Review Article

Effects of Short- and Long-Term Detraining on Maximal Oxygen Uptake in Athletes: A Systematic Review and Meta-Analysis

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VO2max, a gold standard for evaluating cardiorespiratory fitness, can be enhanced by training and will gradually decrease when training stops. This study, which followed the Cochrane Collaboration guidelines, is aimed at assessing the effects of short- and long-term detraining on trained individuals’ VO2max through a systematic review and meta-analysis and performed a subgroup analysis to evaluate the effects of different ages, detraining formats, and training statuses on VO2max variation between short- and long-term training cessation. Web of Science, SPORTDiscus, PubMed, and Scopus, four databases, were searched, from which 21 of 3315 potential studies met the inclusion criteria. Significant decreases in VO2max were identified after short-term training cessation (ES = -0.62 [95% CI -0.94; -0.31], p < 0.01; within-group I2 = 35.3%, Egger s test = -1.22, p = 0.335) and long-term training cessation (ES = -1.42 [95% CI -1.99; -0.84], p < 0.01; within-group I2 = 76.3%, Egger s test = -3.369, p < 0.01), which shows that the detraining effect was found to be larger on VO2max in long-term training cessation than in short-term training cessation (Q = 6.5, p = 0.01). However, there was no significant difference regarding VO2max change between 30-90 days detraining and more than 90 days detraining (Q = 0.54, p = 0.46) when conducting subgroup analysis. In addition, younger (<20) individuals showed a greater reduction in VO2max after long-term detraining than adult individuals (Q = 5.9, p = 0.05), and athletes with higher trained-state VO2max showed a significant decline in VO2max after long-term detraining compared with the lower trained-state group (Q = 4.24, p = 0.03). In conclusion, both short- and long-term training cessation have a detrimental effect on VO2max, and a greater impact on VO2max was found in long-term training cessation compared to short-term training cessation; however, there was no significant change in VO2max when the duration of training cessation was more than 30 days. To buffer the detrimental effects of detraining, especially long-term training cessation, performing some physical exercise during training cessation can effectively weaken detraining effects. Thus, to prevent athlete’s VO2max from decreasing dramatically from detraining, athletes should continue performing some physical exercise during the cessation of training.

1. Introduction

Maximal oxygen uptake (VO2max) is defined as the maximal rate at which oxygen can be taken up and utilized by the body during high-intensity exercise. Generally, VO2max is considered the most effective tool to measure the functionality of the human cardiovascular system [1, 2] and an effective indicator to explain individual cardiorespiratory health [3]. In addition, VO2max is a determinant of endurance performance for athletes [4] and one of the standard methods to evaluate the effects of aerobic training on athletes. Sports training and physical exercise are effective means to improve and maintain VO2max and have been widely verified in healthy [5], obese or overweight [6, 7], and athlete populations [8, 9]. However, the adaptability of VO2max obtained through training is reversible. It will diminish when the training stimulus disappears or decreases significantly [10]. The cessation of training reduces or removes the training stimulus and leads to the loss of anatomical, physiological, and performance training adaptability, which is defined as a detraining effect. The detraining effect on VO2max was related to the periods of training cessation, and the duration

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of the training cessation can be categorized as a short-term (less than four weeks) or long-term (more than four weeks) period in a previous study [10, 11]. Mujika and Padilla [10, 11] summarized some research findings that VO₂max for highly trained athletes decreased by 4-14% after short-term detraining but decreased by 6-20% after long-term detraining. Although long-term detraining seems to have a greater impact on VO₂max than short-term detraining, the lack of effective comparison methods makes it unclear how the detraining length affects athletes’ VO₂max.

The high VO₂max level results from long-term regular exercise to benefit the cardiovascular circulatory system and muscle function. Some studies have reported that VO₂max in trained people can remain unchanged after short-term detraining [12]. However, another study has shown that a higher VO₂max training status results in a greater decrease in VO₂max after short-term detraining [10]. The level of VO₂max in highly trained athletes initially decreases progressively, but eventually, VO₂max can be maintained at the control level after the long-term period [11], while those without an untrained background will completely lose their VO₂max gain after a long-term period. These studies indicated that the training status of VO₂max before detraining might affect the adverse effects of training cessation on VO₂max between short- and long-term periods. Nevertheless, limited research makes the influence of VO₂max training status on the relationship between the duration of training cessation and VO₂max in trained athletes still controversial.

When exposed to the risk of detraining, athletes will face two forms of detraining: one is complete cessation of training (CDT), that is, in addition to daily physical activity, complete interruption of training; the other is partial cessation of training (PDT), that is, doing exercise at a certain intensity of each week during detraining [10, 13]. Compared with CDT, PDT seems to reduce or offset the adverse effects on physiological functions and morphology. A recent study has shown that the losses in training adaptations and exercise capacity that occur during periods of inactivity may at least be partially alleviated with a program of reduced training frequency and/or duration if intensity is maintained [14]. Barry et al. [12] reported that conducting a 40-minute training program at 80% HRmax intensity twice a week can maintain VO₂max for the general population until 15 weeks. For the athlete group, research by Houmard and Mujika and Padilla [13, 15, 16] showed that the training frequency needs to be maintained above 80% of the original to decrease endurance performance. Although PDT is a training strategy to reduce the adverse effects of detraining, athletes have a different physiological response to training cessation in the short term or long term. Compared with CPT, the benefit and validation of PDT have not been evaluated by systematic review.

Changes in VO₂max and endurance performance are related to age. Endurance performance can show the highest level only after 20 [17], and VO₂max in adolescents is lower than that of adults because VO₂max can reach the peak level after 20 years of age [18]. VO₂max reflects muscles’ ability to utilize oxygen. Lemmer et al. confirmed that the strength retention rate of young people is significantly greater than that of elderly people after 12-31 weeks of training cessation [18]. Although these studies may imply that age may play a moderating role in detraining VO₂max, no studies have evaluated the effect of detraining VO₂max between the adolescent population (<20) and adults (≥20).

Recently, the COVID-19 outbreak has exposed athletes to the risk of detraining, which dramatically raises the possibility of a decline in athletic performance, the disappearance of training adaptation, and the risk of injury. It is an emerging challenge for athletes and coaches to formulate appropriate detraining prevention strategies, which require us to comprehend the effect of detraining on VO₂max. Nevertheless, the relevant assessment will be limited by different research methods. High-quality systematic reviews and meta-analyses can help us overcome these challenges, explain the bias and homogeneity of these studies, and provide more accurate assessment of the effects. Therefore, the purpose of this study is to evaluate the impact of short- and long-term detraining on VO₂max and assess the effects of age, training status, and detraining format on VO₂max between the long- and short-term periods by a subgroup analysis.

2. Materials and Methods

This systematic review and meta-analysis followed the Cochrane Collaboration guidelines [19]. The systematic review strategy was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines [20].

The literature search, identification, screening, and data extraction were conducted independently by two reviewers (TP and JZ). Disagreements between the reviewers were resolved by consensus or arbitration through a third reviewer (YkJ). Papers that were clearly not relevant were removed from the database list before abstracts were assessed using predetermined inclusion and exclusion criteria. The process of the study selection is shown in Figure 1.

2.1. Search Strategy. Electronic databases were searched in Web of Science, SPORTDiscus, PubMed, and Scopus. Searches were limited to papers published in English and from relevant publications prior to 31 March 2021. Keywords and synonyms were entered in various combinations (detraining OR deconditioning OR “training cessation” AND endurance* OR lactate* OR VO₂max OR aerobic*).

2.2. Selection Criteria. Studies were eligible for inclusion if (a) the paper reported a specific detraining duration and gave a detailed value of VO₂max before and after detraining, (b) the research subjects were athletes and were not limited by age, sex, event, or competitive level, and (c) articles were written in English.

Studies were excluded if (a) the paper reported relevant information unclearly or (b) the full text could not be obtained.

2.3. Extraction of Data. The characteristics of the 21 studies included in the meta-analysis can be found in Table 1. Two
independent reviewers (TP and JZ) read and coded each included study using the following moderators: authors and year of publication; training status (higher or lower); duration (days); sex (male, female, or mixed); age (<20 or ≥20); and detraining format (CDT or PDT).

2.4. Quality Assessment. Table 2 presents the summary of the STROBE statement checklist. The quality assessment was conducted independently by two reviewers (JZ and YkJ), and disagreements about outcomes were resolved by consensus or arbitration through a third reviewer (TP). The included articles were conducted using the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) checklist for cohort studies [21]. This checklist scores 22 items in the categories of title and abstract (item 1), introduction (items 2-3), methods (items 4-12), the results (items 13-17), discussion (items 18-21), and other information (item 22).

2.5. Synthesis of Results. Meta-analyses were conducted by the Meta package in R Studio (v1.41, Boston, USA). When comparing the duration of detraining effects on \( \dot{V}O_2\text{max} \), the outcome data were divided into short-term (≤30 days) and long-term (>30 days) [10], and long-term periods of detraining were organized into 30-90 days and >90 days for further analysis in the long-term detraining period [11]. The standardized mean difference (SMD) for each study was calculated as Hedge’s g effect size (ES) [22] to evaluate the magnitude of effects in different studies. Cohen’s criteria [23] were used to interpret the magnitude of SMD: <0.5, small; 0.5 to 0.8, moderate; and >0.8, large. Data are presented as the mean and 95% CI. \( I^2 \) is used to quantify statistical heterogeneity as follows [24]: 0% to 40%: might not be important; 30% to 60%: may represent moderate heterogeneity; 50% to 90%: may represent substantial heterogeneity; and 75% to 100%: considerable heterogeneity. A fixed model was used for analysis; however, if statistical heterogeneity was shown (\( I^2 <40\% \)), meta-analyses were performed using a random-effects model. Extended Egger’s test [26] was used to assess the risk of bias across the studies.

3. Results

3.1. Study Identification and Selection. The search of databases and additional titles from other sources identified an
initial 3315 titles. These studies were then exported to reference manager software (EndNoteX9, USA). Duplicates (1865 references) were subsequently removed either automatically or manually. The remaining 1450 articles were screened for their relevance based on titles and abstracts, resulting in the removal of an additional 1271 studies. The full texts of the remaining 179 articles were examined diligently; 158 articles were rejected as they did not satisfy the relevant criteria, including the following: full text could not be obtained \((n = 32)\); studies did not report specific data \((n = 6)\); nonathletes \((n = 51)\); training \((n = 18)\); unrelated \((n = 25)\); and others \((n = 26)\). Twenty-one articles were eligible for the systematic review and meta-analysis (Figure 1).

The 21 studies included provided mean and standard deviation \(\dot{VO}_{2}\text{max} \) data for at least one main outcome.

### 3.2. Study Characteristics
The characteristics of the 21 studies included in the meta-analysis can be found in Table 1. Detraining periods varied between 10 and 730 days across the studies. Twenty-one studies were divided into short-term (<30 days), long-term (30-90 days), and ultralong-term (>90 days) studies.

Table 1: Characteristics of the included studies.

| Study                          | Training status | Duration (days) | Sample size \((n)\) | Sex | Age | Cessation Measures |
|-------------------------------|-----------------|-----------------|---------------------|-----|-----|--------------------|
| Drinkwater et al. (1972) [27] | Lower           | 90              | 7                   | Female | <20 | CDT                |
| Murase, Y et al. (1981) [28]  | Higher          | 730             | 5                   | Male  | <20 | CDT                |
| Coyle et al. (1984) [29]      | Higher          | 12, 21, 56, 84  | 7                   | Mixed | ≥20 | CDT                |
| Cullinane et al. (1986) [30]  | Higher          | 10              | 15                  | Male  | ≥20 | CDT                |
| Miyamura M et al. (1990) [31] | Lower           | 365, 455, 605, 730 | 5             | Male  | ≥20 | CDT                |
| Hounard et al. (1992) [32]    | Higher          | 14              | 12                  | Mixed | ≥20 | CDT                |
| Madsen et al. (1993) [33]     | Higher          | 28              | 9                   | Male  | ≥20 | CDT                |
| LaForgia et al. (1999) [34]   | Lower           | 21              | 8                   | Male  | ≥20 | CDT                |
| Mochizuki et al. (1999) [35]  | Higher          | 30              | 15                  | Mixed | <20 | CDT                |
| Doherty et al. (2003) [36]    | Higher          | 15              | 7                   | Female | ≥20 | CDT                |
| Petibois et al. (2003) [37]   | Higher          | 35, 203, 364    | 10                  | Male  | ≥20 | CDT                |
| Gamelin et al. (2007) [38]    | Lower           | 14,28, 56       | 14                  | Male  | ≥20 | PDT                |
| Caldwell et al. (2009) [39]   | Lower           | 90              | 13                  | Male  | ≥20 | PDT                |
| J Garciapallares (2000) [40]  | Higher          | 35              | 7                   | Male  | ≥20 | CDT                |
| Sotiropoulos et al. (2009) [41]| Higher          | 28              | 20,38               | Male  | ≥20 | PDT                |
| Eastwood et al. (2012) [42]   | Higher          | 30              | 9                   | Male  | ≥20 | PDT                |
| Koundourakis et al. (2014) [43]| Higher          | 42              | 23,22               | Male  | ≥20 | PDT                |
| Koundourakis et al. (2014) [44]| Higher          | 42              | 67                  | Male  | ≥20 | PDT                |
| Melchiorri et al. (2014) [45] | Lower           | 42              | 14                  | Male  | <20 | CDT                |
| Balague et al. (2016) [46]    | Lower           | 21              | 8                   | Male  | ≥20 | CDT                |
| Melchiorri et al. (1999) [47] | Higher          | 56              | 15                  | Mixed | ≥20 | CDT                |

Duration (days): duration of detraining; higher: regular training will be conducted more than or equal to 5 times a week; lower: training will be less than 5 times a week; CDT: completely detraining; PDT: partly detraining.

### 3.3. The Effects of Short-Term and Long-Term Training Cessation on \(\dot{VO}_{2}\text{max}\)
The forest plot shows the effects of short-term and long-term detraining on \(\dot{VO}_{2}\text{max}\). Significant decreases in \(\dot{VO}_{2}\text{max}\) were identified after short-term
3.4. Subgroup Analysis Results.

(A Figure 2).

ation and long-term training cessation varied between 2.8% 

ative weight of each study in the short-term training cessa-

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observed during both short- and long-term training cessa-

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and long-term training cessation (ES = −1.42 [95% CI 

Q̇O2max after short- and long-term training cessation. A 

3.4. Subgroup Analysis Results. The effect of training cessa-

training cessation after the long-term period 

more than 90 days detaining (Q = 0.54, p = 0.46). However, the athletes with higher 

30-90 days detaining and larger than 90 days detaining (Q = 0.54, p = 0.46). However, the athletes with higher 

Table 2: Strengthening the Reporting of Observational Studies in Epidemiology (STROBE).

| Study                          | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | Overall |
|-------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| Murase et al.                 | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 0 | 0  | 2  | 0  | 1  | 2  | 2  | 2  | 0  | 2  | 1  | 2  | 1  | 0  | 28  |
| Doherty et al.                | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 0  | 2  | 2  | 2  | 2  | 2  | 0  | 2  | 2  | 2  | 2  | 1  | 36  |
| Drinkwater et al.             | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 0  | 2  | 2  | 1 | 2  | 2  | 2  | 0  | 2  | 1  | 2  | 1  | 0  | 29  |
| Coyle et al.                  | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 0  | 2  | 2  | 1 | 2  | 2  | 2  | 2  | 2  | 1  | 2  | 1  | 2  | 35  |
| Esatwood et al.               | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 0  | 2  | 2  | 1 | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 1  | 35  |
| Houmard et al.                | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 0  | 2  | 2  | 1 | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 1  | 35  |
| Yi-hung et al.                | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 0  | 2  | 2  | 2 | 2  | 2  | 2  | 2 | 2  | 1  | 2  | 2  | 2  | 2  | 39  |
| Petitbois et al.              | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 0  | 2  | 2  | 1 | 2  | 2  | 2 | 1  | 2 | 1 | 2  | 2  | 2  | 2  | 35  |
| Balague et al.                | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 0  | 2  | 2  | 2 | 2  | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 35  |
| Garcia et al.                 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 0 | 0  | 2  | 2  | 2 | 2 | 2 | 0 | 2 | 2 | 2 | 2 | 1 | 1 | 34  |
| LaForgia et al.               | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 0 | 0  | 2  | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 0 | 35  |
| Rochizuki et al.              | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 0 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 0 | 35  |
| Andoulakas et al.             | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 39  |
| TRAVLOS et al.                | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 39  |
| BRIAN et al.                  | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 0 | 2 | 0 | 2 | 1 | 2 | 2 | 0 | 2 | 2 | 2 | 2 | 1 | 32  |
| Nikolaos et al.               | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 1 | 2 | 2 | 0 | 2 | 2 | 2 | 2 | 1 | 34  |
| Gamelin et al.                | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 38  |
| Eileen et al.                 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 0 | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 0 | 0 | 31  |
| Melchiorelli et al.           | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 2 | 0 | 0 | 35  |
| KLAWS et al.                  | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 0 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 33  |
| Mishau et al.                 | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 0 | 2 | 0 | 1 | 2 | 2 | 1 | 2 | 0 | 1 | 2 | 1 | 30  |

1: title and abstract; 2: background/rationale; 3: objectives; 4: study design; 5: setting; 6: participants; 7: variables; 8: data sources/measurement; 9: bias; 10: study size; 11: quantitative variables; 12: statistical methods; 13: participants; 14: descriptive data; 15: outcome data; 16: main results; 17: other analyses; 18: key results; 19: limitations; 20: interpretation; 21: generalizability; and 22: funding (0: no information; 1: low; and 2: high).

4. Discussion

This systematic review and meta-analysis is aimed at assessing the magnitude of the effect on trained individuals’ V̇O₂max after short- and long-term training cessation. A detrimental impact on trained individuals’ V̇O₂max was observed during both short- and long-term training cessation, and a larger negative effect after the long-term period was identified compared with the short-term period. The subgroup analysis showed that the effects of age, training status, and detraining format led to the differing impacts of detraining on V̇O₂max in the long-term period but did not change in the short-term period.

4.1. The Short-Term and Long-Term Effects on V̇O₂max. The present study revealed that both short- and long-term detraining will cause a significant drop in the trained individual’s V̇O₂max, and the average V̇O₂max decreased by 3.93% in the short-term period and by 9.43% in the long-term period. Training cessation or reduction causes insufficiency or disappearance of training stimulation and leads to morphological and physiological functional changes, which may be the main factor for the harmful effects of long-term and short-term detraining on V̇O₂max [10, 11]. It is
worth noting that there was no significant difference in the decline in VO2max between 30-90 days and longer than 90 days detraining in the subgroup analysis of long-term detraining. This result indicated that when training cessation occurred beyond a certain period, the harmful effects on VO2max no longer increased with the extension of the training suspension time. In fact, even without physical training, daily essential physical activity can also maintain normal physiological function and sustain cardiovascular fitness [48], which may help to explain the nonlinear relationship between the duration of training cessation and detraining effects in the long term. The research results show that there is a dose-effect relationship between the detraining duration and the detraining effect. When the training cessation exceeds a certain period (>90 days), the harmful effects caused by the training suspension will no longer continue to worsen. In practice, coaches and athletes must be aware of the difference between the short- and long-term harmful effects of VO2max to develop detraining prevention strategies. Long-term detraining needs to be avoided because long-term detraining has a greater detrimental effect on VO2max.
4.2. Deteriorating Format Differences in the Short-Term and Long-Term Effects on VO\(_2\)max. An essential finding of this study is that exercise activities during long-term deteriorating can reduce the negative effect of deteriorating on VO\(_2\)max compared with no exercise activities. However, there was no significant difference in the harmful effects of VO\(_2\)max between CDT and PDT. The magnitude of detrimental impacts on VO\(_2\)max in the PDT groups during the long-term period was small, and the percentage of decline in VO\(_2\)max ranged from -4.38% to -0.93%; however, the negative effect was large, and VO\(_2\)max decreased up to -11.12%. Recent research also supports the results of the current study and shows that performing jogging exercises with 50-60% VO\(_2\)max intensity for 20-30 minutes each time 2-3 times a week during off-seasonal periods can offset the harmful effects of deteriorating on VO\(_2\)max in football players [49, 50]. Many studies have shown that regular aerobic exercise can maintain a healthy level of VO\(_2\)max in the human body [51-54]. This may be helpful to explain why athletes who exercise can delay the decline in oxygen uptake during long-term training cessation. It was unexpected that PDT had no buffering effect on the harmful impacts of VO\(_2\)max during the short-term period. There were small negative effects on VO\(_2\)max in both the CDT and PDT groups, and the decrease in VO\(_2\)max levels of athletes ranged from -21.28% to 0.84% in the CDT group and varied from -4.38% to -0.93% in the PDT group. One possible explanation is that the intensity of the exercise is inappropriate. In the sample of this study, the exercise intensity during the short-term period was low, which may not play a role in maintaining VO\(_2\)max. Recent studies have also shown that exercise intensity is the key for athletes to sustain VO\(_2\)max [12]. It has been reported that high-intensity exercise 2 times a week can allow athletes to maintain VO\(_2\)max for 15 weeks without decreasing [12]. In addition, there may be a minimum threshold for the reduction of VO\(_2\)max during training cessation. In this study, a minimum of 2 weeks of training can cause a decrease in VO\(_2\)max, and the research results suggest that athletes and coaches need to consider the different effects of long- and short-term deteriorating when making deteriorating prevention plans. During the long-term period, necessary exercise can offset some of the negative impacts on VO\(_2\)max. In the short term, if there is not enough stimulation, there may be no difference in VO\(_2\)max change between athletes who exercise and those who do not exercise at all.

4.3. The Training Status Difference in the Short-Term and Long-Term Effects on VO\(_2\)max. Long-term deteriorating has a more significant negative impact on athletes with higher levels of oxygen uptake training, which may be related to the training intensity that affects aerobic capacity. Studies have shown that training intensity rather than training frequency is crucial in maintaining VO\(_2\)max levels [1, 55]. Athletes with higher training levels rely on higher training intensity to improve their physiological functions. Once training stimulation is lost, the training-induced gain for VO\(_2\)max cannot be maintained. Long-term deteriorating makes the VO\(_2\)max gain obtained by athletes through high-intensity training decrease or disappear more quickly. Athletes with a higher training status of VO\(_2\)max have a more significant reduction in VO\(_2\)max. The effect of short-term training cessation on VO\(_2\)max was not affected by the level of VO\(_2\)max, and there was no significant difference between the high-level and low-level groups. The current study is inconsistent with previous studies. Mujika and Padilla [10] summarize the results of some studies that show that athletes with higher oxygen uptake or aerobic power capacity have a more significant decrease in VO\(_2\)max ranging between 4 and 14% after short-term training stops. The differences in the results of different studies may be due to the limitations of the previous research methods. Although previous studies have reported a greater percentage drop rate for athletes with a higher training status of VO\(_2\)max, this is not enough to cause a significant difference in the magnitude of an adverse effect of training suspension on VO\(_2\)max.

4.4. The Age Difference in the Short-Term and Long-Term Effects on VO\(_2\)max. After long-term training cessation, the changes in athletes’ VO\(_2\)max were affected by age.

| Table 3: Subgroup analysis of the long-term deteriorating effect on VO\(_2\)max. |
|-----------------|--------|--------|--------|--------|
| Duration        | \(k\)  | SMD    | 95% CI | \(p\)  | \(Q\)  |
| 30-90 days      | 12     | -1.6   | -2.47; -0.74 | <0.001 | 64.36  | 0.83 |
| >90 days        | 7      | -1.20  | -2.13; -0.28 | <0.001 | 14.66  | 0.59 |
| Training state  |        |        |        |        |        |      |
| Higher          | 10     | -1.91  | -2.57; -1.25 | <0.001 | 28.8   | 0.69 |
| Lower           | 4      | -0.85  | -1.83; 0.12  | <0.001 | 24.5   | 0.67 |
| Age             |        |        |        |        |        |      |
| <20             | 3      | -2.81  | -6.32; 0.69  | <0.001 | 9.32   | 0.37 |
| ≥20             | 16     | -1.20  | -1.76; -0.64 | <0.001 | 58.4   | 0.74 |
| Format          |        |        |        |        |        |      |
| CDT             | 16     | -1.69  | -2.41; -0.96 | <0.001 | 52.5   | 0.73 |
| PDT             | 4      | -0.65  | -1.42; 0.11  | <0.001 | 9.2    | 0.67 |

\(k\): number of studies; SMD: <0.5, small; 0.5 to 0.8, moderate; ≥0.8, large; \(I^2\): heterogeneity test.

| Table 4: Subgroup analysis of the short-term deteriorating effect on VO\(_2\)max. |
|-----------------|--------|--------|--------|--------|
| Training status | \(k\)  | SMD    | 95% CI | \(p\)  | \(Q\)  |
| Higher          | 7      | -0.76  | -1.10; -0.41 | <0.001 | 9.32   | 0.37 |
| Lower           | 7      | -0.46  | -0.75; -0.18 | 0.014  | 9.39   | 0.36 |
| Age             |        |        |        |        |        |      |
| <20             | 1      | -0.83  | -1.57; -0.08 | 0.030  | —      | —    |
| ≥20             | 13     | -0.61  | -0.95; -0.26 | <0.001 | 19.3   | 0.38 |
| CDT             | 11     | -0.54  | -0.82; -0.26 | <0.001 | 14.4   | 0.31 |
| PDT             | 4      | -0.65  | -1.00; -0.30 | 0.01   | 5.76   | 0.05 |

\(k\): number of studies; SMD: <0.5, small; 0.5 to 0.8, moderate; ≥0.8, large; \(I^2\): heterogeneity test.
Compared with adult athletes, young athletes have a greater rate of decline in VO\textsubscript{2}\text{max} after long-term suspension. In general, VO\textsubscript{2}\text{max} can reach its peak level at the age of 20-30 and decreases by approximately 1% every year after 30 [56]. Therefore, a lack of long-term training stimulation may have a more significant impact on the cardiovascular function of young athletes than adult athletes. Only one study reported the effect of short-term training on VO\textsubscript{2}\text{max} for the adolescent population [35]. Therefore, it is impossible to examine the effect of age on VO\textsubscript{2}\text{max} during short-term training for subgroup analysis. Meanwhile, only three studies reported on VO\textsubscript{2}\text{max} for the junior [28, 35, 45] group, and the limited research samples required us to treat the study results with caution.

4.5. Research Limitations and Future Prospects. More research samples in this study come from male athletes or mixed genders, and only two studies are female athletes. The differences in the physiological structure of men and women [33] may affect the results of the study. It is necessary to examine the difference in VO\textsubscript{2}\text{max} change between sexes after short- and long-term detraining in subsequent studies. In addition, factors such as nutrition (i.e., sports supplementation), environment, or measurement methods may affect the changes in oxygen uptake during detraining [57–61]. Therefore, the effects of these factors on the change in oxygen uptake during training cessation will also be considered in a follow-up study. Studies have shown that certain exercises can buffer some harmful effects during long-term periods, but current research cannot identify the training intensity and training load of certain exercises. In future research, it is necessary to explore the minimum dose-effect relationship that can maintain VO\textsubscript{2}\text{max} after detraining. Previous studies have reported that VO\textsubscript{2}\text{max} is related to changes in physical fitness levels, and future studies should compare the differences in physical fitness. Finally, research bias may have affected the research results.

5. Conclusion

The detrimental effects of detraining on VO\textsubscript{2}\text{max} were identified in both short-term and long-term training cessation. A greater decline in VO\textsubscript{2}\text{max} after the long-term period was observed when it was compared to short-term training cessation; however, there was no significant difference regarding the reduction in VO\textsubscript{2}\text{max} found between 30-90 days detraining and more than 90 days detraining. Physical exercise during the period of detraining seems to weaken the detrimental effects on VO\textsubscript{2}\text{max} to some extent during long-term training cessation, but it does not work in short-term training cessation. Adolescent and individual trainers with a higher VO\textsubscript{2}\text{max} training status have a greater decline in oxygen uptake after long-term training cessation.

Conflicts of Interest

The authors declare no conflicts of interest.

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References

[1] A. P. Bacon, R. E. Carter, E. A. Ogle, and M. J. Joyner, “VO\textsubscript{2}\text{max} trainability and high intensity interval training in humans: a meta-analysis,” PLoS One, vol. 8, no. 9, article e73182, 2013.

[2] D. C. Lee, E. G. Artero, X. Sui, and S. N. Blair, “Mortality trends in the general population: the importance of cardiorespiratory fitness,” Journal of Psychopharmacology, vol. 24, 4, suppl., pp. 27–35, 2010.

[3] E. T. Howley, D. R. Bassett Jr., and H. G. Welch, “Criteria for maximal oxygen uptake: review and commentary,” Medicine and Science in Sports and Exercise, vol. 27, no. 9, pp. 1292–1301, 1995.

[4] D. R. Bassett Jr. and E. T. Howley, “Limiting factors for maximum oxygen uptake and determinants of endurance performance,” Medicine and Science in Sports and Exercise, vol. 32, no. 1, pp. 70–84, 2000.

[5] M. Siahkouhian, D. Khodadadi, and K. Shahmoradi, “Effects of high-intensity interval training on aerobic and anaerobic indices: comparison of physically active and inactive men,” Science & Sports, vol. 28, no. 5, pp. e119–e125, 2013.

[6] A. E. Tjønna, I. M. Leinan, A. T. Bartnes et al., “Low- and high-volume of intensive endurance training significantly improves maximal oxygen uptake after 10-weeks of training in healthy men,” PLoS One, vol. 8, no. 5, article e65382, 2013.

[7] L. J. Whyte, J. M. R. Gill, and A. J. Cathcart, “Effect of 2 weeks of sprint interval training on health-related outcomes in sedentary overweight/obese men,” Metabolism, vol. 59, no. 10, pp. 1412–1428, 2010.

[8] S. Boucher, Y. Park, S. Dunn, and Y. N. Boucher, “The relationship between cardiac autonomic function and maximal oxygen uptake response to high-intensity intermittent-exercise training,” Journal of Sports Sciences, vol. 31, no. 9, pp. 1024–1029, 2013.

[9] T. J. Hazell, R. E. MacPherson, B. M. Gravelle, and P. W. Lemon, “10 or 30-s sprint interval training bouts enhance both aerobic and anaerobic performance,” European Journal of Applied Physiology, vol. 110, no. 1, pp. 153–160, 2010.

[10] I. Mujika and S. Padilla, “Detraining: loss of training-induced physiological and performance adaptations. Part I: short term insufficient training stimulus,” Sports Medicine, vol. 30, no. 2, pp. 79–87, 2000.

[11] I. Mujika and S. Padilla, “Detraining: loss of training-induced physiological and performance adaptations. Part II: long term insufficient training stimulus,” Sports Medicine, vol. 30, no. 3, pp. 145–154, 2000.

[12] B. A. Spiering, I. Mujika, M. A. Sharp, and S. A. Foulis, “Maintaining physical performance: the minimal dose of exercise needed to preserve endurance and strength over time,” Journal of Strength and Conditioning Research, vol. 35, no. 5, pp. 1449–1458, 2021.

Data Availability

The data used to support the findings of this study are included within the article.
I. Mujika, “The influence of training characteristics and tapering on the adaptation in highly trained individuals: a review,” *International Journal of Sports Medicine*, vol. 19, no. 7, pp. 439–446, 1998.

P. D. Neufer, “The effect of detraining and reduced training on the physiological adaptations to aerobic exercise training,” *Sports Medicine*, vol. 8, no. 5, pp. 302–321, 1989.

J. A. Houmard, “Impact of reduced training on performance in endurance athletes,” *Sports Medicine*, vol. 12, no. 6, pp. 380–393, 1991.

I. Mujika and S. Padilla, “Physiological and performance consequences of training cessation in athletes: Detrainning,” *Rehabilitation of Sports Injuries: Scientific Basis*, vol. 117, p. 143, 2003.

S. V. Allen and W. G. Hopkins, “Age of peak competitive performance of elite athletes: a systematic review,” *Sports Medicine*, vol. 45, no. 10, pp. 1431–1441, 2015.

J. T. Lemmer, D. E. Hurlbut, G. F. Martel et al., “Age and gender responses to strength training and detraining,” *Medicine and Science in Sports and Exercise*, vol. 32, no. 8, pp. 1505–1512, 2000.

C. LeFebvre, J. Glenville, S. Briscoe et al., “Searching for and selecting studies,” *Cochrane Handbook for Systematic Reviews of Interventions*, pp. 67–107, 2019.

K. Knobloch, U. Yoon, and P. M. Vogt, “Preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement and publication bias,” *Journal of Cranio-Maxillofacial Surgery*, vol. 39, no. 2, pp. 91–92, 2011.

J. P. Vandebroucke, E. V. Elm, and D. Altman, “Strengthening the Reporting of Observational Studies in Epidemiology (STROBE),” *Epidemiology*, vol. 18, no. 6, pp. 805–835, 2007.

L. V. Hedges, “Distribution theory for Glass’s estimator of effect size and related estimators,” *Journal of Educational Statistics*, vol. 6, no. 2, pp. 107–128, 1981.

J. Cohen, *Statistical power analysis for the behavioral sciences*, Routledge, 2nd edition, 1988.

J. P. Higgins, T. Li, and J. J. Deeks, “Choosing effect measures and computing estimates of effect,” *Cochrane Handbook for Systematic Reviews of Interventions*, pp. 143–176, 2019.

J. P. Higgins and S. G. Thompson, “Quantifying heterogeneity in a meta-analysis,” *Statistics in Medicine*, vol. 21, no. 11, pp. 1539–1558, 2002.

M. Egger, G. D. Smith, M. Schneider, and C. Minder, “Bias in meta-analysis detected by a simple, graphical test,” *BMJ*, vol. 315, no. 7109, pp. 629–634, 1997.

B. Drinkwater and S. Horvath, “Detraining effects on young women,” *Medicine & Science in Sports & Exercise*, vol. 4, no. 2, p. 91??95, 1972.

Y. Murase, K. A. Kobayashi, S. A. Kamei, and H. I. Matsui, “Longitudinal study of aerobic power in superior junior athletes,” *Medicine and Science in Sports and Exercise*, vol. 13, no. 3, pp. 180??184–180??184, 1981.

E. F. Coyle, W. H. Martin, D. R. Sinacore, M. J. Joyner, J. M. Hagberg, and J. O. Holloszy, “Time course of loss of adaptations after stopping prolonged intense endurance training,” *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, vol. 57, no. 6, pp. 1857–1864, 1984.

E. M. Cullinane, S. P. Sady, L. Vadeboncoeur, M. Burke, and P. D. Thompson, “Cardiac size and VO2max do not decrease after short-term exercise cessation,” *Medicine and Science in Sports and Exercise*, vol. 18, no. 4, pp. 420–424, 1986.

M. Miyamura and K. Ishida, “Adaptive changes in hypercarnic ventilatory response during training and detraining,” *European Journal of Applied Physiology and Occupational Physiology*, vol. 60, no. 5, pp. 353–359, 1990.

J. A. Houmard, T. Hortobágyi, R. A. Johns et al., “Effect of short-term training cessation on performance measures in distance runners,” *International Journal of Sports Medicine*, vol. 13, no. 8, pp. 572–576, 1992.

K. Madsen, P. K. Pedersen, M. S. Djurhuus, and N. A. Kiltgaard, “Effects of detraining on endurance capacity and metabolic changes during prolonged exhaustive exercise,” *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, vol. 75, no. 4, pp. 1444–1451, 1993.

J. Laforgia, R. T. Withers, A. D. Williams et al., “Effect of 3 weeks of detraining on the resting metabolic rate and body composition of trained males,” *European Journal of Clinical Nutrition*, vol. 53, no. 2, pp. 126–133, 1999.

M. Mochizuki, K. Suzuki, S. Nakaji, K. Sugawara, M. Totsuka, and K. Sato, “Effects of maximal exercise on nonspecific immunity in athletes under trained and detrained conditions,” *Japanese Journal of Physical Fitness and Sports Medicine*, vol. 48, no. 1, pp. 147–159, 1999.

R. Doherty, P. Neary, Y. Bhammbhani, and H. A. Wenger, “Fifteen-day cessation of training on selected physiological and performance variables in women runners,” *Journal of Strength and Conditioning Research/ National Strength & Conditioning Association*, vol. 17, no. 3, pp. 599–607, 2003.

C. Petitbois and G. Delèrè, “Effects of short- and long-term detraining on the metabolic response to endurance exercise,” *International Journal of Sports Medicine*, vol. 24, no. 5, pp. 320–325, 2003.

F.-X. Gamelin, S. Berthoin, H. Sayah, C. Libersa, and L. Bosquet, “Effect of training and detraining on heart rate variability in healthy young men,” *International Journal of Sports Medicine*, vol. 28, no. 7, pp. 564–570, 2007.

B. P. Caldwell and D. M. Peters, “Seasonal variation in physiological fitness of a semiprofessional soccer team,” *Journal of Strength and Conditioning Research*, vol. 23, no. 5, pp. 1370–1377, 2009.

J. G. Journal, “Post-season detraining effects on physiological and performance parameters in top-level kayakers: comparison of two recovery strategies,” *Journal of Sports Science and Medicine*, vol. 8, no. 4, pp. 273–276, 2000.

A. Sotropoulos, A. K. Travlos, I. Gissis, A. G. Souglis, and A. Grezios, “The effect of a 4-week training regimen on body fat and aerobic capacity of professional soccer players during the transition period,” *Journal of Strength and Conditioning Research*, vol. 23, no. 6, pp. 1697–1703, 2009.

A. Eastwood, P. C. Bourdon, K. R. Snowden, and C. J. Gore, “Detraining decreases Hb (mass) of triathletes,” *International Journal of Sports Medicine*, vol. 33, no. 4, pp. 253–257, 2012.

N. E. Koundourakis, N. E. Androulakis, N. Malliaraki, C. Tsatsanis, M. Venihaki, and A. N. Margioris, “Discrepancy between exercise performance, body composition, and sex steroid response after a six-week detraining period in professional soccer players,” *PLoS One*, vol. 9, no. 2, article e87803, 2014.

N. E. Koundourakis, N. E. Androulakis, N. Malliaraki, and A. N. Margioris, “Vitamin D and exercise performance in professional soccer players,” *PLoS One*, vol. 9, no. 7, article e101659, 2014.
[45] G. Melchiorri, M. Ronconi, T. Triossi et al., “Detraining in young soccer players,” *The Journal of Sports Medicine and Physical Fitness*, vol. 54, no. 1, pp. 27–33, 2014.

[46] N. Balagué, J. González, C. Javierre et al., “Cardiorespiratory coordination after training and detraining. A principal component analysis approach,” *Physiology*, vol. 7, 2016.

[47] M. Mochizuki, K. Suzuki, S. Nakaji, K. Sugawara, M. Totsuka, and K. Sato, “Effects of Maximal Exercise on Nonspecific Immunity in Athletes under Trained and Detrained Conditions,” *Japanese Journal of Physical Fitness and Sports Medicine*, vol. 48, no. 1, pp. 147–160, 1999.

[48] J. F. Sallis, T. L. Patterson, M. J. Buono, and P. R. Nader, “Relation of cardiovascular fitness and physical activity to cardiovascular disease risk factors in children and adults,” *American Journal of Epidemiology*, vol. 127, no. 5, pp. 933–941, 1988.

[49] F. M. Clemente, R. Ramirez-Campillo, and H. Sarmento, “Detrimental effects of the off-season in soccer players: a systematic review and meta-analysis,” *Sports Medicine*, vol. 51, no. 4, pp. 795–814, 2021.

[50] V. Schneider, B. Arnold, K. Martin, D. Bell, and P. Crocker, “Detraining effects in college football players during the competitive season,” *The Journal of Strength & Conditioning Research*, vol. 12, no. 1, p. 42, 1998.

[51] S. B. Chapman, S. Aslan, J. S. Spence et al., “Shorter term aerobic exercise improves brain, cognition, and cardiovascular fitness in aging,” *Frontiers in Aging Neuroscience*, vol. 5, p. 75, 2013.

[52] H. Guiney and L. Machado, “Benefits of regular aerobic exercise for executive functioning in healthy populations,” *Psychonomic Bulletin & Review*, vol. 20, no. 1, pp. 73–86, 2013.

[53] A. C. King, C. B. Taylor, W. L. Haskell, and R. F. DeBusk, “Influence of regular aerobic exercise on psychological health: a randomized, controlled trial of healthy middle-aged adults,” *Health Psychology*, vol. 8, no. 3, pp. 305–324, 1989.

[54] D. Wen, T. Utesch, J. Wu et al., “Effects of different protocols of high intensity interval training for VO2max improvements in adults: a meta-analysis of randomised controlled trials,” *Journal of Science and Medicine in Sport*, vol. 22, no. 8, pp. 941–947, 2019.

[55] R. C. Hickson and M. A. Rosenkoetter, “Reduced training frequencies and maintenance of increased aerobic power,” *Medicine and Science in Sports and Exercise*, vol. 13, no. 1, pp. 13–16, 1981.

[56] W. L. Kenney, J. H. Wilmore, and D. L. Costill, *Physiology of sport and exercise*, Human kinetics, Champaign, Illinois, 2015.

[57] N. Fauzi and M. Mardiana, “The effect of sports drink gel treatment from chia seeds (Salvia hispanica L.) on the VO2 max capacity of football and futsal players,” *Jurnal Gizi dan Pangan*, vol. 17, no. 1, pp. 19–26, 2022.

[58] F. A. Sinaga, M. Risfandi, and J. I. Mesnan, “The effect of giving red guava fruit juice towards haemoglobin and Vo2max contents on maximum physical activity,” *Inter J Sci Res (IJSR)*, vol. 6, no. 9, pp. 1185–1189, 2017.

[59] H. Carter, A. M. Jones, T. J. Barstow, M. Burnley, C. A. Williams, and J. H. Doust, “Oxygen uptake kinetics in treadmill running and cycle ergometry: acomparison,” *Journal of applied physiology (1985)*, vol. 89, no. 3, pp. 899–907, 2000.

[60] F. T. McSwiney, B. Fusco, L. McCabe et al., “Changes in body composition and substrate utilization after a short-term ketogenic diet in endurance-trained males,” *Biology of Sport*, vol. 38, no. 1, pp. 145–152, 2021.

[61] S. P. Dufour, E. Ponsot, J. Zoll et al., “Exercise training in normobaric hypoxia in endurance runners. I. Improvement in aerobic performance capacity,” *Journal of applied physiology (1985)*, vol. 100, no. 4, pp. 1238–1248, 2006.