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Effects of Different Protocols of High Intensity Interval Training for VO_2max Improvements in Adults: A Meta-Analysis of Randomised Controlled Trials

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Abstract.

Objectives: To examine the effects of different protocols of high-intensity interval training (HIIT) on VO_2max improvements in healthy, overweight/obese and athletic adults, based on the classifications of work intervals, session volumes and training periods.

Design: Systematic review and meta-analysis.

Methods: PubMed, Scopus, Medline, and Web of Science databases were searched up to April 2018. Inclusion criteria were randomised controlled trials; healthy, overweight/obese or athletic adults; examined pre- and post-training VO_2max/peak; HIIT in comparison to control or moderate intensity continuous training (MICT) groups.

Results: Fifty-three studies met the eligibility criteria. Overall, the degree of change in VO_2max induced by HIIT varied by populations (SMD = 0.41–1.81, $p<0.05$). When compared to control groups, even short-intervals (≤ 30s), low-volume (≤ 5 min) and short-term HIIT (≤ 4 weeks) elicited clear beneficial effects (SMD = 0.79–1.65, $p<0.05$) on VO_2max/peak. However, long-interval (≥ 2 min), high-volume (≥ 15 min) and moderate to long-term (≥ 4-12 weeks) HIIT displayed significantly larger effects on VO_2max (SMD = 0.50–2.48, $p<0.05$). When compared to MICT, only long-interval (≥ 2 min), high-volume (≥ 15 min) and moderate to long-term (≥ 4-12 weeks) HIIT showed beneficial effects (SMD = 0.65–1.07, $p<0.05$)

Conclusions: Short-intervals (≤ 30 s), low-volume (≤ 5 min) and short-term (≤ 4 weeks) HIIT represent effective and time-efficient strategies for developing VO_2max, especially for the general population. To maximize the training effects on VO_2max, long-interval (≥ 2 min), high-volume (≥ 15 min) and moderate to long-term (≥ 4-12 weeks) HIIT are recommended.

Keywords: Cardiorespiratory Fitness; Exercise; High-Intensity Intermittent Exercise; Meta-Analysis.

1. Introduction

Aerobic capacity is typically measured as maximal oxygen uptake (VO_2max). It is used frequently as an indicator of cardiorespiratory fitness, which is considered critical for health promotion.[1] Higher relative aerobic capacity levels are related to better physical performance of athletes,[2] and to a lower risk of cardiovascular/coronary heart diseases and all-cause mortality in non-athletic general population.[3-5] Recently, high intensity interval training (HIIT) was ranked Number 1 (most popular) in the annual survey of worldwide fitness trends in 2018.[6] It has been widely used as an alternative to traditional endurance training and was shown to result in higher levels of endurance performance,[7] reduced time commitment and increased exercise adherence.[8] Several studies have demonstrated the effectiveness of HIIT on VO_2max in athletes,[9-11] healthy[12-14] and overweight/obese non-athletes,[15, 16] and even cardiac patients.[17, 18] Moreover, new training programs were developed like the Resistance and Aerobic Program (RAP) that combines resistance exercises with HIIT. It has been shown that these are even more beneficial for improving physical and mental health outcomes in healthy and diabetic populations.[19, 20]

HIIT protocols enable individuals who exercise to maintain at maximal or near maximal oxygen uptake (T@VO_2max) for long periods of time, because a potent stimulus elicits both central (oxygen transport) and peripheral (oxygen utilization) adaptations for VO_2max improvement.[7, 21, 22] Many different components of HIIT such as work intensity, bout duration, number of repetitions, and training periodization have been shown to have substantial influence on T@VO_2max.[7, 21, 22] Correspondingly, HIIT can currently be subdivided into different protocols. For instance, according to different combinations of work intensity and bout duration, HIIT uses different work interval protocols including long-interval (2-4 min of work/bout at sub-maximal intensity, LI-HIIT), short-interval (< 45 s of work/bout at sub-maximal intensity, SI-HIIT), sprint-interval (> 20-30 s of work/bout at near to maximal intensity, SIT) and repeated-sprint exercises (≤ 10 s of work/bout at near to maximal intensity, RST) .[21, 23] When the number of repetitions is added, HIIT protocols can implemented with high (16 min of work) or low (4 min of work) session volume (HV-HIIT or LV-HIIT).[16, 24] Moreover, considering the effect of training periodization, the length of HIIT intervention is classified as long-term (≥ 12 weeks) or short-term (≤ 4 weeks) duration (LT-HIIT or ST-HIIT).[25, 26]

To increase time efficiency and exercise adherence, especially for non-athletes, HIIT training programmes were optimised with shorter work interval, lower session volume or shorter training periods.[14, 15, 27, 28] However, these optimisations need to be further evaluated with respect to whether they retain a meaningful effect on improving VO_2max when compared with traditional HIIT programmes in diverse populations, because they can affect T@VO_2max,.

An increasing body of systematic reviews and meta-analyses[26, 28-32] have been conducted to investigate the efficiency of HIIT for improving VO_2max in adults without disease, and also examined the impact of several moderators of training effects. Batacan et al.,[26] Weston et al.,[28] Sloth et al.,[29] and Gist et al..[30] compared the effects of HIIT on VO_2max with moderate-intensity continuous training (MICT) and no training control groups. However, these meta-analyses included only HIIT research with short work intervals (10-30 s) or low session volumes (≤ 4-6 min). Milanović et al.[31] and Bacon et al.[32] addressed this gap in their meta-analyses that investigated HIIT protocols with longer work intervals (unrestricted) and higher session volumes (unrestricted or ≥ 10 min). However neither study directly examine the differences in VO_2max improvements between the particular protocols mentioned above nor involve athletic or overweight/obese populations. Furthermore, most of the above mentioned meta-analyses included non-randomised controlled trials[26, 28, 29, 32] and even non-control trials[28, 29, 32], which may have led to potential bias or overestimation of treatment effects.[33]

In order to address such deficiencies, this systematic review and meta-analysis aims to review all relevant randomized controlled trials (RCTs), and examined the effects of HIIT on VO_2max improvements with regard to different work intervals, session volumes or training periods in several populations (i.e., healthy, overweight/obese and athletic adults).

2. Methods

This systematic review and meta-analysis was conducted according to the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA) guidelines.[34] All the following steps were implemented by two independent raters (*, *), and any discrepancies were resolved by discussion or consensus with a third rater (*).

A literature search was performed until April 2018 using the scientific databases (PubMed, Scopus, Medline, and Web of Science). The initial search terms included 'high intensity interval training' OR 'high intensity interval exercise' OR 'high intensity intermittent exercise' OR 'high intensity intermittent training' OR 'repeated sprint training' OR 'sprint interval training' OR 'HIIT' OR 'HIIE' OR 'HIT' OR 'HIE'. The second search terms included 'maximum O_2' OR 'maximum VO_2' OR 'maximal VO_2' OR 'maximal oxygen uptake' OR 'maximal oxygen consumption' OR 'peak oxygen uptake' OR 'maximal aerobic capacity' OR 'VO_2max' OR 'VO_2peak'. The third search terms included 'adult*' OR 'men' OR 'women'. The fourth search terms included 'randomised controlled trial' OR 'RCT' OR 'random*'. Finally, the four search terms were combined using the operator 'AND'. Further, reference lists of the included articles and related reviews were then scanned for potentially relevant studies.

Studies were identified using the following inclusion criteria: (1) adult participants including healthy (body mass index [BMI] < 25 kg/m^2) or overweight/obese (BMI ≥ 25 kg/m^2) non-athletic or athletic populations (well-trained); (2) studies comparing HIIT with either control (CON) or MICT group, where training intensity thresholds of HIIT and MICT were defined as high (≥ 80-85% VO_2max, ≥ 85-90% maximal heart rate [HRmax] or ≥ 90% velocity/power at VO_2max [v/pVO_2max]) and moderate (40–65% VO_2max or 55–75% HRmax) respectively;[35-37] (3) studies of multiple treatment arms were treated as separate trails; (4) the training effect on VO_2max/peak was reported or could be calculated; (5) RCTs. Studies were excluded if they met the following criteria: (1) not published in English; (2) included participants suffering from any kind of acute or chronic diseases; (3) training intensity did not meet the previously defined thresholds; (4) HIIT was combined with other training methods in non-athletic populations (this criterion was not used for athletic research, as HIIT intervention is generally combined with the regular training programmes, which also served as the control group in the athletic research). To investigate the effect of various training protocols in this review, HIIT was pre-classified (Fig. 1) by different work intervals (long-interval [LI-HIIT], moderate-interval [MI-HIIT], short-interval [SI-HIIT], sprint-interval [SIT] and repeated-sprint [RST]), session volumes (high-volume [HV-HIIT], moderate-volume [MV-HIIT] and low-volume [LV-HIIT]) and training periods (long-term

[LT-HIIT], moderate-term [MT-HIIT] and short-term [ST-HIIT]) respectively.[16, 21, 23-26, 29, 38, 39]

We extracted the following characteristics from each eligible trial: author; year of publication; populations; sex; mean age; mean body mass index (BMI); baseline mean VO_2max/peak (ml/kg/min); groups; sample size; exercise modality; training period and frequency; training session protocol including number of repetitions, work intensity and duration, rest modality and duration, work/rest ratio and cumulative work time; and changes in VO_2max/peak. For the data that were shown only described in figures or graphs, we used Graph digitizer software (Digitizelt, Germany) to read the data. When the magnitude of changes in VO_2max/peak was not directly reported, we calculated the effect sizes and standard deviations (SDs) based on the baseline and pro-intervention values according to the methods suggested by the Cochrane handbook.[40] To assess the study quality, we used the modified Physiotherapy Evidence Base Database (PEDro) scale and considered a high quality study with a score of ≥ 7/10 points.[41] Additionally, three exercise training-specific criteria from the TESTEX scale[42] were added to the assessment, including activity monitoring in control groups, relative exercise intensity remained constant, and exercise energy expenditure information.

A meta-analysis was conducted to determine the pooled effect of the change in VO_2max/peak (ml/kg/min) for HIIT vs CON/MICT. Standardized mean difference (SMD), weighted mean difference (WMD) and 95% confidence intervals (CIs) were calculated using the random-effects model. A p value < 0.05 was considered statistically significant. The effect sizes are interpreted as trivial (SMD < 0.2), small (SMD 0.2-0.6), moderate (SMD 0.6-1.2), large (SMD 1.2-2.0) or very large (SMD 2.0-4.0).[25, 43] Heterogeneity among studies was explored using Cochrane's Q statistic and I^2 value, with values of 20%, 50% and 75% indicating low, moderate and high heterogeneity, respectively.[44] Sensitivity analysis was performed by removing trials with scores < 7 points (PEDro scale). To investigate different protocols of HIIT, further meta-analyses were performed by evaluating the effect of HIIT on VO_2max/peak by different work intervals (LI-SIIT, MI-SIIT, SI-SIIT, SIT and RST), session volumes (HV-HIIT, MI-HIIT and LV-HIIT) and training periods (LT-HIIT, MT-HIIT and ST-HIIT). Meta-regression analyses were further conducted in an attempt to determine the relationship between sex, age, BMI, baseline VO_2max/peak and the work:rest ratio with training effects on VO_2max/peak. Publication bias was analysed using funnel plot and Egger test.[45] All analyses were using executed using Stata version 13.1 (StataCorp, LP, College Station, TX).

3. Results

The initial search identified 1190 articles from the databases. Additionally, nine records were found via other sources. After excluding the duplicates, the titles and abstracts of 925 articles were screened. Of these, 251 eligible articles were selected for full-text review. Finally, a total of 53 records were included in this study (Supplementary material Fig. S1). Characteristics of the included studies are summarized in Supplementary material Table S1. All included studies compared the effectiveness of HIIT on VO2max/peak with either CON or MICT group in a total of 1,514 adults covering an age range of 19 to 47 years and baseline VO_2max/peak values ranging from 22.7 to 66.5 ml/kg/min. Populations covered by the identified studies included healthy non-athletes (26/53 studies with 29 HIIT groups), overweight/obese non-athletes (18/53 studies with 22 HIIT groups) and athletes (9/53 studies with 13 HIIT groups). Sample sizes in the HIIT groups ranged from 6 to 34 participants. Exercise modalities comprised cycling, handcycling, running, walking, swimming, and rowing. The HIIT protocols ranged from high (80% VO_2max/peak, 85% HRmax or 90% v/pVO_2max) to all-out in intensity, 8 s to 10 min in bout duration and 20 s to 40 min in session volume. Training periods ranged from 2 to 16 weeks. The changes in VO_2max/peak after HIIT intervention varied between -5.4% and 33.1%.

The methodological quality of the reviewed studies is presented in Supplementary material Table S2 A mean PEDro score of 6.77/10 (range from 5 to 9) was achieved. Concealed allocation (8%), blinding of assessors (28%), an explanation of sample size calculations (2%), activity monitoring in control groups (23%) and relative exercise intensity remained constant (38%) were reported in a minority of the studies, while specific eligibility criteria (74%), randomisation (100%), similar baseline groups (98%), outcome measures assessed in 70% of patients (98%), intention-to-treat analysis (70%), between-group statistical comparisons (100%), point measures and measures of variability (100%) and exercise energy expenditure information (92%) were reported in most of the studies.

The results of the overall and subgroup meta-analyses are presented in Table 1, Supplementary material Table S3 and Figs. S2-4, and the magnitude of effects for all protocols of HIIT were integrated and ranked in Fig. 2.

In healthy populations, HIIT had an overall large beneficial effect on VO_2max/peak (WMD = 5.45 ml/kg/min; SMD = 1.81, 95% CI 1.39 to 2.22, $p < 0.05$, $I^2 = 68.0\%$) in comparison to no training controls (NT-CON), while all HIIT protocols elicited significant beneficial effects (SMD = 1.24 to 2.48, $p < 0.05$) in subgroup analyses. When compared to MICT, HIIT showed an overall moderate effect (WMD = 2.06 ml/kg/min; SMD = 0.64, 95% CI 0.23 to 1.05, $p < 0.05$, $I^2 = 75.2\%$) on VO_2max/peak, but only long-interval, high-volume, and moderate-term protocols elicited significant beneficial effects (SMD = 0.65 to 1.07, $p < 0.05$) in subgroup analyses.

In overweight/obese populations, HIIT had an overall large beneficial effect on VO_2max/peak (WMD = 3.54 ml/kg/min; SMD = 1.35, 95% CI 0.81 to 1.88, $p < 0.05$, $I^2 = 68.8\%$) in comparison to NT-CON, while most HIIT protocols (long-interval, moderate to high-volume, moderate to long-term HIIT, and RST) elicited significant beneficial effects (SMD = 1.13 to 1.99, $p < 0.05$) in subgroup analyses. When compared to MICT, HIIT showed an overall small effect (WMD = 1.07 ml/kg/min; SMD = 0.41, 95% CI 0.08 to 0.75, $p < 0.05$, $I^2 = 60.1\%$) on VO_2max/peak, but only long-interval, high-volume, and long-term protocols elicited significant beneficial effects (SMD = 0.77 to 1.02, $p < 0.05$) in subgroup analyses.

In athletic populations, HIIT had an overall small effect (WMD = 1.71 ml/kg/min; SMD = 0.57, 95% CI 0.13 to 1.01, $p < 0.05$, $I^2 = 62.8\%$) in comparison to regular training controls (RT-CON), while most HIIT protocols (moderate to long-interval, moderate to high-volume and short to moderate-term HIIT) elicited significant beneficial effects (SMD = 0.50 to 1.01,

$p < 0.05$) in subgroup analyses.

Sensitivity analysis (Supplementary material Table S3) demonstrated little less pronounced effects of HIIT on VO_2max/peak in comparison to MICT became a little less pronounced after removing 16 trials of poor quality (PEDro scores < 7 points),. Potential publication bias was found by funnel plot (Supplementary material Fig. S5) and Egger test ($p = 0.011$). Regarding meta-regression analyses (Supplementary material Table S4), the work:rest ratio ($\beta = 1.123$, $p = 0.001$) was identified as a moderator for the effect of HIIT on VO_2max/peak in overweight/obese populations when HIIT was compared to MICT.

4. Discussion

This study utilised data from RCTs to confirm the findings from previous meta-analyses that examined the effectiveness of HIIT on VO_2max performance. It also further investigated the effects of different protocols of HIIT in various populations. Overall, irrespective of protocol, the degree of change in VO_2max induced by HIIT varied by populations. Further subgroup analyses revealed that even short work interval (≤ 30 s), low-volume (≤ 5 min) and short-term (≤ 4 weeks) HIIT could elicit clear beneficial effects on VO_2max when compared to CON. However, long-interval (≥ 2 min), high-volume (≥ 15 min) and moderate to long-term (≥ 4-12 weeks) HIIT displayed significantly larger effects on VO_2max than both CON and MICT. Interestingly, when HIIT vs CON and HIIT vs MICT were both taken into consideration, training effects of long-interval and high-volume HIIT were highest in healthy populations, whereas long-term HIIT showed advantages in overweight/obese populations. For athletic adults, HIIT effects were lower with increased training periods, while in general population, the opposite was the case.

The current study found that non-athletic populations benefited more from HIIT than athletic populations, which is consistent with previous findings stating that aerobic training in general having an apparent adaptive effect on VO_2max favouring the subjects with a lower baseline VO_2max value.[28, 31] It is therefore unlikely that large improvements in VO_2max could occur following HIIT in already highly trained athletes. This meta-analysis also found that HIIT appeared to be slightly more effective for healthy people than for overweight/obese people. It seems possible that this result is due to the calculation method of relative VO_2max employed in the included studies, which divides absolute VO_2max by body weight rather than fat-free mass (FFM).[46, 47] Previous findings[48, 49] have demonstrated that VO_2max did not differ between obese and normal-weight people after adjusting for FFM, and VO_2max was significantly correlated with FFM after controlling for fat mass. Therefore, without normalising VO_2max by FFM, the training-induced changes in relative VO_2max in obese subjects would be underestimated due to their higher body weight and body fat percentage.

In terms of the impact of work intervals on VO_2max, previous meta-analyses[29, 30] have demonstrated that SIT with 10-30 s sprints at all-out intensity demonstrated beneficial effects (SMD = 0.63-0.69) on VO_2max levels compared to no training control groups, but a trivial effect (0.04) was observed when comparing it to endurance training in healthy adults, which is in line with the present study results. We also found that short-interval HIIT elicited similar training effects as SIT, but involved lower intensity with more repetitions. This means that although SIT was more time-efficient, short-interval HIIT could be an alternative approach when considering the safety and feasibility issues regarding the application of HIIT in general population.[50] Nevertheless, our findings show that both SIT and short-interval HIIT evoke no significant effect on VO_2max in overweight/obese and athletic populations. Traditional moderate to long-interval HIIT between > 30s and 2 min exercise at sub-maximal intensity are therefore recommended to ensure or enhance the training effect across all populations.

Recently, RST has received increased attention in the literature.[38, 51] We observed large to very large effects on VO_2max improvements in healthy and overweight/obese populations. However, previous studies suggested that RST with overly short bout durations may allow for a limited T@VO_2max as compared to other HIIT protocols that involved longer intervals. It was considered to be more anaerobic dependent.[21, 29] There were only four RCTs that used RST were identified in the present review. Hence high quality studies are needed to confirm our observations in the future.

Exercise volume as determined by work intervals and repetitions together was considered as a key factor that influences VO_2max improvements and time-efficiency of a training program.[1] In accordance with the previous studies,[26, 29] we found that low-volume HIIT elicited a large effect in healthy populations as compared to CON. However, only moderate to high-volume HIIT (> 5 to 15 min) demonstrated moderate to very large effects across the populations when compared to CON or MICT. This finding was supported by Bækkerud et al.'s study[52] where high-volume HIIT (16 min) was superior to low-volume group in most likely improving the VO_2max because of an increased stroke volume.

Moreover, We found that the session volume used in RST studies (8 min) was obviously larger than that used in most SIT studies (< 4 min) due to more sprint repetitions employed in RST. This may be another reason why RST presented greater beneficial effects on VO_2max changes in the included studies. A recent meta-analysis[53] investigating the effect of number of sprint repetitions in SIT showed that fewer repetitions would not attenuate the improvements in VO_2max. However, their conclusion was limited, as the session volumes employed were less than 5 min in all the included studies, suggesting that such a small range of change may not be enough to lead to significant increases in VO_2max. Therefore, we think that at a given individualized work interval, improvements in VO_2max could also be ensured or greatly enhanced across populations by substantially increasing the session volume.

Although a very short training duration (2 weeks) was considered to be sufficiently long to promote aerobic adaptations, a longer duration was more likely to be associated with greater improvements in VO_2max.[16, 54] Our results demonstrated that even short-term HIIT (≤ 4 weeks) can improve VO_2max when compared to CON in healthy populations, but moderate to long-term HIIT (> 4-12 weeks) showed additional further beneficial effects as compared to both CON and MICT in both healthy and overweight/obese populations. These findings are similar to those reported in a previous meta-analysis[26] where long-term HIIT (≥ 12 weeks) exerted a large positive effect (SMD = 1.20) on VO_2 max in overweight/obese populations. Thus, to ensure or more greatly enhance the training effects, it is important to improve exercise adherence and maintenance in general population, especially in overweight/obese populations.

Such positive trends were not observed in athletic populations, with HIIT displaying a reduced effect on VO_2 max improvement over a prolonged intervention duration. This may indicate that the early stage of the training period is more likely to be responsible for the adaptations of VO_2max through HIIT in well-trained athletes.[29] However, this finding should be interpreted with caution as only one RCT used a short-term HIIT protocol on athletic populations were identified, and future work is required to confirm these results.

The present study does not come without limitations. The overall analysis demonstrated significant heterogeneity (I^2 ranged from 60.1% to 75.2%) among the included studies, which may affect the findings of our meta-analysis. While pre-specified subgroup and meta-regression analyses were conducted to investigate the influence of some individual characteristic and training variables on training effect, varying degrees of heterogeneity (I^2 ranged from 0.0% to 79.0%) were detected among results in subgroups, and only work:rest ratio was identified as a moderator for the effect of HIIT on VO_2max in the meta-regression analysis. This may have meant that the heterogeneity is affected by multi-factors that vary across studies rather than single factors. We therefore used the random effects model in the statistical analysis to make the results more conservative.

Although this review included published RCTs, many of these studies have suffered from small sample sizes with some issues in methodological quality, and a publication bias was detected, which may affect the reliability of our results. Moreover, due to the small number of trials included in some subgroup analyses, the findings should be interpreted with caution. Additionally, we extracted the relative values (ml/kg/min) rather than absolute values (L/min) of VO_2max from the included studies, which may in turn magnify the training effect due to a possible decrease of body weight after the intervention.

5. Conclusions

In conclusion, our meta-analysis suggests that, irrespective of protocol, HIIT is effective for improving VO_2max in healthy, overweight/obese and athletic adults. By investigating the different protocols of HIIT, short work interval HIIT (≤ 30 s of work/bout at sub-maximal to all-out intensity), low-volume HIIT (≤ 5 min of work/session) and short-term HIIT (≤ 4 weeks of intervention) are feasible and time-efficient strategies and come with high effectiveness for VO_2max improvements, especially for the general population. To ensure or more greatly improve the training effects on VO_2max, long-interval (≥ 2 min of work/bout at sub-maximal intensity), high-volume (≥ 15 min of work/session) and moderate to long-term (≥ 4-12 weeks of intervention) HIIT are recommended.

Practical implications

- HIIT appears to be an effective alternative approach for improving VO_2max in healthy, overweight/obese and athletic adults.
- Short-interval (≤ 30 s), low-volume (≤ 5 min) and short-term (≤ 4 weeks) HIIT are feasible and time-efficient strategies and come with high effectiveness for improving VO_2max, especially for the general population..
- Long-interval (≥ 2 min), high-volume (≥ 15 min) and moderate to long-term (≥ 4-12 weeks) HIIT protocols should be adopted, if the goal is to maximize the training effects on VO_2max or surpass the MICT.

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Figure Legends

Fig. 1 Classification of HIIT protocols

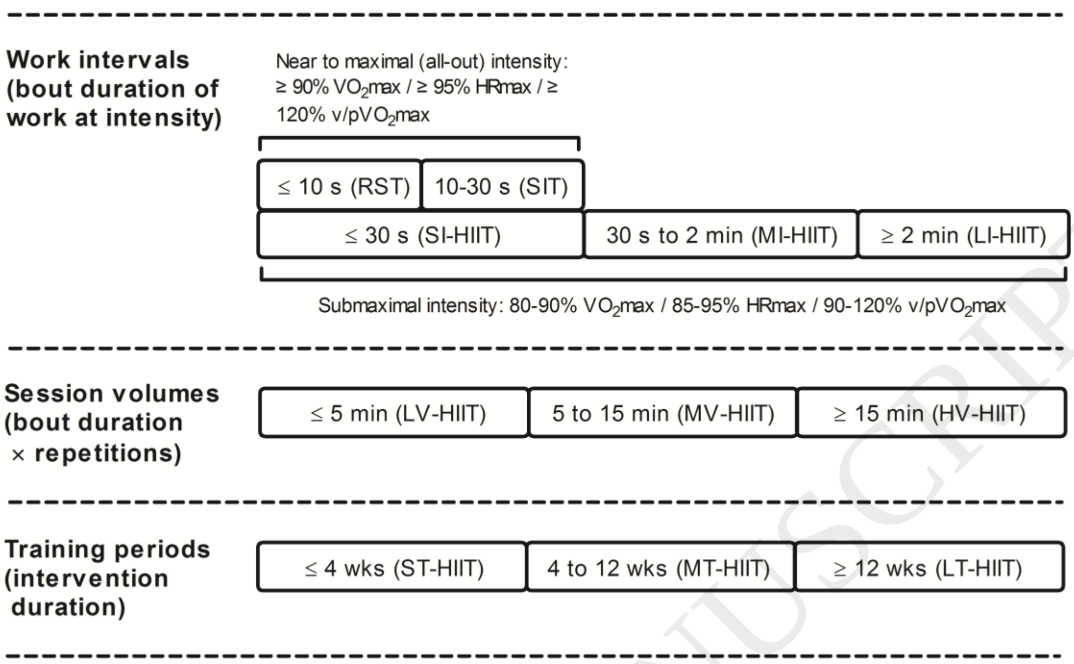

Fig. 2 Magnitude of effect by different protocols of HIIT in different population

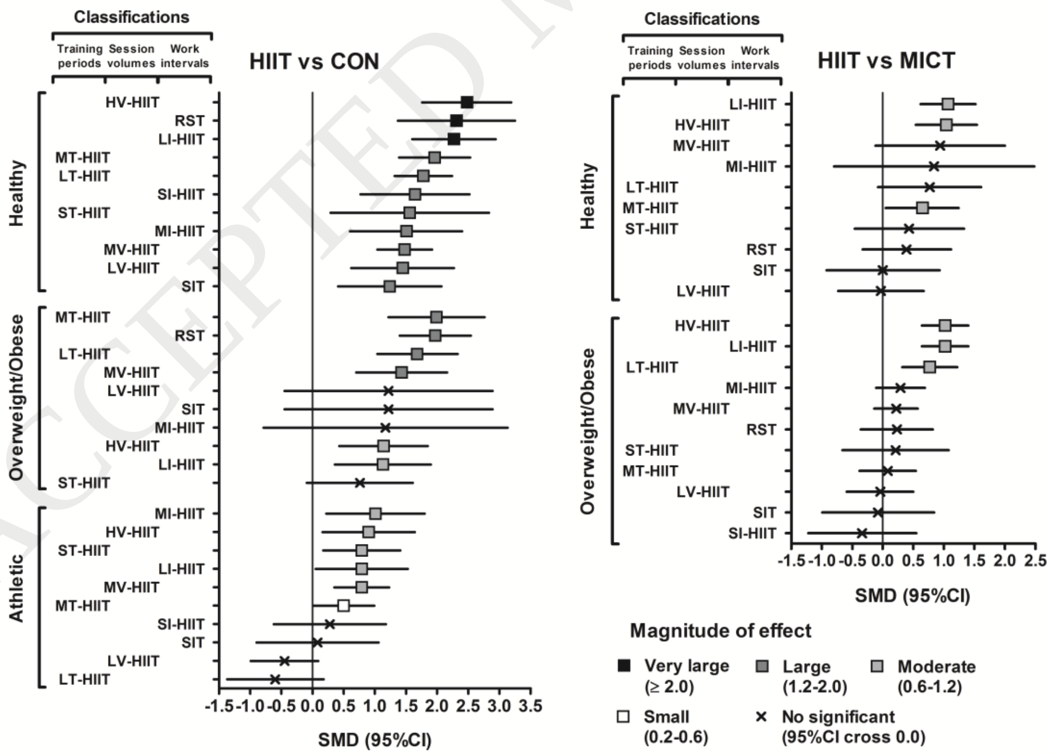

Table 1 General results of the pooled effect of comparison HIIT versus CON/MICT on VO_2max/peak by different HIIT training protocols

	Healthy				Overweight/Obese				Athletic			
	N	WMD (95%CI)	SMD (95%CI)	I^2	N	WMD (95%CI)	SMD (95%CI)	I^2	N	WMD (95%CI)	SMD (95%CI)	I^2
HIIT vs CON												
Work intervals												
LI	8	7.62 (5.36, 9.88)	2.27 (1.60, 2.94)	70.7%	3	3.15 (0.35, 5.94)	1.13 (0.36, 1.90)	59.7%	5	2.46 (0.28, 4.65)	0.79 (0.05, 1.53)	66.2%
MI	2	3.72 (0.98, 6.46)	1.51 (0.60, 2.40)	42.3%	2	3.13 (-1.18, 7.43)	1.17 (-0.79, 3.13)	73.4%	2	2.44 (0.65, 4.23)	1.01 (0.22, 1.80)	0.0 %
SI	3	3.54 (1.85, 5.23)	1.65 (0.77, 2.52)	35.8%					1	1.00 (-2.30, 4.30)	0.28 (-0.62, 1.18)	
SIT	5	3.66 (2.10, 5.23)	1.24 (0.41, 2.07)	72.1%	2	3.49 (-0.31, 7.28)	1.22 (-0.45, 2.89)	74.3%	4	0.21 (-2.24, 2.66)	0.08 (-0.90, 1.06)	75.8%
RST	1	8.30 (5.73, 10.87)	2.31 (1.37, 3.25)		2	4.13 (3.18, 5.08)	1.97 (1.40, 2.54)	0.0 %				
Training volumes												
HV	7	8.26 (5.91, 10.60)	2.48 (1.76, 3.19)	67.4%	1	2.00 (0.86, 3.14)	1.14 (0.43, 1.85)		5	2.87 (0.65, 5.08)	0.90 (0.16, 1.64)	65.9%
MV	6	4.09 (2.33, 5.86)	1.48 (1.04, 1.92)	17.5%	6	3.89 (2.59, 5.19)	1.43 (0.70, 2.16)	73.3%	5	2.56 (1.33, 3.79)	0.79 (0.35, 1.23)	0.0 %
LV	6	3.96 (2.73, 5.18)	1.45 (0.62, 2.27)	73.9%	2	3.49 (-0.31, 7.28)	1.22 (-0.45, 2.89)	74.3%	3	-0.87 (-2.26, 0.53)	-0.45 (-0.99, 0.09)	0.0 %
Training periods												
LT	4	5.64 (3.03, 8.24)	1.78 (1.32, 2.24)	71.3%	4	3.37 (1.87, 4.87)	1.68 (1.04, 2.33)	70.9%	8	-1.80 (-4.06, 0.46)	-0.60 (-1.37, 0.18)	67.5%
MT	11	6.01 (3.94, 8.08)	1.96 (1.39, 2.53)	67.3%	2	5.69 (3.90, 7.48)	1.99 (1.22, 2.76)	0.0 %	4	1.31 (-0.26, 2.87)	0.50 (0.02, 0.99)	0.0 %
ST	4	3.96 (2.47, 5.45)	1.56 (0.29, 2.83)	18.9%	3	2.38 (-0.08, 4.85)	0.76 (-0.09, 1.61)	51.9%	1	2.20 (0.48, 3.91)	0.79 (0.17, 1.41)	
HIIT vs MICT												
Work intervals												
LI	9	3.66 (2.28, 5.04)	1.07 (0.62, 1.52)	58.2%	5	2.51 (1.46, 3.56)	1.02 (0.64, 1.40)	3.6 %				
MI	3	1.82 (-1.84, 5.48)	0.84 (-0.80, 2.48)	75.2%	3	0.92 (-0.22, 2.05)	0.29 (-0.11, 0.69)	0.0 %				
SI					2	-1.15 (-4.19, 1.88)	-0.34 (-1.22, 0.55)	54.1%				

		SIT	5	0.40 (-1.66, 2.45)	0.00 (-0.92, 0.93)	79.0%		3	-0.04 (-1.76, 1.69)	-0.08 (-0.99, 0.84)	67.5%					
		RST	1	1.60 (-1.30, 4.50)	0.39 (-0.33, 1.12)			2	0.69 (-0.87, 2.26)	0.23 (-0.36, 0.82)	4.1%					
	Training volumes															
		HV	8	3.47 (1.99, 4.94)	1.04 (0.54, 1.54)	61.8%		5	2.51 (1.46, 3.56)	1.02 (0.64, 1.40)	3.6%					
		MV	4	2.72 (-0.06, 5.51)	0.94 (-0.12, 2.00)	70.8%		4	0.69 (-0.31, 1.69)	0.22 (-0.14, 0.57)	0.0%					
		LV	7	0.20 (-1.53, 1.94)	-0.03 (-0.73, 0.67)	73.4%		6	-0.07 (-1.34, 1.21)	-0.04 (-0.59, 0.50)	57.1%					
	Training periods															
		LT	3	2.28 (0.11, 4.45)	0.77 (-0.08, 1.61)	51.1%		4	1.83 (0.82, 2.84)	0.77 (0.32, 1.22)	67.3%					
		MT	12	2.25 (0.32, 4.18)	0.65 (0.05, 1.24)	79.0%		5	0.25 (-1.14, 1.64)	0.08 (-0.38, 0.54)	39.1%					
		ST	4	1.20 (-1.24, 3.64)	0.43 (-0.46, 1.33)	76.9%		6	0.69 (-1.45, 2.83)	0.21 (-0.66, 1.08)	50.0%					

The underlined data indicate statistically significant effect ($p < 0.05$).
N: number of trails, HIIT: high intensity interval training, LI: long-interval (≥ 2min of work/bout at sub-maximal intensity), MI: moderate-interval (> 30s and < 2min of work/bout at sub-maximal intensity), SI: shot-interval (≤ 30s of work/bout at sub-maximal intensity), SIT: sprint interval training (10 to 30s of work/bout at near to maximal intensity), RST: repeated sprint training (≤ 10s bout of work/at near to maximal intensity), HV: high-volume (≥ 15min of work/session), MV: moderate-volume (> 5 and < 15min of work//session), LV: low-volume (≤ 5min of work//session), LT: long-term (≥ 12 weeks), MT: moderate-term (> 4 and < 12 weeks), ST: short-term (≤ 4 weeks), WMD: weighted mean difference, SMD: standardized mean difference, CL: confidence interval, CON: control group, MICT: moderate intensity continuous training.