis was performed using SPSS version 21.0 (SPSS, Armonk, NY).

Following a comprehensive search using the protocols outlined in the methodology section a total of 16 original research papers investigating HIIT and its effects on the body were analysed. Meta-analysis studies were not included, only original research material focused on adult, human subjects. SPSS was used to run statistical analysis to investigate correlations between the FITT principles of HIIT and improvements in % V̇*O2max*. There were significant improvements in % V̇*O2max* for all 15 HIIT groups across the studies where % V̇*O2max* was measured and an additional 4 HIIT groups used other measures including % V̇*O2peak*, or reported the relationship between V̇*O2max* and training. Correlations tests were carried out to investigate the null hypotheses that there is no statistically significant relationship between change in % V̇*O2max* and the various FITT principles. The data in the samples was reported as not normally distributed according to Kolmogorov-Smirnov statistics (as outlined by Coakes & Steed, 2007); therefore Spearman’s rho tests (Coakes & Steed, 2007) were conducted. Sample size was 128. The correlations between the variables are reported in Table 1.7below.

**Table 1.7 Correlations between %** V̇*O2max* **increase and FITT principles**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable 1 | Variable 2 | Correlation coefficient | Correlation | Coefficient of Determination |
| o2max | Frequency | -0.331 | Low negative | 10.9% |
| o2max | Intensity | -0.066 | V low negative | 0.4% |
| o2max | Time | -0.175 | Very low negative | 3% |
| o2max | Interval ratio | 0.409 | Modest positive | 17% |
| Intensity | Time | -0.716\* | High negative | 51% |
| Intensity | Frequency | -0.496 | Mod negative | 25% |
| Intensity | Interval | -0.549 | Mod negative | 30% |
| Time | Frequency | 0.741 | High positive | 55% |
| Frequency | Interval | 0.244 | Low positive | 5.9% |
| Time | Interval | 0.554 | Mod positive | 31% |

Combining the individual studies (included in the statistical analyses); the longest interval ratio was 2:1, the highest intensity was over 95% HRmax and the shortest duration was 14 minutes once every 5 days. The most common recovery intensity was 70%HRmax. Table 1.8 provides the results of the FITT recommendations following analyses.

**Table 1.8 FITT recommendations for HIIT protocols.**

|  |  |
| --- | --- |
|  | FITT recommendations |
| Frequency | 3 sessions per week |
| Intensity | 85-95%HRmax (interval), 70% HRmax (recovery) |
| Time | 14 – 20 minutes per session |
| Type | 2:1 intervals (e.g. 2 minutes on to 1 min off) |
| Total Time | 42 - 60 minutes per week |

**4.0 Discussion**

**4.1 Summary of Evidence**

During HIIT, the ability to maintain adequate overload without critical disruption of homeostasis leading to premature fatigue is controlled by either duration of the interval or the duration of the recovery period (Laurent, Vervaecke, Kutz & Green (2014). Combining overall time and work to rest ratios with % V̇*O2max* improvements, there were a range of possible recommendations. For HIIT sessions lasting less than 25 minutes, working at an average intensity of 85-95% HRmax an average increase of 11% V̇*O2max* could be expected. With the longer sessions of up to 40 minutes also working at an average intensity of 85-95% HRmax an average increase of 13% V̇*O2max* could be anticipated. Considering that doubling the workout time offers such a small increase (2%) the more practical recommendation for the general population, offering the greatest return for effort, is approximately 20 minutes workout duration with a 2:1 work to rest ratio at an intensity of 85-95% HRmax, three times per week. The type or mode of exercise does not appear to be a significant contributing factor.

**4.1.1 Study characteristics**

Demographics included recreationally active, college-aged participants and life-long active, trained adults and adults with Metabolic syndrome and life-long sedentary participants. The majority of studies included a control or a moderate intensity group and two studies used different populations as control groups based on either age or activity level.

**4.1.2 Total duration**

Some studies matched energy expenditure of HIIT and MICT sessions while others looked at matching time. 2 studies used matched protocols with different populations, 2 used isocalorically matched protocols, 2 studies matched for workload, 1 for oxygen cost and 9 studies did not match protocols, or compared HIIT to a non-exercise control group. However, one protocol was a resistance training session, which, while high intensity by design, would not be traditionally classed as ‘interval’ training and it took 95 minutes to complete. It was included in this review as an alternative to aerobic or anaerobic training and as a means of including resistance training in the high intensity exercise protocols. Removing that study from the total duration average, gave an average of 28 minutes per HIIT session. This is comparable to a greater average for control group training times of 47 minutes.

**4.1.3 Intensity and recovery**

The range of measures of intensity made it difficult to determine a common intensity level across studies. However, it was noted that of the six studies that used %HRmax the intensities ranged from 75% to above 95% HRmax, with the most common range being 85-95% HRmax. Similar to the intensities, the recovery intervals for the HIIT protocols varied in length and type. The type was not specified in 5 protocols, 4 stated that recovery was passive, 3 specified 65-70% HRmax, 3 outlined cycling at 20-50W, 2 described recovery as a ‘light walk’, the rest were described as 70%Hfmax, 90% PO@VT, a choice of effort or simply ‘active recovery’. %HRmax is one of the more feasible and accessible measurements of intensity with heart rate monitors built into most gym machines and personal heart rate monitors becoming more readily available and user friendly. All other measurements require more explanation, equipment, guidance and calculation. For this reason, the argument could be made for all public recommendations to be based on %HRmax.

However, due to its intense nature and relatively short intervals, it can be quite difficult to accurately gauge a fluctuating heart rate. From this perspective it may prove useful to employ the Borg scale of perceived exertion (RPE scale, Borg, 1970). This may allow exercisers to more readily adjust workload to match intensity to effort for both the interval workload and the recovery. The Borg RPE scale can be used to help determine the appropriate intensity for the exercise interval and according to research, high intensities should be above 15 (Garber et al., 2011; Johnson et al., 2016).

**4.1.4 Mode**

While self-propelled treadmills are not commonplace in the average gym, and boxing and resistance training require specialized equipment, it is fair to say that most people could potentially access some type of cycle ergometer or treadmill through a commercial or home gym, or similar protocols could be implemented using a bicycle or by walking or running outdoors.

**4.1.5 Weight Loss**

There is disparity amongst current studies regarding the effectiveness of HIIT versus MICT for all forms of weight loss (Shiraev & Barclay, 2012, Keating et al., 2014). This review proved to be just as inconclusive and is an area requiring further investigation, as it is a primary concern of the general population with on average, almost 40% of adults being overweight (WHO, 2016).

**4.1.6 Other Outcomes**

Only one study investigated enjoyment levels and found that the Tabata protocol (20 seconds work, 10 seconds rest, repeated 8 times; Tabata et al, 1996) in particular was reported to be less enjoyable than other modes of exercise and overall it was found that the more intense the exercise, the less enjoyable it was. This differs from previous reports (Jung, Zelt, Bourne, & Gurd, 2014; Martinez, Kilpatrick, Salomon, Jung, & Little, 2015; Smith-Ryan, 2015) where no difference was recorded in preference of HIIT over MICT, or where HIIT was the activity of choice over MICT and is therefore worthy of further investigation considering enjoyment levels play an important role in adherence to exercise regimes (Wininger & Pargman, 2003; White, Ransdell, Vener, & Flohr, 2005).

**4.1.7 Results of Correlations tests**

From the 11 HIIT groups where percentage increase in V̇*O2max* was reported, the only high (positive) correlation within the HIIT protocols was found between the total workout time and the frequency of the workouts, implying that the longer and more often HIIT is performed, the more beneficial the results on % V̇*O2max*, which holds true for exercise in general. Modest correlations were also reported between % V̇*O2max* increase and interval ratios, intensity and frequency, intensity and interval duration and total workout time and intervals suggesting that the longer and more intense the interval, the better the impact on V̇*O2max*, but that the duration of the session can be shorter and occur less frequently. Overall these results imply that HIIT can be effective when the intervals are relatively long (1 to 4 minutes) and intense (>85% HRmax) and total workout time can be relatively short (<20 minutes).

The overall total of 42 - 60 minutes per week for HIIT workouts is much lower when compared to the ACSM (Garber et al., 2011) recommendations of 75 minutes per week, while still evoking a significant positive impact on V̇*O2max*. 85-95%HRmax is equivalent to approximately 9METs/min. This equates to approximately 540 METs per week following these recommendations and is inline with the ACSM (Garber et al., 2011) recommendations for health of ≥500-1000 MET/min/week energy expenditure.

**4.2 Limitations**

All studies experienced methodological limitations. Current research consists of a variety of intervals, modes, frequencies, intensities and programme durations. Furthermore, comparison of studies proves difficult when volumes of HIIT and MICT are equated in different ways. There are also discrepancies in the percentage of heart rate used. Some of the studies used a higher definition of moderate intensity (75%HRmax) to the general intensity of moderate exercise suggested by the American College of Sports medicine of 60-70% HRmax (Garber et al., 2011). The studies reviewed consisted of small sample sizes, with studies including unequal male-to-female ratios, a variety of populations and age-groups from healthy, trained adults to sedentary older adults and adults with the Metabolic Syndrome with all factors influencing the study outcomes. In a number of studies where participants were sedentary they participated in preparatory MICT sessions before commencing HIIT. This is an element of health and safety, which may need to be factored into HIIT recommendations, as with the commencement of any exercise regime, it is advisable to consult an expert prior to beginning a new routine.

**4.2.1 Limitations: Risk of bias**

Minimising publication bias requires the use of a comprehensive search strategy but is not guaranteed to be adequate in the prevention of bias. Abstract only publications were excluded from this review for practical reasons (see page 12) therefore it is possible that studies with non-significant findings may have been published as abstracts, but may not have reached full publication. Therefore the potential for publication bias should not be disregarded from this review.

Attempts were made to identify duplicate publications (see p.12), but identification of duplicate publications is difficult due to lack of cross-referencing or common authors, variety of participants and reported outcomes (Centre for Reviews and Dissemination, 2009) therefore duplicate publication bias should not be excluded from this review.

The included record search was conducted as late as possible and it included studies published up until the end of June 2016 in order to minimise the effect of time-lapse bias. However, the studies included in this review were published between 2007 and 2016, indicating that HIIT research is a still a fast growing area of investigation. Therefore the risk of time-lapse bias cannot be excluded from this review. Another limitation is the imposition of English language restrictions, which may have introduced language bias to this review.

Decisions about which studies should be included in a systematic review, and which data should be extracted from them, require judgment and are therefore, by nature, subjective (Centre for Reviews and Dissemination, 2009). Single researcher reviews have been associated with higher number of errors in data screening and extraction (Buscemi, Hartling, Vandermeer, Tjosvold, & Klassen, 2006) necessitating that the systematic review process be conducted by a minimum of two reviewers (Centre for Reviews and Dissemination, 2009). In the pursuit of this MSc dissertation only one reviewer was available. Although this reviewer was not associated with any organizations and did not receive any recompense for this review, the use of a single reviewer can introduce subjectivity, selection bias and a greater number of errors, resulting in single reviewer bias being a limitation of this review.

**5.0 Conclusion**

In conclusion, based on the evidence summarised in this review, the following HIIT guidelines can be recommended for the general public to follow. HIIT should take place approximately 3 times per week and each session should be 20 minutes in duration (including warm-up time). Work to rest intervals should be a 2:1 ratio (e.g. 1 minute of work with 30 seconds of rest) at an intensity of >85% HRmax and recovery of approximately 70% HRmax, totaling roughly 60 minutes or 540 METs per week. In order to maximize ease of access to HIIT exercise, the Borg RPE scale (Borg, 1970) can be used to determine the intensity of the work interval and should be above 15 on the RPE scale (Garber et al., 2011; Johnson et al., 2016). The mode of exercise can vary but the most commonly tested modes incorporate the use of a treadmill or a cycle ergometer. As with any new exercise regime, appropriate professionals should be consulted prior to commencement.

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**Appendices**

**Appendix 1 – PRISMA checklist**

|  |  |  |  |
| --- | --- | --- | --- |
| **Section/topic** | **#** | **Checklist item** | **Reported on page #** |
| **TITLE** | | |  |
| Title | 1 | Identify the report as a systematic review, meta-analysis, or both. | 1 |
| **ABSTRACT** | | |  |
| Structured summary | 2 | Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number. | 3 |
| **INTRODUCTION** | | |  |
| Rationale | 3 | Describe the rationale for the review in the context of what is already known. | 3 |
| Objectives | 4 | Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS). | 15 |
| **METHODS** | | |  |
| Protocol and registration | 5 | Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number. | N/A |
| Eligibility criteria | 6 | Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale. | 15 |
| Information sources | 7 | Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched. | 12 |
| Search | 8 | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated. | (xxi) |
| Study selection | 9 | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis). | 10 |
| Data collection process | 10 | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators. | 15 |
| Data items | 11 | List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made. | 16 |
| Risk of bias in individual studies | 12 | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis. | N/A |
| Summary measures | 13 | State the principal summary measures (e.g., risk ratio, difference in means). | 23 |
| Synthesis of results | 14 | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I2) for each meta-analysis. | 15 |

|  |  |  |  |
| --- | --- | --- | --- |
| Risk of bias across studies | 15 | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies). |  |
| Additional analyses | 16 | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified. |  |
| **RESULTS** | | |  |
| Study selection | 17 | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram. | 10 |
| Study characteristics | 18 | For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations. | N/A |
| Risk of bias within studies | 19 | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12). | N/A |
| Results of individual studies | 20 | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot. | 17, 18 |
| Synthesis of results | 21 | Present results of each meta-analysis done, including confidence intervals and measures of consistency. | 26 |
| Risk of bias across studies | 22 | Present results of any assessment of risk of bias across studies (see Item 15). | N/A |
| Additional analysis | 23 | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]). | 26 |
| **DISCUSSION** | | |  |
| Summary of evidence | 24 | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers). | 23 |
| Limitations | 25 | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias). | 29 |
| Conclusions | 26 | Provide a general interpretation of the results in the context of other evidence, and implications for future research. | 25 |
| **FUNDING** | | |  |
| Funding | 27 | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review. | N/A |

**Appendix 2 – Full eligibility screening criteria**

|  |  |  |
| --- | --- | --- |
| **PICOS** | **Inclusion criteria** | **Exclusion criteria** |
| **Study Design** | Published in English?  Fully published?  Primary research? | Published in language other than English  Abstract only |
| **Outcome** | Specified outcomes included?  HIIT with control or multiple HIIT protocols? | No specified outcomes  Unavailable outcome data for pre and post intervention |
| **Population** | Human, adult, non-patient populations? | Adolescent, patient or non-human population |
| **Comparators** | Controls assigned to normal routine?  Assigned to placebo exercise?  Assigned to other HIIT protocols?  Assigned to SSE or MICT protocols? | No control or HIIT comparison group |
| **Intervention** | Minimum of 4 weeks?  HIIT based?  Supervised?  Full description of protocols?  Full description of the exercise in relation to FITT? | Less than 4 weeks  Non HIIT specified intervention or multi-component intervention e.g. diet and exercise intervention, or supplement and exercise intervention. |

**Appendix 3 – Blank copy and example of completed data extraction form (PICO)**

Blank Data Extraction Tool

|  |  |  |
| --- | --- | --- |
| Date of Data Extraction |  | |
| Study Details | | |
| Author |  |  |
| Year |  |  |
| Title |  |  |
| Journal |  |  |
| Located via |  |  |
| Accessed from |  |  |
| Confirm RCT | Yes: | No: |
| Study Characteristics | | |
| Country |  |  |
| Sample Size | Control: | Exercise group: |
| Population | | |
| Mean Age | Control: | Exercise group: |
| Body Mass/BMI |  |  |
| Intervention | | |
| Specific Type |  |  |
| Frequency (times/week) |  |  |
| Intensity |  |  |
| Duration |  |  |
| Setting |  |  |
| Supervision |  |  |
| Adherence |  |  |
| Adverse Effects |  |  |
| Outcomes | | |
| BM (kg) | Pre: | Post: |
| Control | Pre: | Post: |
| Exercise group | Pre: | Post: |
| VO2max | Pre: | Post: |

**Sample Completed Data Extraction Tool**

|  |  |  |
| --- | --- | --- |
| Date of Data Extraction | June 20th 2016 | |
| Study Details | | |
| Author | Nybo et al |  |
| Year | 2010 |  |
| Title | **High-Intensity Training versus Traditional Exercise Interventions for Promoting Health** |  |
| Journal | Medicine & Science in Sports & Exercise |  |
| Located via | PubMed |  |
| Accessed from | University of Chester online subscription | |
| Confirm RCT | Yes: | No: ✔ |
| Study Characteristics | | |
| Country | Denmark |  |
| Sample Size: 36 | Control: 18 | Exercise group: 18 |
| Population | | |
| Mean Age | Control: 30 ± 2 years old | Exercise group: 37 ± 3 years old |
| Body Mass/BMI kg | 86.5 ± 3.8 | 96.3 ± 3.8 |
| Intervention | | |
| Specific Type | Control | HIIT |
| Frequency (times/week) | N/A | 3/wk |
| Intensity | N/A | >95% HRmax |
| Duration (mins) | N/A | 20 |
| Setting | N/A | Lab |
| Supervision | N/A | Yes |
| Adherence | N/A | N/A |
| Adverse Effects | N/A | N/A |
| Outcomes | | |
| BM (kg) | Post: 86.4.± 3.7 | Post: 94.9 ± 4.2 |
| Fat % | Pre: 22.3 ± 2.7 Post: 22.1 ± 2.8 | Pre: 24.7 ± 1.5 Post: 24.2 ± 1.7 |
| V̇*O2max* | Pre: 39.2 ± 2.7 Post: 38.9 ± 0.1 | Pre: 36.3 ± 1.7 Post: 41.4 ± 2.2\* |

\* significantly higher than pre-intervention (p<0.05)

**Appendix 4 - Details of electronic bibliographical database search results after screening**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Database | Fields Searched | Search | Limits Applied | Number of Records 04 June 2016 |
| *PubMed* | All | *high intensity interval training OR high intensity intermittent training OR high intensity interval exercise OR high intensity training OR high intensity exercise OR HIIT OR HIT OR HIIE ‘AND’ adult ‘NOT’ patient, trained, adolescent, disease* | Publication  Date from  1996/01/01  Adult | 19 |
| **EBSCO (Medline, Psychology & Behavioural Sciences Collection, CINHAL, SPORTDiscus with Full Text)** | All | *high intensity interval training OR high intensity intermittent training OR high intensity interval exercise OR high intensity training OR high intensity exercise OR HIIT OR HIT OR HIIE ‘AND’ adult ‘NOT’ patient, trained, adolescent, disease* | Publication  Date from  1996/01/01  Adult | 39 |
| **Science Direct** |  | *high intensity interval training OR high intensity intermittent training OR high intensity interval exercise OR high intensity training OR high intensity exercise OR HIIT OR HIT OR HIIE ‘AND’ adult ‘NOT’ patient, trained, adolescent, disease* | Publication  Date from  1996/01/01  Adult | 29 |
| **Zetoc** |  | *high intensity interval training OR high intensity intermittent training OR high intensity interval exercise OR high intensity training OR high intensity exercise OR HIIT OR HIT OR HIIE ‘AND’ adult ‘NOT’ patient, trained, adolescent, disease* | Publication  Date from  1996/01/01  Adult | 55 |
| *Cochrane* | All | *high intensity interval training OR high intensity intermittent training OR high intensity interval exercise OR high intensity training OR high intensity exercise OR HIIT OR HIT OR HIIE ‘AND’ adult ‘NOT’ patient, trained, adolescent, disease* | Publication  Date from  1996/01/01  Adult | 0 |