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# Effects of Passive or Active Recovery Regimes Applied During Long-Term Interval Training on Physical Fitness in Healthy Trained and Untrained Individuals: A Systematic Review <br> Check for updates 

Hassane Zouhal ${ }^{1,2^{*}}{ }^{\odot}$, Abderraouf Ben Abderrahman ${ }^{3,4 \dagger}$, Ayyappan Jayavel ${ }^{5}$, Anthony C. Hackney ${ }^{6}$, Ismail Laher ${ }^{7}$, Ayoub Saeidi ${ }^{8}$, Fatma Rhibi ${ }^{1+}$ and Urs Granacher ${ }^{* *+}$ ©


#### Abstract

Background Intermittent exercise programs characterized through intensive exercise bouts alternated with passive or active recovery (i.e., interval training), have been proven to enhance measures of cardiorespiratory fitness. However, it is unresolved which recovery type (active or passive) applied during interval training results in larger performance improvements. Objectives This systematic review aimed to summarize recent evidence on the effects of passive or active recovery following long-term interval exercise training on measures of physical fitness and physiological adaptations in healthy trained and untrained individuals. The study protocol was registered in the Open Science Framework (OSF) platform (https://doi.org/10.17605/OSF.IO/9BUEY). Methods We searched nine databases including the grey literature (Academic Search Elite, CINAHL, ERIC, Open Access Theses and Dissertations, Open Dissertations, PsycINFO, PubMed/MEDLINE, Scopus, and SPORTDiscus) from inception until February 2023. Key terms as high-intensity interval training, recovery mode, passive or active recover were used. A systematic review rather than a meta-analysis was performed, as a large number of outcome parameters would have produced substantial heterogeneity. Results After screening titles, abstracts, and full texts, 24 studies were eligible for inclusion in our final analysis. Thirteen studies examined the effects of interval training interspersed with passive recovery regimes on physical fitness and physiological responses in trained ( 6 studies) and untrained ( 7 studies) individuals. Eleven out of 13 studies reported significant improvements in physical fitness (e.g., maximal aerobic velocity (MAV), Yo-Yo running test, jump performance) and physiological parameters (e.g., maximal oxygen uptake $\left[\mathrm{VO}_{2 \text { max }}\right]$ ] lactate threshold, blood pressure) in trained (effect sizes from single studies: $0.13<$ Cohen's $d<3.27$, small to very large) and untrained individuals (effect sizes: $0.17<d<4.19$, small to very large) despite the type of interval training or exercise dosage (frequency, intensity, time, type). Two studies were identified that examined the effects of passive recovery applied during interval training in young female basketball ( $15.1 \pm 1.1$ years) and male soccer players ( $14.2 \pm 0.5$ years). Both studies showed positive


[^0]effects of passive recovery on $\mathrm{VO}_{2 \text { max }}$ countermovement jump performance, and the Yo -Yo running test. Eleven studies examined the effects of interval training interspersed with active recovery methods on physical fitness and physiological parameters in trained ( 6 studies) and untrained individuals ( 5 studies). Despite the type of interval training or exercise dosage, nine out of eleven studies reported significant increases in measures of physical fitness (e.g., MAV) and physiological parameters (e.g., $\mathrm{VO}_{2_{\text {max }}}$, blood pressures) in trained (effect sizes from single studies: $0.13<d<1.29$, small to very large) and untrained individuals (effect sizes: $0.19<d<3.29$, small to very large). There was no study available that examined the effects of active recovery on physical fitness and physiological responses in youth.
Conclusions The results of this systematic review show that interval training interspersed with active or passive recovery regimes have the potential to improve measures of physical fitness and physiology outcomes in trained and untrained adults and trained youth. That is, the applied recovery type seems not to affect the outcomes. Nonetheless, more research is needed on the effects of recovery type on measures of physical fitness and physiological adaptations in youth.

## Key Points

- Endurance training in the form of interval training is known to increase physical fitness (e.g., MAV) and physiological parameters (e.g., $\mathrm{VO}_{2 \text { max }}$, blood pressure) in both trained and untrained individuals, irrespective of age and sex.
- This review revealed that interval training improves measures of physical fitness (e.g., MAV) and physiological parameters (e.g., $\mathrm{VO}_{2 \text { max }}$, blood pressure) similarly in trained and untrained adults and trained youth, regardless of the type of exercise and the exercise dosage.
- The applied recovery type (active or passive) during interval training seems not to affect the training-induced outcomes, irrespective of the training status (trained versus untrained) and sex.

Keywords Recovery mode, Interval training, Physiological parameters, Performances, Healthy adults

## Background

Maximal oxygen uptake $\left(\mathrm{VO}_{2 \max }\right)$ is an important physiological determinant of sports performance particularly in metabolically demanding sports such as middle and long-distance running, cycling, rowing, cross-country skiing, etc. [1-5]. Training-induced improvements in $\mathrm{VO}_{2 \text { max }}$ depend on factors, such as age, sex, and training status [6-9]. Accordingly, training protocols with the goal to improve $\mathrm{VO}_{2 \text { max }}$ should be individualized according to the needs of the athlete [10-13]. Nevertheless, the available literature provides some guidance on the programming of exercise protocols to enhance $\mathrm{VO}_{2 \max }$. For instance, for the training modalities exercise frequency, intensity, time, and type of exercise (FITT-principle), there is evidence that training at or near an individual's $\mathrm{VO}_{2 \text { max }}$ may be an ideal stimulus to increase $\mathrm{VO}_{2 \text { max }}$ [3, 14]. Regarding the type of training, it seems that intermittent exercise protocols consisting of intensive exercise bouts alternated with passive or active recovery regimes can improve cardiorespiratory fitness [4-6, 15-18].
Interestingly, high-intensity interval training (HIIT) has not only been applied in sub-elite and elite athletes to enhance their aerobic capacity but also in recreational athletes and even in patients (e.g., individuals with obesity, diabetes, etc.) [19-23]. Despite its widespread use, there is no common definition of HIIT; in
the context of performance, HIIT can be defined as intermittent bouts of exercise realized at high-intensity, and in the context of health, HIIT can be characterized as intermittent exercise performed at low or moderate intensity [24]. As such, the dosage of HIIT protocols varies greatly and differs in exercise intensity, duration of intervals, number of repetitions, recovery types, work-to-rest ratio, and rest time between interval bouts [10, 11]. The application of HIIT protocols is particularly popular in intermittent sports, such as team sports (e.g., soccer) or racket sports (e.g., tennis), to improve measures of physical fitness [25, 26]. Physiological adaptations following HIIT are based on complex molecular (e.g., the expression of PGC-1 $\alpha$ mRNA) and cellular mechanisms (e.g., mitochondrial density and biogenesis) [27, 28].
During the performance of HIIT sessions, immediate post-exercise recovery (i.e., after each repetition or interval), represents an important restorative process (e.g., physiological, psychological) that impacts on the magnitude of the training-induced physiological adaptations [29, 30]. Both the type of recovery (active, passive) as well as the recovery time influence maximal performance during each interval and the overall physiological stress [31, 32].

Active recovery at low-to-moderate intensities during HIIT may enable larger adaptive potential during the next HIIT exercise bout than passive recovery, but the experimental data to support this claim are inconclusive [33]. While some studies report a greater magnitude of adaptation with active recovery regimes $[4,5,34,35]$, other studies indicate that the type of recovery does not have an impact on training-induced adaptations [36]. A recent systematic review focused only on acute physiological, perceptual, and performance effects of recovery mode applied between repeated-sprints during running and cycling protocols reported that passive recovery reduced physiological and perceptual demands and reduced loss of performance compared to active recovery in repeatedsprints running, with limited data on cycling studies [37]. In contrast, another systematic review on the effects of recovery mode on performance limited to mean and peak power, time to exhaustion, and distance covered during an interval exercise session only indicated that passive recovery aids in maintaining performance during interval exercise [38].
Accordingly, it seems timely to systematically summarize the literature to identify whether interval training with active or passive recovery shows larger adaptive potential after a long-term exercise training. The objective of this systematic review was to gather recent evidence on the effects of the recovery type (passive or active) applied during long-term interval training on measures of physical fitness and physiological adaptations in healthy trained and untrained youth and adult individuals.

## Methods

## Procedures

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement [39]. The study protocol was registered in the Open Science Framework (OSF) platform (https://doi.org/https://doi.org/10.17605/ OSF.IO/9BUEY).

The PICOS approach (Population, Intervention, Comparator, Outcomes, Study design) was followed to identify inclusion criteria (Table 1). Only randomized controlled trials and controlled trials that examined the effects of passive or active recovery during long-term interval training, for at least 3 weeks, on measures of physical fitness and physiological adaptations in trained and untrained youth and adult individuals were eligible for inclusion. The following criteria were a priori defined for studies to be eligible for inclusion in this systematic review article: (1) published in peer-reviewed journals; (2) included healthy trained and untrained individuals, irrespective of age; (3) used validated methods of exercise training quantification; (4) used training programs with passive or active recovery types; (5) used physical fitness tests (e.g., Léger \& Boucher test, VAMEVAL) and physiological tests (e.g., $\mathrm{VO}_{2 \max }$ ); (6) were written in English, and (7) exercise interventions lasted a minimum of 3 weeks.
Studies were excluded if they (1) did not meet the minimum requirements of an experimental study design (e.g., case reports), (2) did not meet the minimum requirements regarding training design (e.g., lack of information on training methodology or testing sessions), (3) were not written in English, and (4) involved individuals with clinical concerns. Published review articles were also excluded from our analysis.
In the current review, "trained individuals" refers to athletes who exercised at least three times per week, and "untrained" refers to individuals who did not meet the World Health Organization minimum activity guidelines of 60 min per day (youth) and 150 min per week (adults) [40].

## Literature Search Strategy

We searched nine databases including the grey literature (Academic Search Elite, CINAHL, ERIC, Open Access Theses and Dissertations, Open Dissertations, PsycINFO, PubMed/MEDLINE, Scopus, and SPORTDiscus) from inception until February 2023.

Table 1 Inclusion criteria according to the PICOS approach

| PICOS components | Details |
| :--- | :--- |
| Population | Healthy trained and untrained humans aged $>14$ years old |
| Intervention | Interval exercise training using passive or active recovery types during exercise for at least 3 weeks |
| Comparator | Active and/or passive controls |
| Outcomes | Measures of physical fitness (e.g., aerobic performance, jump performance etc.), physiological adapta- <br> tions (e.g., maximal oxygen uptake [VO 2 max, |
| economy etc.) |  |

The following key terms (and synonyms searched for using the MeSH term database) were included and combined using the operators "AND", "OR",: [(exercise OR training OR "exercise training" OR "interval exercise" OR "intermittent exercise" OR "interval training" OR "intermittent training" OR "high-intensity interval exercise" OR "high-intensity interval training") AND (recovery OR "recovery mode" OR "passive recovery" OR "active recovery") AND ("physical fitness" OR "physiological adaptation*" OR "physiological response*")].
In addition, the reference lists and citations (Google Scholar) of included studies were explored further to detect additional related studies. Since the scope of this systematic review article is large in terms of outcome measures (e.g., physical fitness, physiological adaptations), we performed a systematic review rather than a meta-analysis, as a large number of outcome parameters would have produced substantial heterogeneity.

## Study Selection

The final screening was done by two investigators (FR and AJ) based on the relevance of the inclusion and exclusion criteria and the identified items for assessing the effects of passive or active recovery after long-term interval training (at least 3 weeks) on measures of physical fitness and physiological adaptations in trained and untrained individuals using PICOS criteria. If the title of the article was potentially relevant, the manuscript was screened at the abstract level. When abstracts indicated potential inclusion, full texts were reviewed. A third-party consensus meeting was held with another author (HZ) if the two reviewers were not able to reach a consensus.

## Quality and Risk of Bias and Assessment

The methodological quality of the included studies was assessed using the Physiotherapy Evidence Database (PEDro) scale (http://www.pedro.fhs.usyd.edu.au), which has good reliability and validity [39]. The PEDro scale has eleven possible points that examine external validity (criterion 1 ) and internal validity (criteria 2-9) of controlled trials and whether there is sufficient statistical information for interpreting the results (criteria 10-11). A cut-off score of six on the PEDro scale was used to differentiate between low and high methodological quality [41]. Two independent researchers (FR and ABA) assessed the quality of the studies, and if any unambiguity arose, a third researcher (HZ) was contacted to reach a unanimous decision.

## Statistics

The percent change ( $\Delta \%$ ) was calculated (if not available in the study) for each study to evaluate the magnitude of the effects using the following equation:

$$
\Delta \%=(\text { Mpost }- \text { Mpre }) / \text { Mpre } \times 100
$$

where Mpost represents the mean value after intervention and Mpre the baseline mean value.
Effect sizes (ES) were computed for single studies but were not aggregated across studies to present standardized effects of exercise training on the outcome variables (e.g., physical fitness and physiological adaptations). As an ES measure, we consistently used Cohen's d [42] by dividing the raw ES (difference in means) by the pooled standard deviations:

$$
E S=(\text { Cohen } / \mathrm{sd})=(\mathrm{M} 1-\mathrm{M} 2) / \text { SDpooled })
$$

Values for ES were defined as trivial ( $<0.2$ ), small ( $0.2-0.6$ ), moderate ( $0.6-1.2$ ), large (1.2-2.0), and very large $>2.0$ [43]. Results for each outcome variable are presented with several observations ( N ), $\Delta \%$, and ES. The data analysis was processed using SigmaStat 3.5 software (Systat, Inc, USA). The ES and $\Delta \%$ were analyzed in studies where sufficient data were available. A significant difference was indicated when the $95 \%$ confidence interval (CI) of the ES did not overlap zero.

## Results

## Study Selection

We identified 23,815 studies related to the effects of long-term interval training on physical fitness and physiological parameters in healthy trained and untrained individuals (Fig. 1). After the screening of titles, abstracts, and full texts, 24 studies were eligible to be included in our final analysis. The characteristics of the included studies are summarized in Table 2. A total of 501 individuals participated in the interval training programs with active recovery and 229 in interval training programs with passive recovery regimes. Participants' age ranged from 14 to 48 years.
Thirteen studies (229 participants) examined the effects of interval training interspersed with passive recovery regimes on physical fitness and physiological performances in trained (6 studies) and untrained (7 studies) individuals. Eleven studies (501 participants) examined the effects of interval training interspersed with active recovery methods on measures of physical fitness and physiological parameters in trained (6 studies) and untrained individuals (5 studies) (Table 3).
The 24 studies used different interval training types (e.g., running, cycling, swimming) lasting between 3 and 15 weeks. The training duration mainly ranged between three [44] and 7 weeks [4], with two studies using a 12 - and 15 -week intervention period [45, 46].


Fig. 1 Selection process for research articles $(N=24)$ included in this systematic review [39]

## Effects of Interval Exercise Training Using Passive Recovery on Measures of Physical Fitness and Physiological Adaptations in Trained and Untrained Individuals

Table 4 summarizes the 13 studies that examined the effects of long-term interval training interspersed with passive recovery on measures of physical fitness and physiological parameters in both trained and untrained youth and adult individuals. Six studies [4, 26, 47-50] involved trained individuals and the seven remaining studies comprised untrained subjects [51-57]. Irrespective of the type of interval training or exercise protocol (type of exercise, duration, or intensity of exercise training), eleven out of 13 studies reported increases in measures of physical fitness (e.g., maximal aerobic velocity [MAV], Yo-Yo running test, jumping) and physiological parameters (e.g., $\mathrm{VO}_{2 \max }$, lactate threshold, blood pressures) in both trained (effect size for single studies: $0.13<d<3.27$, small to very large) and untrained adults as well as trained youth (effect size: $0.17<d<4.19$, small to very large).
Two studies were identified that examined the effects of passive recovery applied during interval training in young
female basketball players aged $15.1 \pm 1.1$ years [49] and in male soccer players aged $14.2 \pm 0.5$ years. [48]. Both studies showed positive effects of passive recovery on $\mathrm{VO}_{2 \max }$, countermovement jump (CMJ), and the Yo-Yo intermittent running test level 1 (YYIRTL-1).

## Effects of Interval Exercise Training Using Active Recovery on Measures of Physical Fitness and Physiological Adaptations in Trained and Untrained Individuals

Table 5 summarizes the findings of eleven studies that examined the effects of interval training interspersed with active recovery on physical fitness and physiological parameters in trained and untrained adults. Six studies [4, 5,58-61] involved trained individuals and the five remaining studies incorporated untrained subjects [4446, 62, 63].
Irrespective of the type of interval training or exercise protocol (type of exercise, duration, or intensity of exercise training), nine out of 11 studies reported increases in physical fitness (e.g., MAV) and physiological parameters (e.g., $\mathrm{VO}_{2 \max }$, lactate threshold, blood pressures)
Table 2 Characteristics of the studies that examined the effects of interval training with active or passive recovery on measures of physical fitness and physiological adaptations in trained and untrained individuals

| Study | PEDro score | Country | Sample size/ sex | Physical activity level/sport | Age, years (mean $\pm$ SD or range) | Recovery type | Training volume | Training intensity | Intervention duration (weeks) | Session duration (min) | Training frequency |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Buckley et al. [54] | 7 | Canada | 28 healthy females | Active | $24.7 \pm 5.4$ | Passive | Row-HIIT and MM-HIIT group performed 60 s of all-out intensity rowing followed by 3 min of rest (passive recovery) for a total of 6 rounds. High-volume | All out inten- <br> sity; 9/10 or 10/10 in RPE scale | 6 weeks | 24 | 3 times/week |
| Kong et al. [53] | 7 | Macau | 18 overweight and obese females | Inactive | 18-30 | Passive | 60 repetitions of highintensity interval exercise (8 s cycling and 12 s passive recovery) on a cycle ergometer for 20 min . High-volume | $90 \% \mathrm{VO}_{2 \text { max }}$ | 5 weeks | 20 min | 4 session/week |
| Aschendorf et al. [49] | 7 | Germany | 24 females | Basketball | $15.1 \pm 1.1$ | Passive | Two different types of HIIT: Session A $4 \times 4$ HIIT with 3 min of recovery; Session B $2 \times 30 \mathrm{~s}$ HIIT with 15 s recovery. High and low volume | $90-95 \% \mathrm{VO}_{2 \max }$ | 5 weeks | 25 min | 3 times/week |
| Wiewelhove et al. [26] | 7 | Germany | 26 males | Soccer, handball, basketball, tennis | $23.5 \pm 2.5$ | Passive | Straight-line runs at $95-100 \% \mathrm{VVO}_{2}$ with 2-4 min of rest. Low-volume | 90-100\% | 4 weeks | 40 min | 3 times/week |
| Jabbour et al. [52] | 6 | Qatar | 10 males and 20 females | Inactive | 18-71 | Passive | 6 repetitions of SCT intervals with 2 min of passive recovery between each repetition. Low-volume | all out SCT | 6 weeks | 15 min | 3 times/week |
| Fransson et al. [47] | 7 | Sweden | 39 males | Soccer | $21.1 \pm 2.4$ | Passive | The drill was performed as a time trial drill in 30-s intervals separated by 150 s of passive recovery. The number of exercise intervals was 6 during the first intervention week, 8 during the second and third weeks, and 10 during the fourth week. High-volume | maximal speed drills | 4 weeks | 30 min | 3 times/week |

Table 2 (continued)

| Study | PEDro score | Country | Sample size/ sex | Physical activity level/sport | Age, years (mean $\pm$ SD or range) | Recovery type | Training volume | Training intensity | Intervention duration (weeks) | Session duration (min) | Training frequency |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Menz et al. [50] | 7 | Austria | 15 participants (female ( $n=11$ ) and male ( $n=4$ ) (age $25.6 \pm 2.6$ years) | Running, cycling, fitness, ball sports and alpine sports | $25.6 \pm 2.6$ | Passive | Running HIIT ( $3-4$ sets; $8 \times 20 \mathrm{~s}, 10$ s rest; set rest: 5 min )/Functional HIIT executed with their own body weight (3-4 sets; $8 \times 20$ s, 10 s rest; set rest: 5 min ). Lowvolume | 90-100\% HR $\max$ | 4 weeks | 15-20 min | 3 times/week |
| Evangelista et al. [55] | 7 | Brazil | 25 males and females | Active | $28.3 \pm 6.8$ | Passive | 20 sets of 30 s all-out exercise and 30 s of passive recovery between sets. Highvolume | All out exercise | 6 weeks | 20 min | 3 times/week |
| Alizadeh and Safarzade [51] | 7 | Spain | 20 adolescent boys | Active | $18.0 \pm 1.5$ | Passive | $3 \times 10$ repetitions of 30 s of aerobic exercises all out (cycling, rowing, and running) interspersed by 30 s of rest. High-volume | 90\% HR $\max$ | 6 weeks | 10-20 min | 3 times/week |
| Moro et al. [56] | 7 | Italy | 20 healthy young adults | Inactive | $22.1 \pm 1.9$ | Passive | HIIRT: first set of 6 repetitions at $80 \% 1$ RM followed by a 20" rest; then, subjects were asked to lift the same weight until failure (habitually 2 or 3 repetitions) followed by another $20^{\prime \prime}$ rest period with repetitions to fatigue. Low-volume | 80\% of 1RM | 6 weeks | 43 min (including warm up and cool down) | 3 times/week |
| Arslan et al. [48] | 6 | Turkey | 20 males | Soccer | $14.2 \pm 0.5$ | Passive | Intermittent running at 90-95\% of players' VIFT for 15 s (around the pitch), followed by 15 s of passive recovery. Low-volume | 90-95\% VIFT | 5 weeks | 5-10 min | 2 times/week |
| Martínez- <br> Rodríguez <br> et al. [57] | 7 | Spain | 14 females | Active | $27 \pm 6$ | Passive | $3 \times 10$ repetitions of 30 s of aerobic exercises all out (cycling, rowing, and running) interspersed by 30 s of rest. High-volume | All out training | 8 weeks | 40 min | 3 times/week |

Table 2 (continued)

| Study | PEDro score | Country | Sample size/ sex | Physical activity level/sport | Age, years (mean $\pm$ SD or range) | Recovery type | Training volume | Training intensity | Intervention duration (weeks) | Session duration (min) | Training frequency |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Ben Abderrahman et al. [4] | 7 | Tunisia | 9 males | Physical education students | $20.4 \pm 0.6$ | Passive | 2 set $\times(8$ rep $\times 30$ sIE) with 5 min recovery. High-volume | 100\% MAV | 7 weeks | 45 (including warm up and cool down) | 3 times/week |
| Martins et al. [45] | 7 | Norway | 30 females and 16 males | Sedentary | $34.4 \pm 8.8$ | Active | 8 s of sprinting (during which participants worked as hard as possible) and 12 s of recovery phase. Low-volume | Exercise: all out | 12 weeks | 20 min | 3 times/week |
| Ben Abderrahman et al. [4] | 7 | Tunisia | 9 males | Physical education students | $20.9 \pm 0.8$ | Active | 2 set $\times$ ( 8 rep $\times 30$ sIE) $100 \%$ MAV with 5 min recovery at $50 \% \mathrm{MAV}$. High-volume | Exercise: 100\% MAV. recovery: 50\% | 7 weeks | 45 min (including warm up and cool down) | 3 times/week |
| Heydari et al. [63] | 7 | Australia | 34 males | Inactive | $24.4 \pm 4.7$ | Active | 8 s sprint and 12 s recovery, and a 5-min cool-down. During recovery, the cadence was reduced to 40 rpm with no change in resistance. Participants kept their exercise intensity at a level with 80-90\% MHR. Low-volume | Exercise: all out recovery: 40 rpm | 12 weeks | 20 min | 3 times/week |
| Trapp et al. [46] | 7 | Australia | 34 females | Inactive | $22.4 \pm 0.7$ | Active | Each subject performed 8 s of sprinting and 12 s of turning the pedals over slowly (between 20 and 30 rpm .) for a maximum of 60 repeats a session. Lowvolume | Exercise: all out recovery: 20-30 rpm | 15 weeks | 20 | 3 times/week |

Table 2 (continued)

| Study | PEDro score | Country | Sample size/ sex | Physical activity level/sport | Age, years <br> (mean $\pm$ SD <br> or range) | Recovery type | Training volume | Training intensity | Intervention duration (weeks) | Session duration (min) | Training frequency |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Smith-Ryan et al. [44] | 7 | USA | 35 males | Inactive | 18-50 | Active | High-intensity training (2 min-HIIT): 5 bouts of 2 min cycling with 1 min recovery utilizing undulating intensities (80-100\% $\mathrm{VO}_{2 \text { pea }} \mathrm{k}$ ) or no exercise at all (CON). Highvolume | HIIT intensity 80-100\% of $\mathrm{VO}_{2 \text { max }}$ | 3 weeks | 20 min | 3 times/week |
| Menz et al. <br> [59] | 7 | Austria | 8 females and 27 males | Well-trained athletes | $25 \pm 1$ | Active | Four 4-min interval bouts at an exercise intensity of 90-95\% of the individual maximal heart rate (HRmax), separated by 4-min active recovery periods. High-volume | $\begin{aligned} & 90-95 \% \\ & \text { of } \mathrm{HR}_{\max } \end{aligned}$ | 4 weeks | 32 min | 3-4 session/ week |
| Astorino et al. [60] | 7 | USA | 192 women | Trained | $22.5 \pm 5.8$ | Active | ** SIT (HIIT + SIT) consisted of 8-12 "all-out" sprints (4-6 min training duration per day) during which participants were required to pedal maximally High-volume interval training (HIIT + HIITHI) required repeated 2.5 min bouts of cycling with 60 s recovery HIIT + PER) consisted of 3 sessions of highvolume HIIT, 3 sessions of SIT, and 4 sessions of low-volume HIIT. High-volume | All out sprint | 6 weeks | 20-30 min | 3 times/week |

Table 2 (continued)

| Study | PEDro score | Country | Sample size/ sex | Physical activity level/sport | Age, years (mean $\pm$ SD or range) | Recovery type | Training volume | Training intensity | Intervention duration (weeks) | Session duration (min) | Training frequency |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Czuba et al. [58] | 7 | Poland | 16 males | Swimmers | $19.1 \pm 1.3$ | Active | Each training session consisted of a $10-\mathrm{min}$ general warm-up, 45-55-min main part, and a 10-min cool-down. The main part of the circuit consisted of exercise performed on an upper limb rotator (50 W) with a cadence of 80 rpm lasting 60 s This circuit was repeated four times in the first four interval training sessions, after which a 5th circuit was added to increase the overall training load. Highvolume | $\begin{aligned} & 50-95 \% \\ & \text { of } \mathrm{VO}_{2 \max } \end{aligned}$ | 4 weeks | 45-55 min | 2 times/week |
| Rhibi et al. [5] | 7 | France | 39 males | Physical education students | $21.4 \pm 1.1$ | Active | 30 s IE run at 100-110\% MAV alternating with 30 s at $50 \%$ MAV. High-volume | 100-110\% MAV | 8 weeks | 25 min (training and warm up, cool down) | 3 times/week |
| Poon et al. [62] | 7 | Hong-kong | 42 participants | Inactive | $42 \pm 5$ | Active | HIIT: $10 \times 1$-min bouts of running at 80-90\% HRmax separated by 1 -min active recovery. High-volume | 80-90\% HR $\max$ | 8 weeks | 21-29 min | 3 times/week |
| Rhibi et al. [61] | 8 | France | 37 males | Physical education students | $21.9 \pm 1.3$ | Active | 30 s IE run at 100-110\% MAV alternating with 30 s at $50 \%$ MAV. High-volume | 100-110\% MAV | 8 weeks | 25 min (training and warm up, cool down) | 3 times/week |

[^1]Table 3 Physiotherapy Evidence Database (PEDro) score of the included longitudinal studies

| Study | Eligibility criteria | Randomized allocation | Blinded allocation | Group homogeneity | Blinded subjects | Blinded therapists | Blinded assessor | Drop out\15\% | Intention-to treat analysis | Betweengroup comparison | Point estimates and variability | PEDro sum |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Martins et al. [45] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Trapp et al. [46] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Ben Abderrahman et al. [4] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Heydari et al. [63] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Buckley et al. [54] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Smith-Ryan et al. [44] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Menz et al. [59] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Kong et al. [53] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Astorino et al. [60] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Czuba et al. [58] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Aschendorf et al. [49] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Wiewelhove et al. [26] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Jabbour et al. [52] | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 6 |
| Fransson et al. [47] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Menz et al. [50] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Rhibi et al. [5] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Evangelista et al. [55] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Alizadeh and Safarzade[51] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Moro et al. [56] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Poon et al. [62] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Arslan et al. [48] | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 6 |
| Martínez-Rodríguez et al. [57] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 |
| Rhibi et al. [61] | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 8 |

Table 4 Effects of interval training using passive recovery on physical fitness and physiological adaptations in trained and untrained individuals

| Study | Participants (number/age/sex) | Intervention | Physical fitness and physiological adaptations (unit) | Data |  | \% Changes ( $p$ value) | Effect size (Cohen's d) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | before | after |  |  |
| Trained individuals |  |  |  |  |  |  |  |
| Ben Abderrahman et al. [4] | 24 male physical education students/20.4 $\pm 0.6$ | 2 set $\times$ ( 8 rep $\times 30$ sIE) $100 \%$ MAV with 5 min recovery | $\begin{aligned} & \mathrm{VO}_{2 \max }\left(\mathrm{ml} \cdot \min ^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \mathrm{MAV}\left(\mathrm{~km} \cdot \mathrm{~h}^{-1}\right) \end{aligned}$ | $\begin{aligned} & 58.6 \pm 4.2 \\ & 15.5 \pm 1.0 \end{aligned}$ | $\begin{aligned} & 60.35 \pm 4.7 \\ & 16.5 \pm 1.1 \end{aligned}$ | $\begin{aligned} & 2.88(p<0.001) \\ & 6.4(p<0.001) \end{aligned}$ | $\begin{aligned} & 0.38 \\ & 0.95 \end{aligned}$ |
| Fransson et al. [47] | 39 elite male soccer players/21.1 $\pm 2.4$ | The drill was performed as a time trial drill in 30-s intervals separated by 150 s of passive recovery. The number of exercise intervals was six during the first intervention week, eight during the second and third weeks, and ten during the fourth week | Yo-Yo (m) Lactate (mmol.L ${ }^{-1}$ ) | $\begin{aligned} & 222 \pm 113 \\ & 2.6 \pm 1.9 \end{aligned}$ | $\begin{aligned} & 323 \pm 125 \\ & 3.4 \pm 1.7 \end{aligned}$ | $\begin{aligned} & 45.49(p<0.05) \\ & 30.76(p<0.05) \end{aligned}$ | $\begin{aligned} & 0.85 \\ & 0.44 \end{aligned}$ |
| Arslan et al. [48] | 20 young male soccer players/ $14.2 \pm 0.5$ | Intermittent running at 90-95\% of players VIFT for 15 s (around the pitch), followed by 15 s of passive recovery | $\begin{aligned} & \mathrm{VO}_{2 \text { max }}\left(\mathrm{ml} \cdot \mathrm{~min}^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \mathrm{CMJ}(\mathrm{~cm}) \\ & \text { YYIRTL-1 }(\mathrm{m}) \end{aligned}$ | $\begin{aligned} & 46.8 \pm 0.6 \\ & 28.2 \pm 2.0 \\ & 1240 \pm 75 \end{aligned}$ | $\begin{aligned} & 48.9 \pm 0.9 \\ & 30.6 \pm 1.8 \\ & 1484 \pm 74 \end{aligned}$ | $\begin{aligned} & 4.4(p \leq 0.05) \\ & 8.51(p \leq 0.05) \\ & 19.6(p \leq 0.05) \end{aligned}$ | $\begin{aligned} & 2.61 \\ & 1.26 \\ & 3.27 \end{aligned}$ |
| Aschendorf et al. [49] | 24 females' basketball players/15.1 $\pm 1.1$ | Two t types of HIIT sessions: Session A consisting of $4 \times 4$ HIIT with 3 min of recovery. Session B consisting of $2 \times 30 \mathrm{~s} \mathrm{HIIT}$ with 15 s recovery | YYIRTL-1 (m) CMJ (cm) | $\begin{aligned} & 1498 \pm 266 \\ & 26.5 \pm 3.3 \end{aligned}$ | $\begin{aligned} & 1895 \pm 421 \\ & 27.0 \pm 3.6 \end{aligned}$ | $\begin{aligned} & 26.5(p=0.34) \\ & 1.8(p=0.10) \end{aligned}$ | $\begin{aligned} & 1.13 \\ & 0.05 \end{aligned}$ |
| Wiewelhove et al. [26] | 26 males intermittent sport (i.e., soccer, handball, basketball, hockey, floorball, tennis)/23.5 $\pm 2.5$ | Straight-line runs at 95-100\%vV O2 with 2-4 min of rest | $\begin{aligned} & \mathrm{VO}_{2 \text { max }}\left(\mathrm{ml} \cdot \mathrm{~min}^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \mathrm{LT}\left(\operatorname{mmol} . \mathrm{L}^{-1}\right) \end{aligned}$ | $\begin{aligned} & 55.5 \pm 4.2 \\ & 12.5 \pm 1.1 \end{aligned}$ | $\begin{aligned} & 55.0 \pm 3.6 \\ & 12.8 \pm 1.4 \end{aligned}$ | $\begin{aligned} & 0.9(p<0.001) \\ & 0.024(p<0.05) \end{aligned}$ | $\begin{aligned} & 0.13 \\ & 0.27 \end{aligned}$ |
| Menz et al. [50] | 15 moderately trained healthy male and female/ $25.6 \pm 2.6$ | Running HIIT (3-4 sets; $8 \times 20$ s, 10 s rest; set rest: <br> $5 \mathrm{~min}) / f u n c t i o n a l ~ H I I T ~ e x e c u t e d ~$ with their own body weight (3-4 sets; $8 \times 20$ s, 10 s rest; set rest: 5 min ) | $\begin{aligned} & \mathrm{VO}_{2 \text { max }}\left(\mathrm{ml} . \mathrm{min}^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \mathrm{HR}_{\max }(\mathrm{rpm}) \end{aligned}$ | $\begin{aligned} & 47.8 \pm 5.6 \\ & 187 \pm 10 \end{aligned}$ | $\begin{aligned} & 54.1 \pm 5.6 \\ & 184 \pm 10 \end{aligned}$ | $\begin{aligned} & 13.17(p=0.011) \\ & 1.6(p \leq 0.001) \end{aligned}$ | $\begin{aligned} & 1.13 \\ & 0.42 \end{aligned}$ |
| Untrained individuals |  |  |  |  |  |  |  |
| Alizadeh and Safarzade[51] | 14 sedentary overweight male students/18.0 $\pm 1.5$ | 30 s of all out exercise and 30 s of rest | $\begin{aligned} & \text { Body weight (kg) } \\ & \text { BMI (kg.m }{ }^{-2} \text { ) } \\ & \text { Body fat (\%) } \end{aligned}$ | $\begin{aligned} & 83.7 \pm 3.6 \\ & 27.8 \pm 0.6 \\ & 23.7 \pm 3.0 \end{aligned}$ | $\begin{aligned} & 80.4 \pm 3.6 \\ & 25.2 \pm 0.7 \\ & 20.3 \pm 3.0 \end{aligned}$ | $\begin{aligned} & 3.94(p=0.001) \\ & 9.35(p=0.002) \\ & 14.3(p=0.007) \end{aligned}$ | $\begin{aligned} & 0.87 \\ & 3.99 \\ & 0.33 \end{aligned}$ |
| Jabbour et al. [52] | 30 sedentary healthy male and female/38 | 6 repetitions of SCT intervals with 2 min of passive recovery between each repetition. Each SCT repetition lasted 6 s , and participants were asked to pedal at maximal velocity against the resistance for 15 min | $\begin{aligned} & \mathrm{VO}_{2 \text { max }}\left(\mathrm{ml} \cdot \mathrm{~min}^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \mathrm{BMI}\left(\mathrm{~kg} \cdot \mathrm{~m}^{-2}\right) \\ & \text { Systolic BP (cmHg) } \\ & \text { Diastolic BP (cmHg) Hematocrit } \\ & \text { (\%) } \end{aligned}$ | $\begin{aligned} & 26.9 \pm 1.4 \\ & 30.1 \pm 1.2 \\ & 114.5 \pm 2 \\ & 78.3 \pm 1.6 \\ & 40.4 \pm 3.1 \end{aligned}$ | $\begin{aligned} & 27.2 \pm 1.2 \\ & 29.9 \pm 1.2 \\ & 109.1 \pm 2.2 \\ & 71.6 \pm 1.6 \\ & 39.9 \pm 2.1 \end{aligned}$ | $\begin{aligned} & 1.1(p=0.11) \\ & 0.66(p=0.11) \\ & 4.71(p=<0.001) \\ & 8.5(p<0.001) \\ & 1.2(p=0.13) \end{aligned}$ | $\begin{aligned} & 0.23 \\ & 0.17 \\ & 1.49 \\ & 4.19 \\ & 0.19 \end{aligned}$ |

Table 4 (continued)

| Study | Participants (number/age/sex) | Intervention | Physical fitness and physiological adaptations (unit) | Data |  | \% Changes ( $p$ value) | Effect size (Cohen's d) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | before | after |  |  |
| Kong et al. [53] | 18 inactive overweight and obese females/ $19.8 \pm 0.8$ | 60 repetitions of high-intensity interval exercise (8 s cycling and 12 s passive recovery) on a cycle ergometer for 20 min | $\begin{aligned} & \mathrm{VO}_{2 \text { max }}\left(\mathrm{ml} \cdot \mathrm{~min}^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \mathrm{PPO} \text { (watts) } \end{aligned}$ | $\begin{aligned} & 34.1 \pm 5.7 \\ & 134.2 \pm 23.7 \end{aligned}$ | $\begin{aligned} & 36.6 \pm 6.6 \\ & 150.2 \pm 24.2 \end{aligned}$ | $\begin{aligned} & 7.33(p=0.006) \\ & 11.9(p<0.001) \end{aligned}$ | $\begin{aligned} & 0.41 \\ & 0.41 \end{aligned}$ |
| Buckley et al. [54] | 28 recreationally active females $/ 25.1 \pm 5.6$ | Row-HIIT and MM-HIIT group performed 60 s of all-out intensity rowing followed by 3 min of rest (passive recovery) for a total of 6 rounds | $\begin{aligned} & \mathrm{VO}_{2 \max }\left(\mathrm{ml} \cdot \mathrm{~min}^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \text { AT (watts) } \end{aligned}$ | $\begin{aligned} & 36.2 \pm 5.7 \\ & 27.2 \pm 6.7 \end{aligned}$ | $\begin{aligned} & 38.5 \pm 5.4 \\ & 29.7 \pm 5.7 \end{aligned}$ | $\begin{aligned} & 6.3(p=0.99) \\ & 9.1(p=0.09) \end{aligned}$ | $\begin{aligned} & 0.41 \\ & 0.40 \end{aligned}$ |
| Evangelista et al. [55] | 25 active healthy adults/28.7 $\pm 4.9$ | 20 sets of 30 s all-out exercise and 30 s of passive recovery between sets | Horizontal jump (min) Push Ups | $\begin{aligned} & 1.6 \pm 0.3 \\ & 27.8 \pm 13.9 \end{aligned}$ | $\begin{aligned} & 1.7 \pm 0.3 \\ & 34.3 \pm 12.8 \end{aligned}$ | $\begin{aligned} & 6.2(p=0.02) \\ & 23.38(p=0.02) \end{aligned}$ | $\begin{aligned} & 0.33 \\ & 0.49 \end{aligned}$ |
| Moro et al. [56] | 21 young healthy males and females $/ 22.1 \pm 1.9$ | HIIRT: first set of 6 repetitions at $80 \% 1$ RM followed by a 20" rest; then, subjects were asked to lift the same weight until failure (habitually 2 or 3 repetitions) followed by another 20" rest period with repetitions to fatigue | $\begin{aligned} & \mathrm{VO}_{2 \max } \text { (ml.min } \mathrm{min}^{-1} \cdot \mathrm{~kg}^{-1} \text { ) } \\ & \mathrm{PPO} \text { (watts) } \\ & \text { Squat jump (sec) } \end{aligned}$ | $\begin{aligned} & 41.4 \pm 11.3 \\ & 196.1 \pm 52.4 \\ & 0.32 \pm 0.10 \end{aligned}$ | $\begin{aligned} & 44.5 \pm 9.1 \\ & 213.0 \pm 53.4 \\ & 0.36 \pm 0.08 \end{aligned}$ | $\begin{aligned} & 7.3(p>0.05) \\ & 8.6(p>0.05) \\ & 12.5(p=0.02) \end{aligned}$ | $\begin{aligned} & 0.3 \\ & 0.32 \\ & 0.44 \end{aligned}$ |
| Martínez-Rodríguez et al. [57] | 14 active, normal-weight females $/ 27 \pm 6$ | $3 \times 10$ repetitions of 30 s of aerobic exercises all out (cycling, rowing, and running) interspersed by 30 s of rest (Passive recovery) | CMJ (cm) | $17.5 \pm 4.3$ | $18.5 \pm 3.9$ | 5.7 ( $p<0.001$ ) | 0.24 |

[^2]Table 5 Effects of interval exercise training using active recovery on physical fitness and physiological adaptations in trained and untrained individuals

| Study | Participants (number/age/sex) | Intervention | Physical fitness and physiological adaptations | Data |  | \% Changes ( $p$ value) | Effect size (Cohen's d) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | before | after |  |  |
| Trained individuals |  |  |  |  |  |  |  |
| Ben Abderrahman et al. [4] | 30 males' physical education students/20.4 $\pm 0.6$ | 2 set x (8 rep x 30sIE) 100\% MAV with 5 min recovery | $\begin{aligned} & \mathrm{VO}_{2 \max }\left(\mathrm{ml} \cdot \min ^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & M A V\left(\mathrm{~km} \cdot \mathrm{~h}^{-1}\right) \end{aligned}$ | $\begin{aligned} & 59.37 \pm 7.5 \\ & 16.1 \pm 1.2 \end{aligned}$ | $\begin{aligned} & 62.85 \pm 7.9 \\ & 17.0 \pm 1.0 \end{aligned}$ | $\begin{aligned} & 5.86(p<0.001) \\ & 5.55(p<0.001) \end{aligned}$ | $\begin{aligned} & 0.45 \\ & 0.81 \end{aligned}$ |
| Czuba et al. [58] | 16 male sprint swimmers/19.1 $\pm 1.3$ | Circuit based intermittent hypoxic training 2 times per week. Upper limb $60 s \times 30$ s rest. Lower limb 2 min $\times 3$-min rest | $\mathrm{VO}_{2 \max }\left(\mathrm{ml} \cdot \min ^{-1} \cdot \mathrm{~kg}^{-1}\right)$ <br> Lactic acid (mmol.L- ${ }^{-1}$ ) pH Change | $\begin{aligned} & 56.0 \pm 4.0 \\ & 9.14 \pm 0.92 \\ & 0.147 \pm 0.051 \end{aligned}$ | $\begin{aligned} & 59.9 \pm 4.3 \\ & 11.05 \pm 1.33 \\ & -0.178 \pm 0.048 \end{aligned}$ | $\begin{aligned} & 6.9(p=0.025) \\ & 20.8(p=0.001) \\ & 21(p=0.0129) \end{aligned}$ | $\begin{aligned} & 0.94 \\ & 1.67 \\ & 0.77 \end{aligned}$ |
| Menz et al. [59] | 35 trained male and female athletes $25 \pm 1$ | Four 4-min interval bouts at an exercise intensity of 90-95\% of the individual maximal heart rate (HRmax), separated by 4-min active recovery periods | $\mathrm{VO}_{2 \text { max }}\left(\mathrm{ml} . \mathrm{min}^{-1} \cdot \mathrm{~kg}^{-1}\right)$ | $47.8 \pm 5.6$ | $54.1 \pm 5.6$ | $13.1(p=0.011)$ | 1.13 |
| Astorino et al. [60] | 192 trained women/21.9 T 1.9 | SIT (HIIT + SIT) consisted of 8-12 "all-out" sprints (4-6 min training duration per day) during which participants were required to pedal maximally. High-volume interval training $\left(H I I T+\mathrm{HIIT}_{H}\right)$ required repeated $2.5-\mathrm{min}$ bouts of cycling with 60 s recovery, leading to training duration equal to 12.5-17.5 | $\begin{aligned} & \mathrm{VO}_{2 \max }\left(\mathrm{ml} \cdot \mathrm{~min}^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \mathrm{VT} \\ & \mathrm{a}-\mathrm{VDO} 2 \end{aligned}$ | $\begin{aligned} & 41.1 \pm 4.9 \\ & 112 \pm 19 \\ & 14.1 \pm 1.6 \end{aligned}$ | $\begin{aligned} & 44.6 \pm 7.0 \\ & 120 \pm 18 \\ & 14.3 \pm 2.0 \end{aligned}$ | $\begin{aligned} & 8.5(p<0.001) \\ & 7.1(p 0.001) \\ & 1.41(p<0.001) \end{aligned}$ | $\begin{aligned} & 0.58 \\ & 0.43 \\ & 0.13 \end{aligned}$ |
| Rhibi et al. [5] | 39 male physical education students/21.4 $\pm 1.1$ | 30 s run at $100 \%$ MAV or $110 \%$ of MAV (EG110) alternating with 30 s active recovery | Hemoglobin (g/dl) <br> Hematocrit (\%) <br> Lactate (mmol. $\mathrm{L}^{-1}$ ) <br> PW (\%) | $\begin{aligned} & 16.1 \pm 0.8 \\ & 49.3 \pm 3.4 \\ & 9.9 \pm 2.5 \\ & -9.0 \pm 1.5 \end{aligned}$ | $\begin{aligned} & 15.5 \pm 0.6 \\ & 47.1 \pm 3.4 \\ & 8.6 \pm 1.9 \\ & -6.8 \pm 1.9 \end{aligned}$ | $\begin{aligned} & 3.72(p<0.010) \\ & 4.46(p=0.085) \\ & 13.1(p=0.014) \\ & 22.2(p=0.014) \end{aligned}$ | $\begin{aligned} & 0.85 \\ & 0.65 \\ & 0.59 \\ & 1.29 \end{aligned}$ |
| Rhibi et al. [61] | 37 male physical education students/21.9 $\pm 1.3$ | 30 s run at $100 \%$ MAV or $110 \%$ of MAV (EG110) alternating with 30 s active recovery (50\% MAV) | MAV $\left(\mathrm{km} \cdot \mathrm{h}^{-1}\right)$ <br> Glucose (g/l) <br> Insulin ( $\mu \mathrm{U} . \mathrm{mL}^{-1}$ ) <br> Cortisol (ng.ml ${ }^{-1}$ ) <br> \|L-6 (pg.mi ${ }^{-1}$ ) <br> TNF-a (pg.ml ${ }^{-1}$ ) | $\begin{aligned} & 15.8 \pm 1.6 \\ & 6.4 \pm 1.3 \\ & 16.9 \pm 1.7 \\ & 386.0 \pm 95.9 \\ & 4.7 \pm 1.2 \\ & 6.8 \pm 1.7 \end{aligned}$ | $\begin{aligned} & 16.7 \pm 1.5 \\ & 5.6 \pm 1.0 \\ & 15.5 \pm 1.7 \\ & 465.7 \pm 60.0 \\ & 3.5 \pm 1.1 \\ & 5.2 \pm 1.6 \end{aligned}$ | $\begin{aligned} & 5.6(p<0.05) \\ & 12.5(p=0.021) \\ & 8.2(p=0.017) \\ & 20.4(p<0.001) \\ & 25.5(p<0.001) \\ & 23.5(p<0.001) \end{aligned}$ | $\begin{aligned} & 0.58 \\ & 0.69 \\ & 0.82 \\ & 0.88 \\ & 1.04 \\ & 0.97 \end{aligned}$ |
| Untrained individuals |  |  |  |  |  |  |  |
| Trapp et al. [46] | 34 inactive healthy women/22.4 $\pm 0.7$ | Each subject performed 8 s of sprinting and 12 s of turning the pedals slowly (between 20 and 30 rpm ) for a maximum of 60 repeats a session | $\begin{aligned} & \mathrm{VO}_{2 \text { max }}\left(\mathrm{ml} \cdot \mathrm{~min}^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \text { HOMA-IR } \end{aligned}$ | $\begin{aligned} & 28.8 \pm 2.1 \\ & 3.6 \pm 0.7 \end{aligned}$ | $\begin{aligned} & 36.4 \pm 2.5 \\ & 2.4 \pm 0.7 \end{aligned}$ | $\begin{aligned} & 23.38(p<0.05) \\ & 33.38(p<0.05) \end{aligned}$ | $\begin{aligned} & 3.29 \\ & 1.71 \end{aligned}$ |

Table 5 (continued)

| Study | Participants (number/age/sex) | Intervention | Physical fitness and physiological adaptations | Data |  | \% Changes ( $p$ value) | Effect size (Cohen's d) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | before | after |  |  |
| Poon et al. [62] | 24 physically inactive and overweight/obese Asian men/49.6 $\pm 7.8$ | HIIT: $10 \times 1$-min bouts of running at 80-90\% HRmax separated by 1 -min active recovery | $\begin{aligned} & \mathrm{VO}_{\text {max }}\left(\mathrm{ml}_{2} \cdot \mathrm{~min}^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \mathrm{BMII}\left(\mathrm{~kg} . \mathrm{m}^{-2}\right) \\ & \text { Systolic } \mathrm{BP}(\mathrm{cmHg}) \\ & \text { Diastolic } \mathrm{BP}(\mathrm{cmHg}) \\ & \text { Glucose }(\mathrm{mmol} / \mathrm{l}) \end{aligned}$ | $\begin{aligned} & 32.5 \pm 5.6 \\ & 26.1 \pm 1.6 \\ & 120.6 \pm 11.8 \\ & 79.8 \pm 6.8 \\ & 4.90 \pm 0.46 \end{aligned}$ | $\begin{aligned} & 36.0 \pm 6.2 \\ & 25.8 \pm 1.5 \\ & 125.8 \pm 8.8 \\ & 75.2 \pm 5.2 \\ & 5.05 \pm 0.29 \end{aligned}$ | $\begin{aligned} & 10.7 p=0.013 \\ & 1.14 p=0.035 \\ & 3.6(p=0.377) \\ & 5.7(p=0.721) \\ & 3.06(p=0.656) \end{aligned}$ | $\begin{aligned} & 0.59 \\ & 0.19 \\ & 0.50 \\ & 0.76 \\ & 0.39 \end{aligned}$ |
| Martins et al. [45] | 46 sedentary male and female obese individuals/34.4 $\pm 8.8$ | The HIIT protocol consisted of 8 s of sprinting and 12 s of recovery (pedals as slowly as possible) | $\mathrm{VO}_{2 \text { max }}\left(\mathrm{ml} . \mathrm{min}^{-1} . \mathrm{kg}^{-1}\right)$ | $31.1 \pm 4.9$ | $33.9 \pm 5.2$ | $9(p<0.00)$ | 0.55 |
| Heydari et al. [63] | 34 young overweight males/1835 | 8 s sprint and 12 s of slow pedaling recovery for 20 min | $\begin{aligned} & \mathrm{VO}_{2 \max }\left(\mathrm{ml} \cdot \mathrm{~min}^{-1} \cdot \mathrm{~kg}^{-1}\right) \\ & \mathrm{SV}^{\text {Systolic } \mathrm{BP}(\mathrm{cmHg})} \\ & \text { Diastolic BP }(\mathrm{cmHg}) \end{aligned}$ | $\begin{aligned} & 33.9 \pm 1.1 \\ & 72 \pm 4.2 \\ & 120 \pm 2.4 \\ & 64 \pm 1.8 \end{aligned}$ | $\begin{aligned} & 39.8 \pm 0.9 \\ & 86 \pm 5.1 \\ & 115 \pm 2.5 \\ & 58 \pm 1.8 \end{aligned}$ | $\begin{aligned} & 17.4(p<0.0001) \\ & 19.4(p<0.0001) \\ & 4.1(p=0.004) \\ & 0.9(p=0.002) \end{aligned}$ | $\begin{aligned} & 5.87 \\ & 3.00 \\ & 2.04 \\ & 3.33 \end{aligned}$ |
| Smith-Ryan et al. [44] | 35 inactive overweight men/38.3 $\pm 11.5$ | 5 bouts of 2 min cycling with 1 min recovery with passive recovery | Fat mass (kg) Lean mass (kg) Body fat (\%) Glucose (mmol/l) Cholesterol (mg) | $\begin{aligned} & 29.5 \pm 0.9 \\ & 69.5 \pm 3.4 \\ & 28.8 \pm 1.4 \\ & 98.9 \pm 36.8 \\ & 200.1 \pm 48.4 \end{aligned}$ | $\begin{aligned} & 28.3 \pm 1.4 \\ & 71.6 \pm 2.4 \\ & 27.5 \pm 1.2 \\ & 91.7 \pm 16.3 \\ & 175.3 \pm 76.2 \end{aligned}$ | $\begin{aligned} & 4.06(p=0.001) \\ & 3.2(p=0.001) \\ & 4.5(p=0.633) \\ & 7.2(p=0.008) \\ & 12.5(p=0.898) \end{aligned}$ | $\begin{aligned} & 0.95 \\ & 0.76 \\ & 1.03 \\ & 0.29 \\ & 0.36 \end{aligned}$ |

CMJ Countermovement jump, LT Lactate threshold, PPO Peak power output, AT Anaerobic threshold, $a$-v do2 Maximal arteriovenous difference, HOMA_IR Homeostasis model assessment of insulin sensitivity, PVV Plasma volume variation, VTVentilatory threshold, MAV Maximal aerobic velocity, IL-6 Interleukin-6, TNF alpha Tumor necrosis factor-alpha, BF Body fat, BMI Body mass index, CRP C-reactive protein, SSG Small sided soccer game, $\mathrm{VO}_{2_{\text {max }}}$ Maximal oxygen consumption, BP Blood pressure, HR Heart rate, YYIRTL-1 Yo-Yo intermittent recovery test level 1, Row-HIIT Traditional HIIT using rowing, MM-HITT Multimodal HIIT, RPE Rating of perceived exertion, SCT Supramaximal cycling test, VIFTMaximum speed reached in the last stage of the 30-15 intermittent fitness test, 1 RM One-repetition maximum, IE Intermittent exercise, HIIRT High-intensity interval resistance training
in trained (effect size: $0.13<d<1.29$, small to large) and untrained individuals (effect size: $0.19<d<3.29$, small to very large).

## Discussion

Our main finding was that irrespective of the recovery type (passive or active) long-term interval traininginduced enhancements in measures of physical fitness and physiological parameters in trained and untrained males and females aged 14-48 years.

## Effects of Interval Exercise Training Using Passive Recovery on Measures of Physical Fitness and Physiological Adaptations in Trained and Untrained Individuals

Our analysis showed that on average, exercise performance was increased after long-term interval exercise training with passive recovery in healthy-trained individuals. Nine studies [4, 26, 47-50, 58, 59, 63] were of high quality and included both sexes [4, 26, 47-50, 58, 59] and reported that passive recovery had a large positive effect on $\mathrm{VO}_{2 \text { max }}$ and physical fitness using aerobic exercise training at $90-100 \%$ of $\mathrm{VO}_{2 \max }$. Eleven studies used aerobic interval training as an intervention [4, 26, 47-51, 53, 54, 56, 57], while another two studies used either sprint interval training [52] or repeated sprint ability as interventions [55]. Most included studies showed large effect sizes of passive recovery during long-term interval exercise training on $\mathrm{VO}_{2 \max }$. Two studies showed a small [26] or trivial [4] impact on $\mathrm{VO}_{2 \max }$. For jump performance, researchers from two studies reported a trivial [49] to large [48] effect after long-term interval exercise training with passive recovery on CMJ performance in youth male soccer [48] and youth female basketball players [49]. Results from these studies indicate positive effects of passive recovery on $\mathrm{VO}_{2 \text { max }}$, CMJ, and the YYIRTL-1. This result has to be interpreted with caution due to the limited number of available studies. More research is needed on the effects of passive recovery on measures of physical fitness and physiological adaptations in youth.
Our analysis indicated small improvements in measures of physical fitness after long-term interval exercise training with passive recovery in healthy untrained individuals. Indeed, the seven included studies [51, 52, 54] were of high quality, included both sexes, and the population was restricted to healthy individuals [52, 54-57], overweight, and obese [51, 53] individuals, aged 18-38 years old. Three studies with passive recovery reported slight positive training-induced changes in $\mathrm{VO}_{2 \max }$ [5254, 56], jump tests [55-57], muscle strength [55], and body composition [52]. Researchers from one study [51] reported a very large positive impact on the body mass index in overweight participants aged $18.0 \pm 1.5$ years. after a $30 \mathrm{~s} / 30 \mathrm{~s}$ training program with a passive recovery.

The largest training-induced effects on $\mathrm{VO}_{2 \text { max }}$ and physical fitness were observed in trained athletes compared to untrained individuals aged 18-38 years old. To better appreciate the impact of passive recovery on high-intensity interval exercise training, it is important to understand how this recovery mode relates to $\mathrm{VO}_{2 \text { max }}$ and physical fitness. Accordingly, Ben Abderrahman et al. [4] showed that the longer time limit observed in trained adults could mainly be explained by the resynthesis of a higher proportion of the muscle phosphocreatine used during the 30 s intensive runs at $105 \%$ of MAV during the passive recovery. Another potential explanation for the observed result might be the difference in body mass between trained ( $74.2 \pm 10.3 \mathrm{~kg}$ ) and untrained individuals ( $67.0 \pm 6.5 \mathrm{~kg}$ ) [4].

The studies included in this systematic review reported that weight-bearing high-intensity interval exercises have a greater positive impact on anthropometrics [51] and cardiovascular [52] parameters compared with physical fitness and $\mathrm{VO}_{2 \text { max }}$ in healthy non-obese or obese untrained individuals aged 18-38 years old.
Further, it was previously demonstrated that passive recovery facilitates a greater interval performance in trained athletes aged 20-25 years old [4, 47, 50]. The fact that athletes completed exercise training with large $\mathrm{VO}_{2 \text { max }}$ increases and small changes in peak HR [50] and blood lactate [47] suggests that athletes could perform more bouts in this condition and, therefore, accumulate more time spent at high $\% \mathrm{VO}_{2 \text { max }}$ levels compared to untrained individuals. Regarding the effects of passive recovery during HIIT sessions on exercise performance, some studies [24, 38] indicated that, compared to active recovery, passive recovery was associated with a greater time to exhaustion (i.e., the accumulation of more work intervals or time spent at high intensities close to $\mathrm{VO}_{2 \max }$ ), but also a higher mean velocity/power development during work intervals when the number of bouts was fixed and the intensity self-regulated $[24,38]$.

Effects of Long-Term Interval Exercise Training Using Active Recovery on Measures of Physical Fitness and Physiological Adaptations in Trained and Untrained Individuals
Our analysis showed that on average, exercise performance is slightly increased during long-term high interval exercise training with active recovery in healthy trained individuals. Indeed, six included studies [4, 5, $50,58,60,61$ ] were of high quality, included both sexes, and the population was restricted to young athletes aged $19-25$ years. The studies, using aerobic interval training at $100-110 \%$ of MAV, found that active recovery had a small but positive effect on $\mathrm{VO}_{2 \max }[4,60]$ and a large, positive effect on MAV [4, 5, 61]. Some other studies used sprint interval training [45, 46, 63], or maximal
repeated sprint ability [5,61] and observed significant small to large effects on $\mathrm{VO}_{2 \max }$.
Our analysis showed that on average, exercise performance can be improved (large to very large effects) after long-term interval exercise training with active recovery in healthy untrained individuals. Indeed, the four included studies $[45,46,62,63$ ] were of high quality, including both sexes and restricted to healthy [46] and overweight/obese $[45,62,63]$ subjects. Those studies found that active recovery had large to very large positive effects on $\mathrm{VO}_{2 \text { max }}[45,56,62,63]$ and was associated with a trivial change in body composition [62] using interval exercise training at $80-100 \%$ of power output or $\mathrm{HR}_{\text {max }}$. Three studies used maximal interval exercise training [45, $46,63]$, and one study applied $80-90 \%$ HRmax during interval exercise training [62].
It is generally accepted that active recovery during long-term high-intensity interval exercise training has a very large effect on $\mathrm{VO}_{2 \max }$ in healthy or overweight untrained individuals compared to athletes [64]. In other words, these $\mathrm{VO}_{2}$ and mechanical efficiency data suggest that untrained individuals benefit more from maximal interval exercise training with active recovery than athletes [23].

The largest increase in $\mathrm{VO}_{2 \max }$ was reported in the study from Trapp et al., [46]. A possible explanation for this result might be related to the population and sex (inactive healthy females) with wide variations in $\mathrm{VO}_{2 \max }$ values. Moreover, the training duration was 15 weeks with 3 weekly sessions, which is a greater volume compared to the studies of Poon et al., [62] (3 times/week over 8 weeks) and Smith-Ryan et al., [44] (3 times per week over 3 weeks).
To the best of our knowledge, there is no study available that examined the effects of active recovery on physical fitness and physiological adaptations in youth.

## Study Limitations

There are some limitations to the current systematic review that should be noted. First, the studies examined were highly heterogeneous. In fact, the study populations varied in terms of sample size, sex, age (only two studies involved young individuals), and country of recruitment. Second, the training program's duration (3-15 weeks) and volume ( $15-45 \mathrm{~min}$ per session) were variable. Third, to our knowledge, no study currently available has reported the variation by effect size in physical fitness and physiological adaptations between trained and untrained individuals during high-intensity interval exercise training with passive or active recovery. Finally, due to the small number of studies included in our analysis, we were unable to consider sex and age as moderators of
active recovery on physical exercise and $\mathrm{VO}_{2 \max }$. Furthermore, except for the work of Rhibi et al. [5], the majority of studies did not measure lactate concentration, which could provide more information on the relation between active recovery and lactate clearance during high-intensity exercise training.

## Practical Applications

The findings of our systematic review suggest that interval training, irrespective of the intensity level, has the potential to improve selected measures of physical fitness (e.g., MAV) and physiological responses (e.g., $\mathrm{VO}_{2 \max }$, blood pressure) similarly in trained and untrained adults and trained youth, regardless of the type of exercise and exercise dosage. More specifically, our findings suggest that the type of recovery (active or passive) applied during interval training results in similar training-induced outcomes, irrespective of the training status (trained, untrained) and sex (males, females). Thus, when longterm interval training programs ( $\geq 3$ weeks) are performed, coaches and athletes can use either passive or active recovery modes. The decision should be based on the overall exercise programming parameters of the respective interval training. High exercise workloads may demand passive recovery whereas low workloads may favor active recovery.

## Conclusions

To conclude, our findings suggest that irrespective of the recovery mode (passive or active), long-term interval exercise training has the potential to enhance physical fitness and physiological adaptations in trained and untrained male and female adults. More research examining the effects of passive or active recovery on measures of physical fitness and physiological adaptations in youth is recommended.

| Abbreviations |  |
| :--- | :--- |
| 1 RM | One-repetition maximum |
| AT | Anaerobic threshold |
| a-v do2 | Maximal arteriovenous difference |
| BF | Body fat |
| BMI | Body mass index |
| CMJ | Countermovement jump |
| CRP | C-reactive protein |
| ES | Effect size |
| FITT | Frequency, intensity, time, and type |
| HII | High-intensity interval resistance training |
| HIIT | High-intensity interval training |
| HOMA-IR | Homeostasis model assessment of insulin sensitivity |
| HR | Heart rate |
| IE | Intermittent exercise |
| IL-6 | Interleukin-6 |
| LT | Lactate threshold |
| MAV | Maximal aerobic velocity |
| MM-HIIT | Multimodal HIIT |


| PEDro | Physiotherapy Evidence Database |
| :--- | :--- |
| PER | Periodized interval training |
| PGC-1a mRNA | Peroxisome proliferator-activated receptor- $\gamma$ coactivator-1a |
| PPO | Peak power output |
| PRISMA | Preferred Reporting Items for Systematic Reviews and |
|  | Meta-Analyses |
| PVV | Plasma volume variation |
| Row-HIIT | Traditional HIIT using rowing |
| RPE | Rating of perceived exertion |
| Rpm | Revolution per minute |
| SCT | Supramaximal cycling test |
| SIT | Sprint interval training |
| SSG | Small side soccer game |
| TnF alpha | Tumor necrosis factor-alpha |
| VIFT | Maximum speed reached in the last stage of the 30-15 inter- |
|  | mittent fitness test |
| VO | Maximal oxygen uptake |
| VT | Ventilatory threshold |
| YYIRTL-1 | Yo-Yo intermittent running test level 1 |

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## Author Contributions

HZ and UG were involved in the conceptualization of the study, data analysis, and the writing of the manuscript. $A B A$ and $A J, A S$ and $F R$ were involved in the data assessment, data analysis, and the writing of the manuscript. ACH and IL were involved in the writing of the manuscript. All authors approved the final version of the manuscript.

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## Availability of Data and Materials

All data supporting the findings of this study are available in this published article.

## Declarations

## Ethics Approval and Consent to Participate

Not applicable.

## Consent for Publication

Not applicable.

## Competing interests

The authors declare that they have no competing interest.

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[^1]:    MAV Maximal aerobic velocity, HIIT High intensity interval training, SIT Sprint interval training, IL-6 Interleukin-6, TnF alpha Tumor necrosis factor alpha, BF Body fat, BMI Body mass index, CRP C-reactive protein, SSG Small sided soccer game, $\mathrm{VO}_{2 \max }$ Maximal oxygen consumption, $H R$ Heart rate, rpm Revolution per minute, $P$ PR Periodized interval training, Row-HIITTraditional HIIT using rowing, MM-HIIT Multimodal HIIT, RPE Rating of perceived exertion, SCT Supramaximal cycling test, VIFT Maximum speed reached in the last stage of the 30-15 intermittent fitness test, 1 RM one-repetition maximum, IE Intermittent exercise, HIIRT High-intensity interval resistance training

[^2]:    CMJ Countermovement jump, LT Lactate threshold, PPO Peak power output, $A T$ Anaerobic threshold, $P V V$ Plasma volume variation, VT Ventilatory threshold, $M A V$ Maximal aerobic velocity-alpha, $B F$ Body fat, $B M I$ body mass index, CRP C-reactive protein, SSG Small sided soccer game, $V O_{2 \text { max }}$ Maximal oxygen consumption, BP Blood pressure, HR Heart rate, YYIRTL-1 Yo-Yo intermittent recovery test level 1, Row-HIIT Traditional HIIT using rowing, MM-HIIT Multimodal HIIT, RPE Rating of perceived exertion, SCT Supramaximal cycling test, VIFT Maximum speed reached in the last stage of the 30-15 intermittent fitness test, 1 RM One-repetition maximum, IE Intermittent exercise, HIIRT High-intensity interval resistance training

