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Review

Effectiveness of Training Prescription Guided by Heart Rate Variability Versus Predefined Training for Physiological and Aerobic Performance Improvements: A Systematic Review and Meta-Analysis

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Abstract: A systematic review and meta-analysis were performed to determine if heart rate variability-guided training (HRV-g), compared to predefined training (PT), maximizes the further improvement of endurance physiological and performance markers in healthy individuals. This analysis included randomized controlled trials assessing the effects of HRV-g vs. PT on endurance physiological and performance markers in untrained, physically active, and well-trained subjects. Eight articles qualified for inclusion. HRV-g training significantly improved maximum oxygen uptake (VO_2max) (MD = 2.84, CI: 1.41, 4.27; $p < 0.0001$), maximum aerobic power or speed (WMax) (SMD = 0.66, 95% CI 0.33, 0.98; $p < 0.0001$), aerobic performance (SMD = 0.71, CI 0.16, 1.25; $p = 0.01$) and power or speed at ventilatory thresholds (VT) VT1 (SMD = 0.62, CI 0.04, 1.20; $p = 0.04$) and VT2 (SMD = 0.81, CI 0.41, 1.22; $p < 0.0001$). However, HRV-g did not show significant differences in VO_2max (MD = 0.96, CI −1.11, 3.03; $p = 0.36$), WMax (SMD = 0.06, CI −0.26, 0.38; $p = 0.72$), or aerobic performance (SMD = 0.14, CI −0.22, 0.51; $p = 0.45$) in power or speed at VT1 (SMD = 0.27, 95% CI −0.16, 0.70; $p = 0.22$) or VT2 (SMD = 0.18, 95% CI −0.20, 0.57; $p = 0.35$), when compared to PT. Although HRV-based training periodization improved both physiological variables and aerobic performance, this method did not provide significant benefit over PT.

Keywords: autonomic nervous system; cardiac autonomic regulation; cardiorespiratory fitness; daily training; endurance

1. Introduction

To maximize the physical fitness of athletes, correct management of training program variables (i.e., volume, intensity, frequency, density, etc.) is needed [1]. The optimal training dosage promotes physiological adaptations and reduces the risk of injury and overtraining syndrome, finally improving athletic performance [2]. The rational distribution of training sessions would be the pillar to obtain the correct physiological modifications in athletes [3]. Therefore, several training periodization strategies have been applied to manage the training load and obtain performance enhancement [4]. However, the relationship between training stimulus and physiological responses depends on the individual and varies widely [5]. Thus, to provide correct feedback to the training process and its optimization, the physiological monitoring of the athlete's individual response to the training program plays an essential role [6]. This way, the physiological monitorization allows the correct management of the training load, according to the athlete's individual response [6].

Recently, the autonomic nervous system analysis has been commonly used to manage the training load [7,8] and the endurance training prescription [9–14]. Heart rate variability (HRV) has been widely used, since it reflects the balance between sympathetic and parasympathetic modulation, showing autonomic nervous system (ANS) regulation [15–19]. After physical exercise, the ANS decreases the sympathetic activity and produces a rapid restoration of vagal tone (parasympathetic component) that allows performance improvements [20]. However, due to the misbalance between intensity, volume, and density of training, nonfunctional training loads produce a nonfunctional overreach, promoting a reduction in vagal indices of HRV and impairing the recovery process [21]. Consequently, changes in ANS regulation, assessed by HRV, can identify the relationship between training (stress) and recovery status. Thus, HRV can support the training process as an internal load marker or a long-term monitoring indicator [2].

Lately, a systematic literature review (five randomized controlled trials) critically discussed the potential of heart rate variability-guided training (HRV-g) as an intervention to improve aerobic performance in athletes [2]. Limitations of this previous work include the analysis of the effect of HRV-g only on runners. Only in 2018 and 2019, three additional randomized controlled trials [10,11,22] using cyclists or skiers were published, representing almost half of the total number of studies that were available until then. A potential limitation of a systematic review is that it does not include a data synthesis and statistical analysis to determine the summary effect of the intervention on the outcome's measures; it implies that results obtained in the literature review [2] could be oversized without a specific statistical analysis that offers a more accurate and general picture of the HRV-guided effects on aerobic performance. This highlighted the growing interest in the HRV-guided potential and the need to conduct a large meta-analysis; hence, it is necessary to systematically analyze the effect of this type of training as an intervention to improve aerobic performance in trained and untrained participants.

The aim of this study was to perform a systematic review and meta-analysis to determine if endurance HRV-g maximizes aerobic performance and/or aerobic physiological adaptation, compared to a predefined training (PT) program.

2. Materials and Methods

2.1. Study Design

The methodological process was based on the recommendations indicated by the PRISMA (preferred reporting items for systematic review and meta-analysis) statement [23]. All phases of the meta-analysis were conducted in duplicate. For the meta-analysis, only randomized controlled trials that investigated the effects of training prescription guided by HRV on any physiological (i.e., maximum oxygen uptake—VO_2max) or aerobic performance variables (performance at VO_2max, performance at VT1 and VT2, or performance test) were considered. The study was registered in PROSPERO (International Prospective Register of Systematic Reviews) (www.crd.york.ac.uk/prospero/index.asp, identifier CRD42020204461).

2.2. Data Sources and Search Profile

A comprehensive literature search was performed using PubMed–Medline, Web of Science, and the Cochrane Library databases. The search was performed without date restriction and was completed on 15 August 2020. The following combination of terms was used: "HRV or heart rate variability", "autonomic nervous system", "parasympathetic nervous system", "cardiac autonomic regulation", and "vagal activity". The Boolean operator "AND" was used to combine these descriptors with "training guided", "training periodization", or "exercise prescription".

2.3. Data Extraction and Selection Criteria

The following inclusion criteria were considered: randomized clinical trials, studies examining the effects of endurance training prescription guided by HRV on physiological or performance variables, studies that include a control group with a PT program, studies published in English, and studies that should report information on variables in one baseline and one post-treatment measure. Conversely, studies were excluded if they were not an original fully published work, if they did not specify the tests utilized or detailed the training program, and if they did not provide numerical data.

The articles analyzed were reviewed separately by two authors (J.P.M.R. and D.J.R.C.). Studies that fulfilled the inclusion criteria were coded and recorded on an Excel spreadsheet. In addition, the substantive aspects were extracted for Table 1: authors, country, methodology, number of participants per group, age, gender, level of physical activity, and methodological aspects; similarly, for Table 2: HRV variable, decision-making algorithm, volume, intensity distribution, frequency, load, and duration of the experiment. Finally, pre- and post-intervention means and the standard deviation of the studies included in the quantitative analysis were recorded.

2.4. Outcomes

The primary outcome was VO_2max. The secondary outcomes analyzed were (1) maximum aerobic power or speed (WMax) as a performance indicator in the VO_2max, (2) aerobic performance as an extrapolated value from a field test (i.e., 40 km time trial, 3 and 5 km running test), and (3) power or velocity at VT1 (WVT1) and VT2 (WVT2) as the performance variables at those points.

2.5. Evaluation of the Methodology of the Studies Selected

The methodological quality of the selected studies was assessed with the Cochrane risk-of-bias tool [24] that includes the following parameters: (1) random sequence generation (selection bias), (2) allocation concealment (selection bias), (3) blinding of participants and personnel (performance bias), (4) blinding of outcome assessment (detection bias), (5) incomplete outcome data (attrition bias), (6) selective reporting (reporting bias), and (7) other bias. For each study, each item was described as having either a low, an unclear, or a high risk of bias. In addition, the Egger's test was used to assess publication bias.

2.6. Data Synthesis and Statistical Analysis

The meta-analysis and the statistical analysis were conducted using the Review Manager software (RevMan 5.2; Cochrane Collaboration, Oxford, UK). A random-effects model was applied to determine the effect of endurance training prescription guided by HRV on physiological or performance variables. The effects of training on these outcomes between HRV-g and PT groups were expressed as mean differences (MD) or standard mean differences (SMD) and their 95% confidence intervals (CI). The inverse of variance model was used for the analysis. The heterogeneity between the studies was evaluated through the I^2 statistic and between-study variance, using the tau-square (τ^2) [25]. The I^2 values between 30 and 60% were considered as moderate levels of heterogeneity. Additionally, a value of τ^2 more than one suggests the presence of substantial statistical heterogeneity. The publication bias was evaluated through an asymmetry test as estimated from a funnel plot. A p value of less than 0.05 was considered to be statistically significant.

3. Results

3.1. General Characteristics of the Studies

A total of 849 studies were identified from the databases and no items were included from other sources. After removing duplicated articles from the different databases, 605 titles and abstracts were screened, 593 were excluded, and 12 were screened as full texts. Finally, statistical analysis was performed on 8 studies [9–12,22,26–28] (Figure 1).

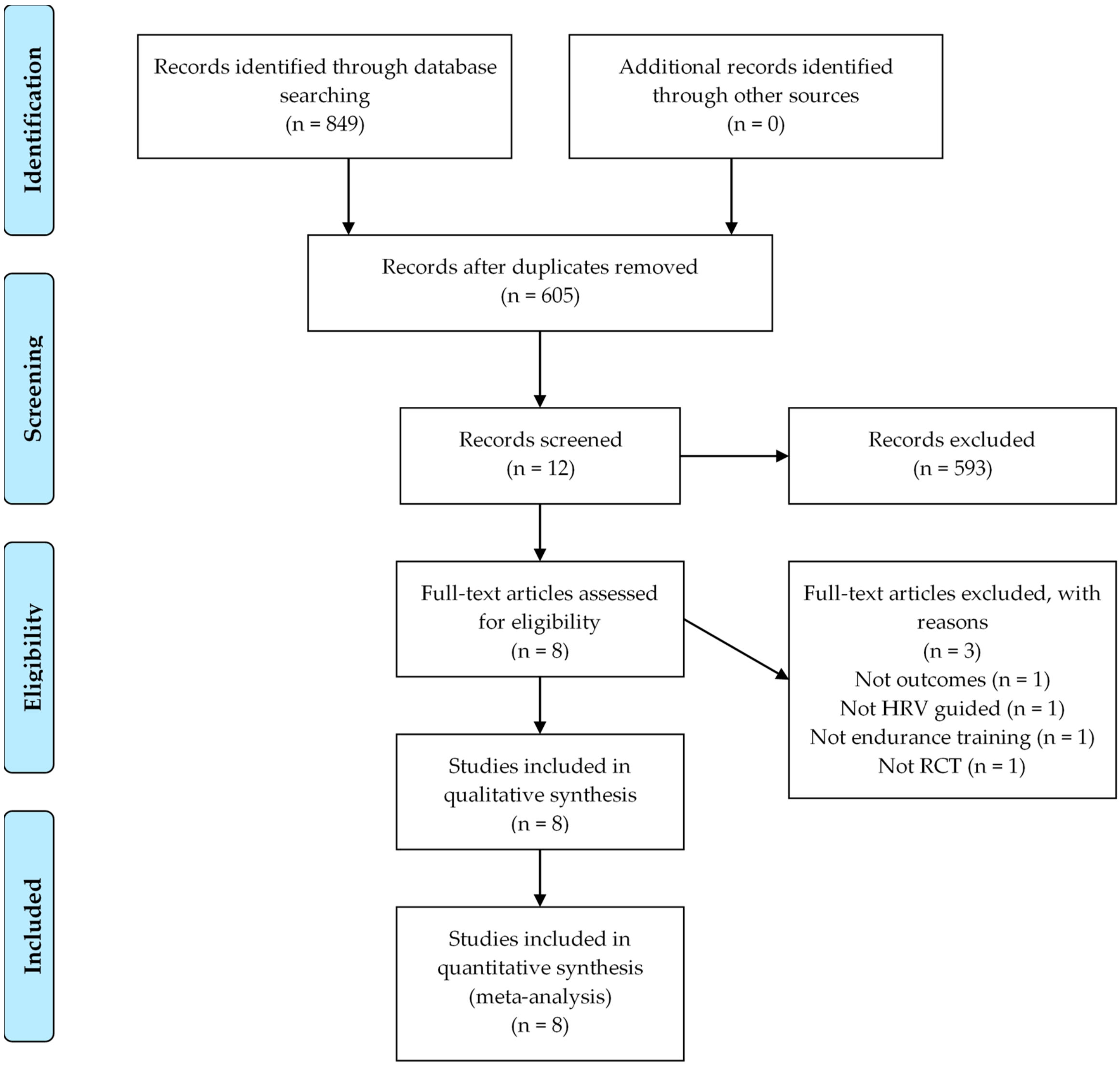

Figure 1. PRISMA flow diagram for studies included.

Table 1 provides an overview of the participants' characteristics of the studies included in the quantitative analysis. The total participants was 190 (males and females), mostly trained or active subjects. The mean age ranged from 20.5 ± 1.3 to 39.2 ± 5.3 years (men: 21.8 ± 0.3 to 39.2 ± 5.3; women: from 20.5 ± 1.3 to 35.0 ± 7.0). Training experience was reported in some articles and it ranged from 11.3 ± 3 to 15.0 ± 8 years. In addition, VO_2max values were between 35.0 ± 5.0 and 66.7 ± 5.9 mL/kg/min.

Table 1. Characteristics of the studies included in the meta-analysis.

Study, Year of Publication	Country of the Study	Groups	n	Type of Athletes	Sex	Age (Years)
Da Silva et al. [28]	Canada	HRV-g	15	Untrained	Females	25.8 ± 3.1
		PT	15			27.7 ± 3.6
Javaloyes et al. [11]	Spain	HRV-g	9	Trained cyclist	Males	39.2 ± 5.3
		PT (TP)	8			37.6 ± 7.1
Javaloyes et al. [10]	Spain	HRV-g	8	Trained cyclist	Not specified	28.1 ± 13.2
		PT (BP)	7			30.8 ± 10.5
Kiviniemi et al. [27]	Finland	HRV-g-I	14	Actives	50% Males	♂35 ± 4 ♀33 ± 4
		HRV-g-II	10		Females	35 ± 4.0
		PT	14		50% Males	♂37 ± 3 ♀34 ± 4
Kiviniemi et al. [9]	Finland	HRV-g	8	Recreational endurance runners	Males	31 ± 6.0
		PT (TP)	9			32 ± 5.0
Nuuttila et al. [12]	Finland	HRV-g	13	Endurance trained	Males	29.0 ± 4.0
		PT (BP)	11			31.0 ± 5.0
Schmitt et al. [22]	France	HRV-g +SH	9	Elite Nordic skiers	M = 7; W = 2	M = 22.9 ± 4.3; W = 20.5 ± 0.7
		PT+SH	9		M = 6; W = 3	M = 21.8 ± 1.3; W = 24.3 ± 4.9
Vesterinen et al. [26]	Finland	HRV-g	13	Recreational endurance runners *	M = 10; W = 10	M = 34 ± 8.0
		PT (TP)	18		M = 10; W = 10	W = 35 ± 7.0

M = men; W = women; SH = sleeping in hypoxia; BP: block periodization; TP: training periodization. * There were 9 dropouts, gender is not specified.

The intervention programs were eight weeks long [10–12,26–28], except for Kiviniemi et al. [9] (four weeks) and Schmitt et al. [22] (15 days); the frequency of training was between 3 to 6.3 sessions per week. Regarding the distribution of time by intensity zones, the studies that reported these variables ranged from 49 to 84% in zone 1, from 12 to 39% in zone 2, and from 3 to 13% in zone 3 [10–12,26]. The predominant method of analysis for HRV monitoring was time domain, followed by frequency domain. Remarkably, only one study used nonlinear measures (Table 2).

Table 2. Characteristics of the training intervention of studies included in the meta-analysis.

	Group	Type of HRV-g	Duration	Training Distribution (% Time)			Training Volume (Hours)	Training Volume (km)	Training Frequency	Training Load
				Z1	Z2	Z3				
Da Silva et al. [28]	HRV-g	Ref: 10-day average rMSSD. If rMSSD < mean rMSSD-1SD: MT; If not: HIT	8 weeks	-	-	-	-	-	3	-
	PT								3	
Javaloyes et al. [11]	HRV-g	SWC of rMSSD7D: If rMSSD7D outside the SWC: low intensity or rest	8 weeks	66	24	10	9.3 ± 2.8	-	-	-
	PT (TP)			64	27	9	8.8 ± 2.8			
Javaloyes et al. [10]	HRV-g	SWC of rMSSD7D: If rMSSD7D outside the SWC: low intensity or rest	8 weeks	49	39	12	11.1 ± 3.1	-	-	1033.3 ± 312.5 a.u.
	PT (BP)			54	33	13	11.4 ± 3.1			1028.8 ± 214.5 a.u.
Kiviniemi et al. [27]	HRV-g-I	Ref: 10-day average SD1. HRV-I: If SD1 ≥ SD1 ref:VG; SD1 ↓ SD SD1 ref:MD; If SD1 ↓ 2 consecutive days: rest; HRV-II = HRV-I but only VT if SD1 > SD1 ref.	8 weeks						♂5.8 ± 0.2 ♀5.8 ± 0.3	♂515 ± 49 ♀390 ± 42 TRIMPS × week
	HRV-g-II								5.0 ± 0.3	314 ± 46 TRIMPS × week
	PT								♂5.3 ± 0.6 ♀5.0 ± 0.8	♂492 ± 91 ♀343 ± 107 TRIMPS × week
Kiviniemi et al. [9]	HRV-g	Ref: 10-day average HF power. If HF > HF ref ↓ load; If HF ↓ 2 consecutive days: rest	4 weeks	-	-	-	-	36 ± 4	-	463 ± 74 TRIMPS × week
	PT (TP)							38 ± 6		529 ± 49 TRIMPS × week
Nuuttila et al. [12]	HRV-g	LIT if QRT was higher than ref	8 weeks	82 ± 8	15 ± 6	3 ± 3	5.7 ± 2.1	-	6.3 ± 1.4	-
	PT (BP)			84 ± 7	12 ± 5	4 ± 3	6.0 ± 1.9		6.1 ± 0.4	
Schmitt et al. [22]	HRV-g+SH	If HF ↑ or →: ↑ load; If HF ↓ ≥30%: ↓ load; If HF ↓ 2 consecutive days: rest	15 days	-	-	-	-	-	-	3365 ± 425 a.u.
	PT+SH									3481 ± 179 a.u.
Vesterinen et al. [26]	HRV-g	SWC of rMSSD7D: If rMSSD7D outside the SWC: low intensity or rest	8 weeks	83 ± 27	14 ± 25	3 ± 5	6.5 ± 2.8	42 ± 22	6.1 ± 1.8	
	PT (TP)			84 ± 12	13 ± 10	3 ± 4	6.3 ± 2.5	41 ± 20	5.6 ± 1.6	

a.u.: arbitrary units; HF: high frequencies; HIT: high-intensity training; MT: moderate training; Ref: reference; rMSSD: root of the mean squared differences of successive R-R-intervals; rMSSD7D: 7-day rolling average of vagal-mediated square; QRT: quick recovery test using rMSSD; SWC: smallest worthwhile change; TRIMPS: training impact; VT: vigorous training.

3.2. Heterogeneity and Risk of Bias Assessment

Risk of bias assessment is shown in Figure 2. The high risk of bias specified that none of the studies blinded the participants (performance bias) or the evaluators (detection bias). Visual inspection of the funnel plots showed an absence of asymmetry. Moreover, the Egger test demonstrated an absence of significant asymmetry in PT and HRV-g in VO_2max (PT: −0.369, $p = 0.712$; HRV-g: −0.752, $p = 0.452$), WMax (PT: −0.539, $p = 0.590$; HRV-g: 0.103, $p = 0.918$), Performance (PT: −0.273, $p = 0.785$; HRV-g: −0.07, $p = 0.944$), WVT1 (PT: 0.095, $p = 0.924$; HRV-g: 1.898, $p = 0.058$), and WVT2 (PT: 1.542, $p = 0.123$; HRV-g: 1.598, $p = 0.110$) (Figure 3).

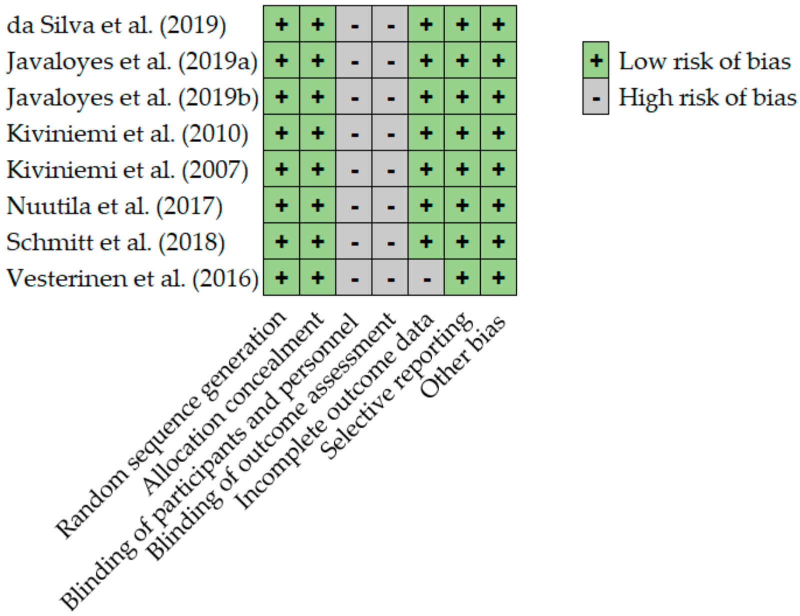

Figure 2. Risk of bias in the included randomized controlled trials.

3.3. Meta-Analyses

Regarding cardiorespiratory fitness, a significant improvement in VO_2max in participants who trained using HRV-g (MD = 2.84, 95% CI 1.41, 4.27; $p < 0.0001$) and PT (MD = 1.80, 95% CI 0.24, 3.36; $p = 0.02$) was found after training (Figure 4a). Thus, HRV-g and PT led to a significant increase in maximum aerobic power or speed (HRV-g: SMD = 0.66, 95% CI 0.33, 0.98; $p < 0.0001$; PT: SMD = 0.48, 95% CI 0.12, 0.83; $p = 0.009$) (Figure 5a) after training. Moreover, aerobic performance increased after HRV-g (SMD = 0.71, 95% CI 0.16, 1.25; $p = 0.01$) and PT programs (SMD = 0.47, 95% CI 0.07, 0.86; $p = 0.02$) (Figure 6a); however, no significant differences in training were observed for VO_2max (MD = 0.96, 95% CI −1.11, 3.03; $p = 0.36$), maximum aerobic power or speed (SMD=0.06, 95% CI −0.26, 0.38; $p = 0.72$), or aerobic performance (SMD = 0.14, 95% CI −0.22, 0.51; $p = 0.45$) (Figure 4b, Figure 5b, and Figure 6b, respectively).

Concerning power or speed at VT1 and VT2, performance at VT1 increased significantly after HRV-g programs (SMD = 0.62, 95% CI 0.04, 1.20; $p = 0.04$) but not after PT (SMD = 0.17, 95% CI −0.25, 0.59; $p = 0.42$) (Figure 7a). In addition, performance at VT2 improved significantly after HRV-g (SMD = 0.81, 95% CI 0.41, 1.22; $p < 0.0001$) and PT (SMD = 0.53, 95% CI 0.13, 0.93; $p = 0.009$) training programs (Figure 8a). Nevertheless, no significant differences were observed between both training methods in performance at VT1 (SMD = 0.27, 95% CI −0.16, 0.70; $p = 0.22$) and VT2 (SMD = 0.18, 95% CI −0.20, 0.57; $p = 0.35$) (Figures 7b and 8b, respectively).

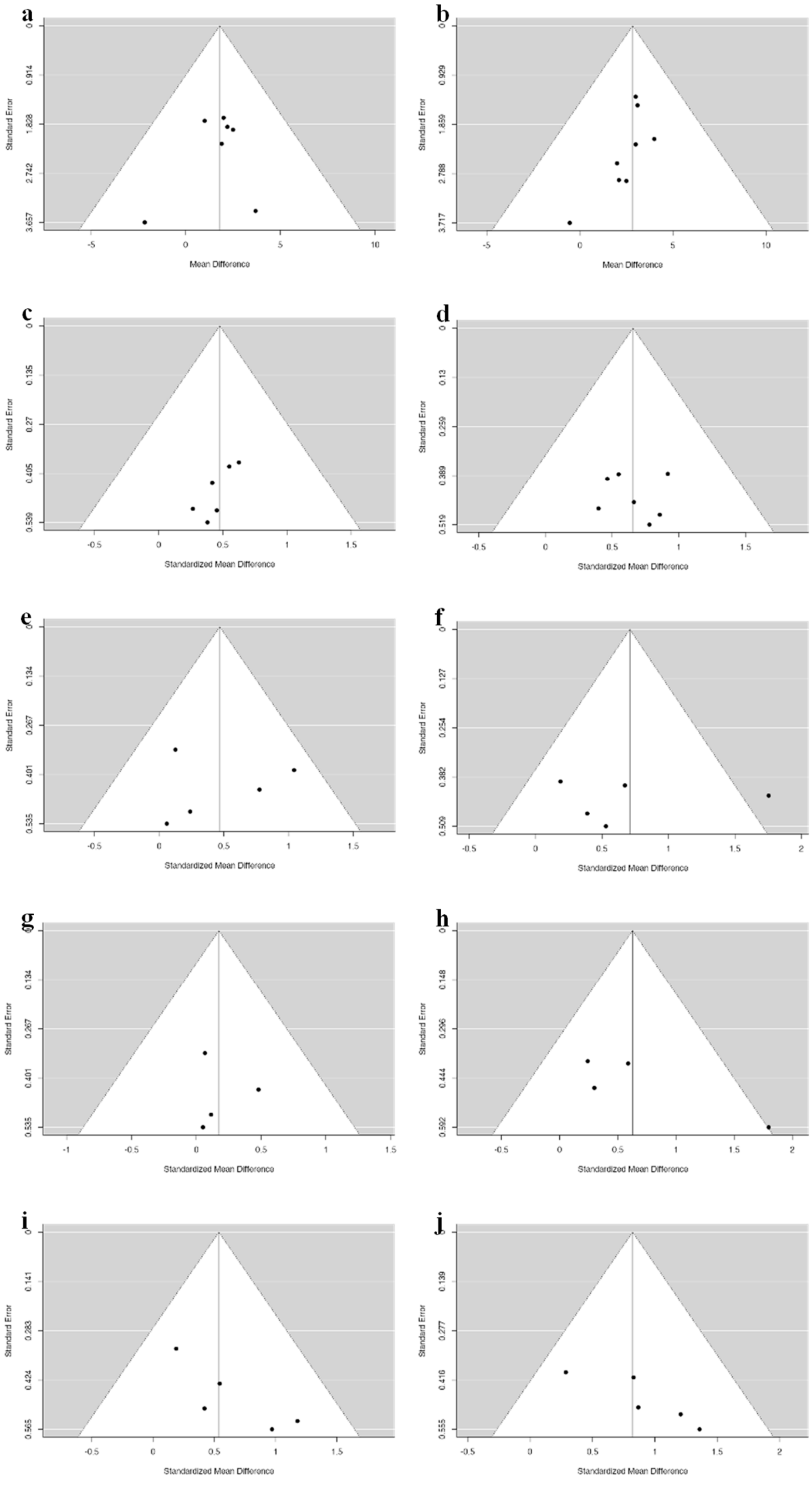

Figure 3. Test for funnel plot asymmetry. (**a**) VO_2max PT; (**b**) VO_2max HRV-g; (**c**) WMax PT; (**d**) WMax HRV-g; (**e**) Performance PT; (**f**) Performance HRV-g; (**g**) WVT1 PT; (**h**) WVT1 HRV-g; (**i**) WVT2 PT; (**j**) WVT2 HRV-g.

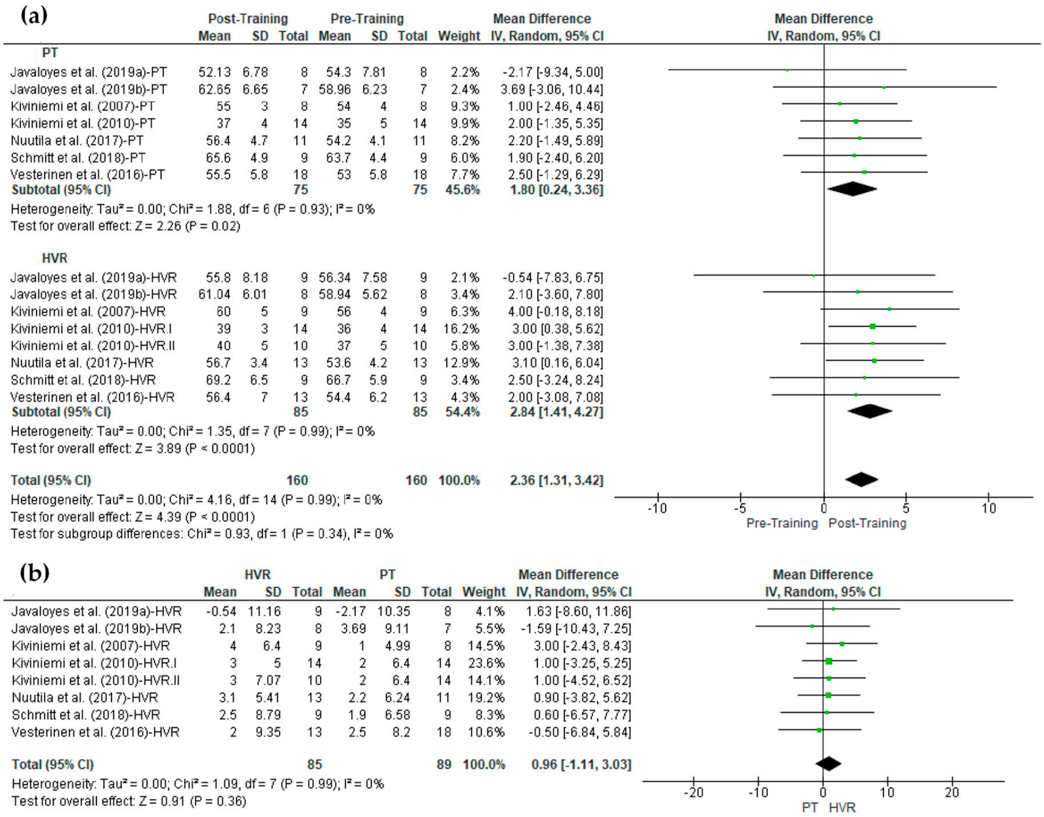

Figure 4. (**a**) Effects of endurance training on VO_2max pre-training vs. post-training; (**b**) effects of endurance training on VO_2max HRV-g vs. PT.

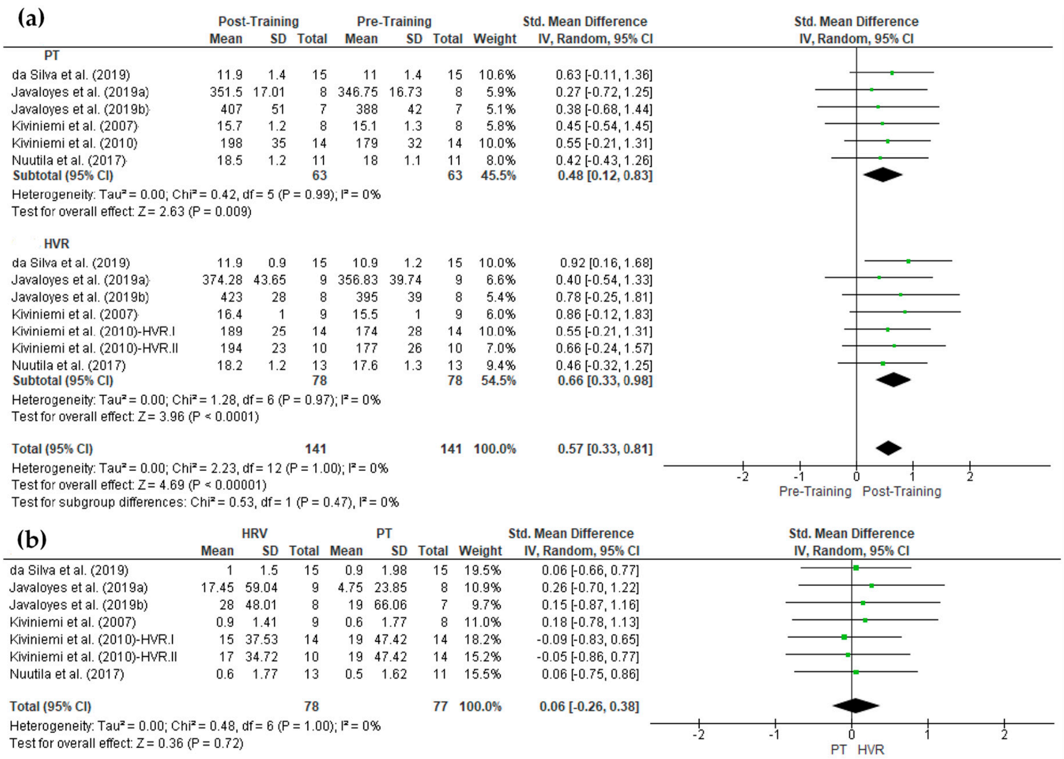

Figure 5. (**a**) Effects of endurance training on WMax pre-training vs. post-training; (**b**) effects of endurance training on WMax HRV-g vs. PT.

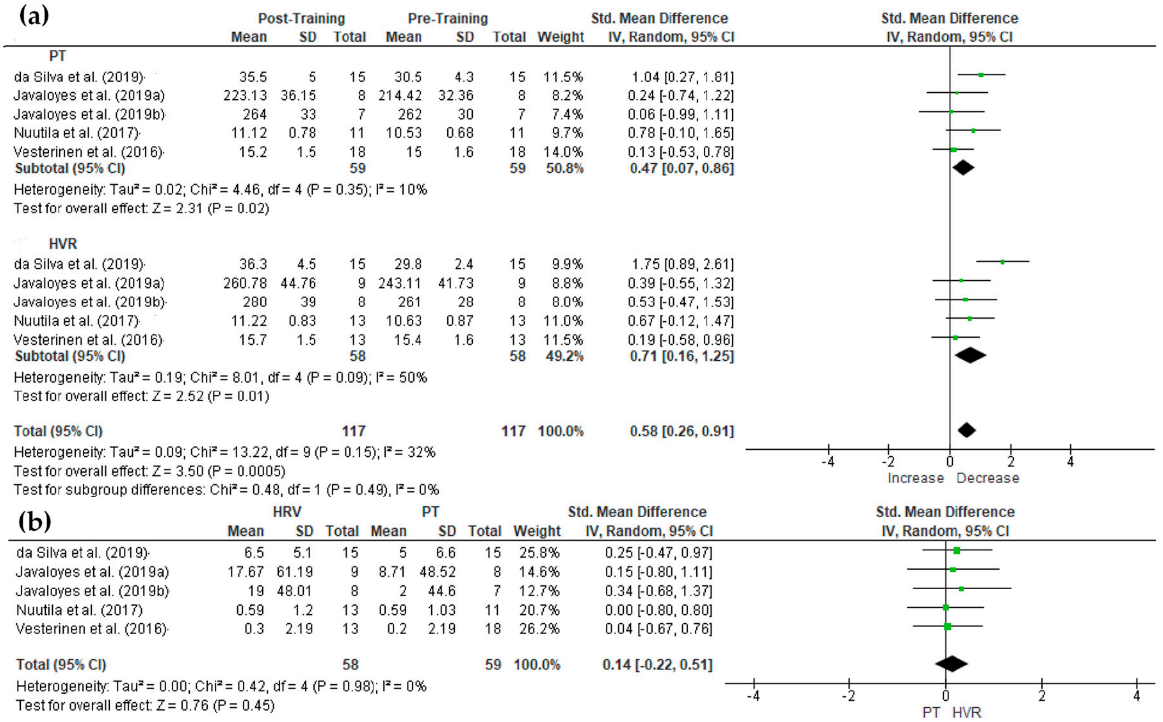

Figure 6. (**a**) Effects of endurance training on aerobic performance pre-training vs. post-training; (**b**) effects of endurance training on aerobic performance HRV-g vs. PT.

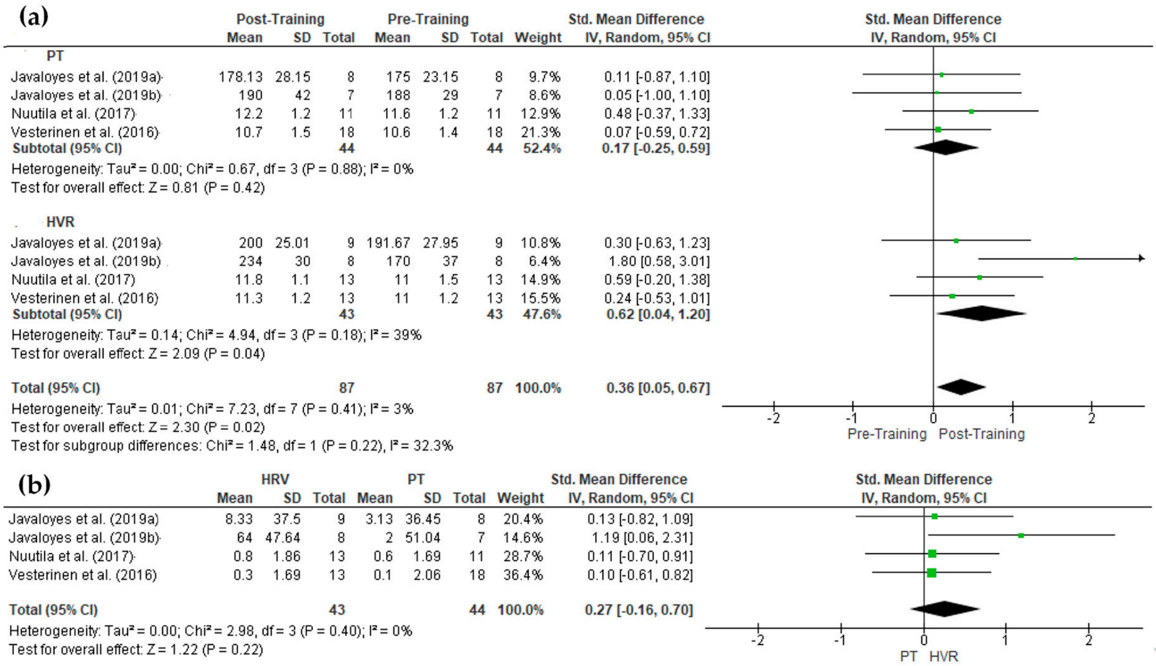

Figure 7. (**a**) Effects of endurance training on WVT1 pre-training vs. post-training; (**b**) effects of endurance training on WVT1 HRV-g vs. PT.

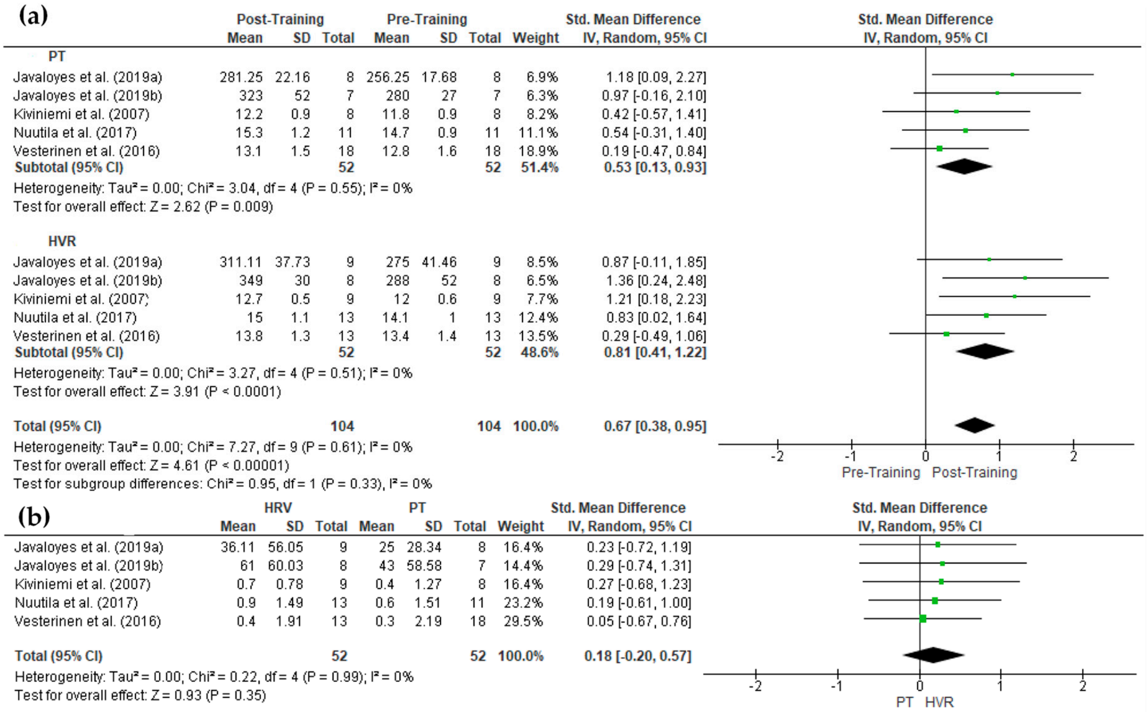

Figure 8. (**a**) Effects of endurance training on WVT2 pre-training vs. post-training; (**b**) effects of endurance training on WVT2 HRV-g vs. PT.

4. Discussion

This systematic review with meta-analysis aimed to determine if endurance HRV-g maximizes aerobic performance and/or aerobic physiological adaptation, compared to a PT program. The major findings indicate that HRV-g significantly improves VO_2max, maximum aerobic power or speed, performance at VT1 and VT2, and aerobic performance in running or cycling field test; however, these adaptations were not significantly greater than PT programs. Although these findings do not appear to support the use of HRV-g over PT programs, this study also highlights notable differences in the methodologies used between studies, which may impact the potential efficacy of HRV-g. Despite that both forms of training promote physiological adaptations and improve performance, most parameters related to aerobic performance and aerobic physiological indexes were improved further following HRV-based training.

One of the key physiological variables that determines endurance performance is VO_2max [29], showing that high-level endurance athletes can achieve a large VO_2max [10]. Therefore, a common aim of endurance training programs is to improve VO_2max. This way, it was found how both training programs significantly increase cardiorespiratory fitness (VO_2max) (HRV-g: MD = 2.84, $p < 0.0001$; ~5%) and PT (MD = 1.80, $p = 0.02$; ~3%). It could be assumed that both types of training models led to improvements in VO_2max, because there were no significant differences between PT and HRV-g ($p = 0.36$); but some factors could modulate the results obtained. Hence, the intensity training distribution and the fitness level of participants could play a key role in the VO_2max improvements. Although VO_2max has been improved in untrained [30], recreational [9,26], and trained athletes [10,22], the trainability and the increase of this parameter are limited in trained athletes [11]; specifically, only one study did not find an increase in VO_2max [11] and, remarkably, it used a trained cyclist sample. In addition, the intensity training distribution used by Javaloyes et al. [11] was a pyramidal distribution (~60% VT1, 30% VT2, 10% VO_2max).

In another study [26] with low fitness level (recreational athletes), participants spent much more time in zone 1 (below VT1) (~80% of total training program) and less time in zone 3 (VO_2max or higher) (~3% of total training program). While only one study found an improvement in VO_2max with trained athletes [10], that study applied an intensity distribution with a pyramidal distribution (~52% VT1, 35% VT2, 13% VO_2max). Thus, it seems that high intensity training (Z3) has to be higher in trained athletes than in untrained or recreational athletes; it is a fact that new periodization models are highlighted and defined as a crucial factor to increase athletes' performance [3,4]. For this reason, the use of HRV-g training could optimize the improvement in VO_2max (as the trend to higher increases in this training condition have shown; $p = 0.36$), because if the high-intensity training is individualized and it is performed when the athlete is in optimal autonomic homeostasis, it could lead to an improved adaptive response to training [11].

Regarding aerobic performance measured by field test and maximum aerobic power or speed, both training programs led to a similar increase. Nevertheless, one of the characteristics of the HRV-g is the individualization of the training, making this strategy less variable, with fewer nonresponders than PT programs. For example, Vesterinen et al. [26] found that the HRV-g had lower dispersion of results in a 3000 m test (−1 to +6%) than the PT group (−4 to +8%). Similarly, Javaloyes et al. [10,11] reported less variation in their two studies of 40 km time trial following HRV-based training, compared to PT program. Therefore, participants have a greater probability to increase their aerobic performance and reduce the risk of injury and overtraining by following a day-to-day training based on HRV-g. Additionally, in some of the studies included in the present review, the number of high-intensity training sessions of the participants in HRV-g programs varied according to the individual's recovery response of HRV. For example, the number of high-intensity training (HIT) sessions ranged from 11 to 21 in PT and from 5 to 24 sessions in the HRV-g program of Vesterinen et al. [26]. Although previous research reported a nonsignificant correlation between the training adaptation and the number of HIT sessions [26], this finding suggests that the use of HRV-g to manage the inclusion of a HIT session in the program could increase the effectiveness of the training and could diminish the variation in the adaptation.

Regarding performance (power or speed) at VT, results showed that WVT1 increased in the HRV-g but not in the PT; hence, performance at VT2 improved significantly after HRV-g and PT programs. Furthermore, the meta-analysis showed a trend towards higher WVT1 ($p = 0.22$; Δ 13%) and WVT2 ($p = 0.35$; Δ 10%) improvements after HRV-g than PT (Δ 2.2%; Δ 7%, respectively). These statistical trends that showed greater effects for HRV-g than PT were in line with the results reported by the studies included in the present review [11,12,31,32]. Some possible reasons to explain these findings could be related to the aforementioned training intensity distribution developed by each training group, which could affect the results.

In some of the studies included, HRV-g led to a lower proportion of moderate and greater intensity training (as did HIT), in comparison to PT [11]; while in another study, higher moderate intensity training was performed by HRV-g, compared to the PT [10]. Besides, as it was explained above, the individualization and adjustment of the training load by HRV-g reduced the number of nonresponders to training, increasing the number of athletes that improved their VT1 and VT2. Therefore, HRV, as a monitoring tool, would allow taking the principle of individualization of the load a step further.

Notably, the main findings of the present meta-analysis reported that the aerobic performance and aerobic physiological adaptations after HRV-g are not significantly greater than those observed after the PT, and only some trends were found. It could be considered that the HRV-g program, in comparison to the PT, may have a small impact, or some confounding variables may adjust its magnitude. This way, the duration of the training program is one variable to emphasize. It seems that the length needed to achieve meaningful increases in performance using the HRV-g training program could be shorter than the PT, due to the individualized training and the greater training quality, but the duration of the published studies (all of them with less than eight weeks) seems to be very short to obtain a significant difference. Therefore, longitudinal randomized controlled trials, using programs with more duration, are needed to obtain more conclusive results.

The HRV measurement protocol applied in each study included in the present review is another factor to highlight. Different variables to assess HRV were found: (a) time domain variables (root mean square of successive differences of RR intervals—rMSSD) [10,11,26,28]; (b) frequency domain variables (high frequency—HF, low frequency—LF) [9,22]; and (c) nonlinear variables (standard deviation of the intervals to the transverse diameter (short axis) of the ellipse—SD1) [27]. Therefore, frequency domain variables identify some types of fatigue [33], whereas rMSSD has been suggested as a global fatigue measurement [34]. In addition, the HRV assessment ranged from ultrashort records of 90 s [10,11] to 15 min [22], depending on the HRV variables analyzed. Thus, recording time shorter than five minutes was applied if the study used rMMSD as an indicator, while longer records were reported if the study used a frequency-based or a nonlinear variable [35,36]. Moreover, frequency domain variables were more influenced by breathing patterns than time-domain analysis [37]; there were divergencies in the participants measurement postures that included sitting [28], supine lying [10–12,26], standing, or a combination of some of them (lying + standing [22]; sitting + standing [9,27]). It seems that the supine position measures showed lower daily coefficient of variation than standing measures [38], but a standing position was recommended previously [2]. Therefore, the posture differences could also affect the HRV results obtained in the studies and, consequently, to the present meta-analysis.

There are several limitations in this meta-analysis related to the available randomized controlled trials (RCTs) and the divergent methodologies employed, including (i) the small number of studies; (ii) the different intensity training distribution, training programs, and modalities applied in the studies; (iii) the lack of systematic information about the training load performed in most of the study; (iv) the different methodologies applied to assess HRV; (v) the small number of studies using trained athletes to obtain a more specific picture about the effect of this type of training in this population; and (vi) the lack of longer studies to analyze the chronic effect of HRV-g (the duration of the studies was <8 weeks). Additionally, readers should take into consideration that the sport modality (running, cycling, or skiing) can influence the aerobic enhancement and this fact could modify the results obtained in the present review. In addition, it was found that the available evidence has high risk of bias primarily due to the low quality of available RCTs. Therefore, to develop further studies with a better-quality design, and before a more comprehensive training trend, trained athletes' samples are needed in order to analyze the effect of longer interventions (>8 weeks).

According to the results obtained in the present study, while no significant benefits were observed for HRV-g compared with PT, small effects were evident in the larger increases in aerobic performance and physiological adaptations following HRV-g. This suggests that some individuals may benefit more from HRV-g compared with PT, which would be important in well-trained athletic cohorts, where small changes in physical attributes are difficult to achieve and the individualization of the training plays a key role. Further research is required to investigate these responses in more detail, but it appears that the efficacy of HRV-g strategies have been affected by large variations in the structure of the training program (intensity distribution, duration, volume, etc.) performed and the methodology used to assess HRV. Hence, practitioners and coaches must use HRV with caution, due to the factors that affect its measurement. In terms of practical applications, HRV assessment should be carried out daily in the morning, standing or lying in a supine position, in a standardized condition (e.g., with an empty urinary bladder and spontaneous breathing) and using a validated sensor to assess HRV. In addition, it seems that the rMSSD should be the indicator of HRV, since it produces fewer disturbances in the athlete's daily routine and has several advantages, such as its quick and easy accessibility, and the lower sensitivity for the breathing pattern in comparison with spectral variables.

5. Conclusions

The current systematic review with meta-analysis concludes that HRV-g produces significant improvements in endurance performance and aerobic physiological adaptations. However, these adaptations are not significantly higher than in PT. Nevertheless, the findings from this meta-analysis are likely affected by the divergent methodologies employed in studies, specifically, in the HRV assessment, the training program, and the participant's characteristics. Therefore, the results of this meta-analysis reinforce the importance of additional detailed studies to analyze the effects of this novel training method.

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