



Review

# Effects of Exercise on the Resting Heart Rate: A Systematic Review and Meta-Analysis of Interventional Studies

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**Abstract:** Resting heart rate (RHR) is positively related with mortality. Regular exercise causes a reduction in RHR. The aim of the systematic review was to assess whether regular exercise or sports have an impact on the RHR in healthy subjects by taking different types of sports into account. A systematic literature research was conducted in six databases for the identification of controlled trials dealing with the effects of exercise or sports on the RHR in healthy subjects was performed. The studies were summarized by meta-analyses. The literature search analyzed 191 studies presenting 215 samples fitting the eligibility criteria. 121 trials examined the effects of endurance training, 43 strength training, 15 combined endurance and strength training, 5 additional school sport programs. 21 yoga, 5 tai chi, 3 qigong, and 2 unspecified types of sports. All types of sports decreased the RHR. However, only endurance training and yoga significantly decreased the RHR in both sexes. The exercise-induced decreases of RHR were positively related with the pre-interventional RHR and negatively with the average age of the participants. From this, we can conclude that exercise—especially endurance training and yoga—decreases RHR. This effect may contribute to a reduction in all-cause mortality due to regular exercise or sports.

**Keywords:** sports; physical activity; trail; cardiovascular health; PRISMA

## 1. Introduction

A major goal in healthcare is to increase life expectancy and eminently improve healthy and happy aging by compressing morbidity into a shorter period in a later stage of the lifespan [1]. Life expectancy has increased rapidly during the last century and disability-adjusted life expectancy has been extending as well. Regular exercise and physical activity throughout a lifespan can improve life expectancy [2,3] and disability-adjusted life expectancy, as shown in many studies [4,5].

One possible mechanism explaining increases in life expectancy through exercise and physical activity might be the mediating effect of resting heart rate (RHR): possibly, regular exercise and/or physical activity cause a reduction in RHR [6–8], and RHR seems to be inversely related with life expectancy [9] and positively related with cardiovascular and all-cause mortality [10]. The relationship between RHR and life expectancy has been studied in mammals by Levine [11], who found a semi-logarithmic relationship in mammals and concluded that the total number of heartbeats per lifetime is remarkably constant. Furthermore, he calculated that the inverse relationship of RHR and life expectancy in mammals could be expressed mathematically with on average  $7.3 \pm 5.6 \times 10^8$  heart beats per lifetime. Only humans fall out of the alignment and have reached a life expectancy of about

80 years [11]. This might be due to advances in science, medicine, and sociology. However, in humans, RHR also seems to be an indicator of mortality, which has been analyzed in some studies [9,12,13].

Thus, the examination of effects regular exercise and physical activity on RHR is of particular interest, and has been studied in previous systematic reviews: Cramer, Lauche, Haller, Steckhan, Michalsen, and Dobos [8] found a significant reduction in heart rate through yoga interventions in their systematic review of randomized controlled trials on effects of yoga on diverse cardiovascular risk factors. Their meta-analysis revealed a reduction in heart rate of 6.59 bpm in studies that compared yoga with no-treatment usual care, or any active treatment in healthy participants. In another meta-analysis encompassing 13 studies, Huang, Shi, Davis-Brezette, and Osness [6] concluded that endurance training causes RHR reductions of 8.4% in older individuals which were even higher in controlled clinical trials with a training length of more than 30 weeks. Furthermore, a decrease in heart rate at quiet condition was found after tai chi exercise in healthy adults as shown in the meta-analysis of Zheng, Li, Huang, Liu, Tao and Chen [7]. However, to the best of our knowledge, a comprehensive review and meta-analysis of the effects of regular physical exercise on the RHR in various sports and exercise and a comparison of the effects of different exercise and sports is still missing.

Thus, the aim of this systematic literature review was to calculate the effects of any regular sports and/or exercise on RHR of healthy subjects through meta-analysis by considering different types of sports and exercise and by considering differences between men and women.

## 2. Materials and Methods

The review was performed adopting the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [14].

### 2.1. Search Strategy

Six electronic databases were searched on 13 May 2018: Google Scholar (the first 500 citations ordered by relevance), LIVIVO (the search engine of the German Central Library of Medicine), PubMed, Scopus, Springer Link, and Web of Science. If available, the search term has been applied in the search field “all fields”, and the “in humans” filter has been used (if available). The search term applied was: “(resting heart rate or resting pulse rate or resting heart frequency or resting pulse frequency) and (sport or training or exercise or yoga or tai chi or qigong) and control\*”.

### 2.2. Study Selection

Only three relevant journal articles presented titles including the search term “resting heart rate” (or synonyms of this term). Moreover, in many of the relevant articles, RHR was presented as a less important outcome instead of the primary outcome and has not been mentioned in the abstract or even as a keyword. Nevertheless, to ensure identification of relevant primary studies through the study selection process, both the title and the abstract—and additionally, if available, the keywords—were considered in the first step of the screening process. All relevant references that could not be conclusively excluded were kept for further screening.

Next, the abstracts of all articles (if available) were checked regarding the characteristics of the participants, study design, and the intervention program. If the abstract indicated that the study potentially fulfilled the eligibility criteria or did not provide sufficient information for decision-making, the full text of the article was screened in a third step. Afterwards, articles presenting (nearly) the same content regarding the participants and results have been judged as double publications.

Finally, the references cited in the former systematic reviews and meta-analysis on the topic at hand [6–8,15] as well as cited by two own meta-analyses focussing on the effects of sports interventions on the arterial blood pressure and/or lipids [16,17] were screened and considered for inclusion (additional records identified through these sources:  $n = 130$ ; cf. Figure 1). The screening process has been conducted by one reviewer. If necessary, a second reviewer was consulted for deciding on eligibility of the reference.

### 2.3. Eligibility Criteria

The following eligibility criteria have been defined a priori to the study selection process. Only primary studies that fulfilled all of the eligibility criteria were included in the present systematic review.

#### 2.3.1. Types of Studies

Only controlled trials (randomized or non-randomized) were considered, and the study had to be published as a peer-reviewed journal article written in English, German, French, Spanish, or Portuguese language. Additionally, if an English language abstract and RHR data presented in English in the full text article were available, the translation of the article was considered. Thus, one Japanese article [18] has been translated and could be included in the present review.

#### 2.3.2. Types of Participants

Studies with individuals being pregnant or having diseases like diabetes mellitus, metabolic syndrome, or a limited physical mobility due to diseases (e.g., cardiac and musculoskeletal disorders) were excluded whereas studies with participants that were overweight, obese, or had arterial hypertension or dyslipidaemia were included. If the individuals in the study were regularly exercising at the beginning of the study, the study was not excluded due to this fact.

#### 2.3.3. Types of Interventions

The intervention should have comprised any type of sports and/or exercise including aerobic and anaerobic (e.g., high intensity interval training), endurance (including ball and team sports) or strength training, school sports, yoga, qigong, or tai chi.

#### 2.3.4. Types of Outcome Measures

For inclusion in the meta-analyses, the trials had to report the RHR before and after the intervention (pre/post-measurements), presenting the mean values plus scale parameters (standard deviation or standard error or the 95% confidence interval).

### 2.4. Data Management and Data Extraction

After checking the potentially relevant primary studies according to the eligibility criteria mentioned above, the articles were additionally checked for double publication. The following data was extracted from each primary study included in this systematic review: author(s); year of publication; number, gender, and age of the participants; type of sports/exercise; duration of the intervention; frequency of exercise sessions; method of RHR measurement; randomisation; blinding; RHR at the beginning and end of the interventional period in the intervention and control groups, resp.

In case of studies with more than two arms (one control group and more than one exercise group), those comparisons with the higher exercise intensity, duration or frequency, continuous (versus interval) and concentric (versus eccentric) strength training, land-based (versus aquatic) training, and jogging/running (versus soccer) were considered for the meta-analyses. Additionally, if both pre and post-menstrual or pre and post-menopausal RHR results were presented, the first ones were included in the meta-analyses.

### 2.5. Risk of Bias Assessment

The methodological quality of the studies included was evaluated by one reviewer by considering three aspects: (1) the mode of randomization of the study participants to the intervention and control groups, (2) possible blinding of the examiners, and (3) the mode of assessing RHR have been registered (Table 1).

## 2.6. Statistical Analyses

### 2.6.1. Statistical Methods for the Meta-Analyses

The meta-analysis was carried out using the meta and metafor packages in the freely-available statistical R software, version 3.4.4 [19]. Most studies reported mean and standard deviation or standard error of RHR before and after the intervention separately for intervention and control group. When confidence intervals for the mean or the mean difference were reported, we calculated the relevant standard errors. We chose the standardized mean difference (SMD) as the primary effect size. For both groups we firstly calculated the difference between the mean RHR after and before the intervention, and then calculated the difference of these differences between intervention and control group divided by an appropriate standard deviation—either the common standard deviation of the two groups or a suitable combination of both individual standard deviations. Consequently, negative values are in favor of the intervention group for reducing the mean RHR. The random-effects meta-analysis was used for combining the study-specific results. We report the classical meta-analysis confidence interval as well as the modified confidence interval proposed by Hartung and Knapp [20]. Two-sided  $p$ -values  $< 0.05$  are considered as significant. We judge the heterogeneity with the homogeneity test statistics denoted by Cochran's  $Q$  and Higgins–Thompson  $I^2$ , a measure which judges the impact of heterogeneity.

Additionally, we calculated the meta-analytical mean values of the RHR before and after intervention, separately for both groups using random-effects meta-analysis approach. Finally, relative changes defined as (mean after intervention minus mean before intervention)/(mean before intervention) were combined in the random-effects meta-analysis model for both groups.

### 2.6.2. Additional Statistical Methods

The Bravais–Pearson correlation coefficients  $r$  between the age of the participants, number, and frequency of the sportive interventions, and the pre-interventional RHR of the training group have been calculated on the one hand and the extent of the change of the RHR due to physical activity on the other. Two-sided  $p$ -values of  $< 0.05$  were considered as significant.

## 3. Results

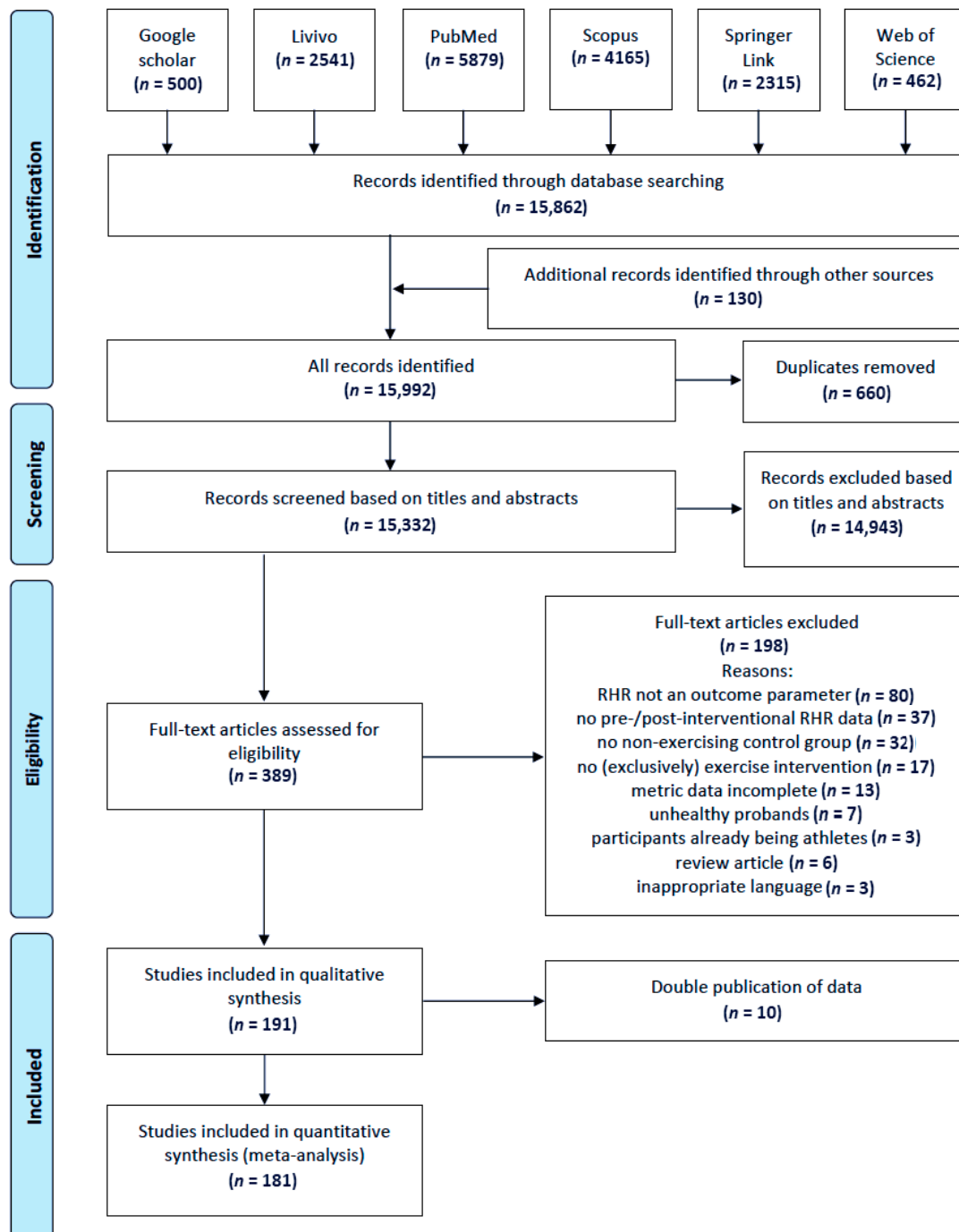
### 3.1. Studies, Participants, and Exercise

Initially based on database queries and through screening of additional sources 15,992 articles have been identified and included in the screening process. After exclusion of 660 duplicates, 15,332 articles have been screened. Finally, the literature search yielded 191 studies meeting the eligibility criteria. Ten of these articles presented the same data as presented in another article and therefore were excluded. Thus, finally the data of 181 articles encompassing 215 samples were included in the meta-analytical synthesis. The selection process of the articles included in this systematic review is presented in Figure 1 and detailed descriptions of the 215 samples included in the meta-analysis are presented in Table 1.

All studies included have been published between 1971 and 2018. Altogether, 12,952 individuals were incorporated in the intervention ( $n_I = 6763$ ) and control groups ( $n_C = 6189$ ). The sample sizes of these groups ranged from 5 to 1456 within the studies with a median sample size of 17 participants (interquartile range, 12 to 26.5 participants). Of the 215 comparisons 92 included both female and male participants, whereas 65 only included females and 58 only males. Wiley et al. [21] did not report the gender of their participants (denoted as 'human subjects' only). This study was considered in the group of studies including both sexes.

Of the 191 studies presenting 215 samples, 121 looked into the effects of endurance training, 43 strength training, 15 combined endurance and strength training, and 5 additional school sports. The interventions included the following sports types: 21 yoga, 5 tai chi, 3 qigong, and 2 unspecified

sport types. The exercise interventions lasted between 2 weeks and 2 years (median value, 12 weeks, interquartile range, 8 to 16.75 weeks). The participants exercised 0.8 to 7 times per week (median value, 3 times, interquartile range, 3 to 3.6 times per week). Altogether, they completed between 7 and 312 exercise sessions (median value, 36 sessions, interquartile range, 24 to 54 sessions) during their participation in the intervention studies.



**Figure 1.** Flow chart of the screening and selection process for the identification of studies for inclusion in the present systematic review according to PRISMA (Moher et al. [14]).

**Table 1.** Descriptive characteristics of the samples included in the meta-analyses.

Author(s)	Sex	N (IG)	Age * (yr)	Exercise in the IG			Measurement of RHR	Randomization	Blinding	IG		CG		Rel. RHR Change IG/CG (%)
				Duration (/wk)	Frequency (/wk)	Overall Number of Units				Baseline RHR (/min)	Final RHR (/min)	Baseline RHR (/min)	Final RHR (/min)	
<b>Endurance training</b>														
Abadi et al. [22]	♀+ ♂	25	22.6	12	3	36	EKG	random	n.p.	73.96	72.44	73.88	73.72	−1.8
Akinpelu [23]	♂	10	55.7	10	4	40	n.p.	n.p.	n.p.	73	72.8	81.8	78.6	3.8
Akwa et al. [24]	♀	8	61.25	8	3	24	ASP	random	n.p.	76.5	72	83	78.5	−0.5
Andersen et al. [25]	♂	13	46.7	17	2	34	ASP	random	n.p.	79	67	72	73	−16.4
Anek & Bunyaratavej [26]	♀	26	50.67	4	3	12	n.p.	random	n.p.	79.26	75.85	79.33	79.53	−4.5
Anek et al. [27]	♀	15	39.86	16	3	48	ASP	random	n.p.	78.26	76.8	79.13	79.56	−2.4
Apekey et al. [28]	♀+ ♂	12	18–38	8	2	16	EKG	random	n.p.	85	78	83	76	0.2
Aweto et al. [29]	♀+ ♂	23	44.1	4	2	8	auscultation	random	n.p.	77.2	70.9	75.4	73.1	−5.3
Baker et al. [30,31]	♀+ ♂	39	47.3	12	3	36	ASP	IVRS	n.p.	68.6	69.5	67.9	68.9	−0.2
Beck et al. [32,33]	♀+ ♂	9	20.1	8	3	24	n.p.	random	n.p.	64	56	60	58	−9.5
Blum et al. [34]	♀	21	32.8	12	4	48	n.p.	not random	n.p.	80.1	71.4	69.3	72.4	−14.7
Blumenthal et al. [35,36]	♀+ ♂	33	67	17	3	51	EKG	random	n.p.	74	72	70	69	−1.3
Bocalini et al. [37]	♀	25	64	12	5	60	EKG	random	n.p.	90	85	90	89	−4.5
Braith et al. [38]	♀+ ♂	14	65	26	3	78	n.p.	random	n.p.	69	63	65	66	−10.1
Boutcher & Stein [39]	♂	25	46.2	8	3	24	EKG	random	n.p.	71.3	67.9	73.1	77.3	−10.0
Broman et al. [40]	♀	15	69	8	2	16	EKG	random	n.p.	78.7	72.2	69.4	71.1	−10.5
Carroll et al. [41]	♀+ ♂	29	68.4	26	3	78	EKG	random	n.p.	63.4	61.8	61	60.3	−1.4
Ciolac et al. [42]	♀	11	24.4	16	3	48	n.p.	random	n.p.	80	77	79	79	−3.7
Connolly et al. [43]	♀	13	39	16	2	32	ASP	random	n.p.	77	73	77	74	−1.4
Connolly et al. [44]	♀	15	44	12	3	36	n.p.	random	n.p.	70	65	68	69	−8.5
Cononie et al. [45]	♀+ ♂	11	72	8	3	24	EKG	n.p.	n.p.	66	61	68	67	−6.2
Cononie et al. [45]	♀+ ♂	6	72	8	3	24	EKG	n.p.	n.p.	66	62	66	65	−4.6
Davies & Daggett [46]	♀	8	29.2	8	3	24	n.p.	n.p.	n.p.	64.9	64.8	79.3	76.4	3.6
Delecluse et al. [47]	♂	20	64.5	20	2.5	50	EKG	random	n.p.	78.2	68.9	73.3	73.9	−12.6
Dowdy et al. [48]	♀	18	31.5	10	3	30	n.p.	non random	n.p.	67.1	61.7	71.8	73.3	−9.9
Duey et al. [49]	♀	16	23.6	6	3	18	EKG	n.p.	n.p.	80.7	77.1	78	78	−4.5
Duncan et al. [50]	♂	44	30.4	16	3	48	EKG	random	n.p.	73.7	65.2	74.3	73.8	−10.9
Ewart et al. [51]	♀	44	Adol.	18	n.p.	n. c.	EKG	random	n.p.	79.7	79.2	83.8	83.8	−0.6
Finucane et al. [52]	♀+ ♂	48	71.4	12	3	36	EKG	random	n.p.	66	62.1	65.2	64.4	−4.7
Geenen et al. [53]	♀+ ♂	38	6.8	8	4	32	EKG	random	n.p.	84	89	85	84	7.2
Goldberg et al. [54]	♂	15	20.5	4	3	12	EKG	random	n.p.	69.4	61	63.6	59.2	−5.6
Gormley et al. [55]	♀+ ♂	13	21	6	3	18	EKG	random	n.p.	64	65	67	67	1.6
Gossard et al. [56]	♂	23	49	12	5	60	EKG	random	n.p.	68	66	74	74	−2.9

Table 1. Cont.

Author(s)	Sex	N (IG)	Age * (yr)	Exercise in the IG			Measurement of RHR	Randomization	Blinding	IG		CG		Rel. RHR Change IG/CG (%)
				Duration (/wk)	Frequency (/wk)	Overall Number of Units				Baseline RHR (/min)	Final RHR (/min)	Baseline RHR (/min)	Final RHR (/min)	
Gutin et al. [57]	♀+♂	17	9.6	17	5	85	EKG	random	n.p.	81	77.5	85	86.8	-6.3
Hagberg et al. [58]	♀+♂	11	64	37	2.5	92.5	n.p.	random	n.p.	73	65	75	76	-12.1
Halbert et al. [59]	♀+♂	149	67.3	52	3	156	n.p.	random	n.p.	70.9	71.1	71.3	71.6	-0.1
Hamdorf & Penhall [60]	♀	18	82.4	26	2	52	EKG	random	n.p.	74.4	71.8	72.7	75.4	-7.0
Hamdorf et al. [61]	♀	27	64.8	26	2	52	n.p.	random	n.p.	76	74	76	74	0.0
O'Hartaigh et al. [62]	♀+♂	213	76.8	52	3	106	n.p.	random	n.p.	69	66	68	66	-1.4
Hespele et al. [63]	♂	13	39.2	16	3	48	EKG	random	n.p.	65	58.2	66	64.8	-8.8
Hewitt et al. [64]	♀+♂	12	41	8	4	32	EKG	random	n.p.	66	63.8	67	65.3	-0.8
Heydari et al. [65,66]	♂	25	24.7	12	3	36	EKG	random	n.p.	62.2	57.9	62.7	63.7	-8.4
Heydari et al. [67]	♂	17	24.4	12	3	36	EKG	random	n.p.	67	61	69	70	-10.3
Higashi et al. [68]	♀+♂	20	53	12	6	72	n.p.	random	n.p.	71.8	68.8	73.1	69.2	1.2
Hill et al. [69]	♀+♂	87	64	10.5	4	42	EKG	n.p.	n.p.	85.03	76.94	79.15	78.89	-9.2
Hiruntrakul et al. [70,71]	♂	19	21	12	1	12	n.p.	random	n.p.	88	78	90	93	-14.2
Hornstrup et al. [72]	♀	14	23.9	12	1.7	20.4	ASP	random	n.p.	59	57	61	62	-4.9
Jahromi et al. [73]	♀	30	10-11	8	3	24	pulse monitor	n.p.	n.p.	81.12	72.31	80.05	80.26	-11.1
Jurca et al. [74]	♀	49	PMP	8	3.5	28	EKG	random	n.p.	68.1	65	66	65.8	-4.3
Karavirta et al. [75]	♂	23	55.6	7	1	7	EKG	random	n.p.	61	57	54	53	-4.8
Karavirta et al. [76]	♀	26	52	7	1	7	EKG	random	n.p.	63	60	65	62	-0.2
Kiens et al. [77]	♂	24	40	12	3	36	EKG	random	n.p.	69.4	59.3	64.9	60.7	-8.6
Kim et al. [78]	♂	14	17	6	5	30	n.p.	random	n.p.	75.1	70.4	76.3	76.2	-6.1
Knoepfli-Lenzin et al. [79]	♂	15	36	12	2.5	30	n.p.	random	n.p.	70	61	74	68	-5.2
Kokkinos et al. [80]	♂	23	57	16	3	48	n.p.	random	n.p.	73	71	73	75	-5.3
Korshoj et al. [81,82]	♀+♂	57	44.9	52	2	104	EKG	c.r.	n.p.	71.7	69.98	70.5	70.3	-2.1
Krustrup et al. [83]	♂	12	20-43	12	2.5	30	EKG	random	n.p.	59	53	60	61	-11.6
Krustrup et al. [84]	♀	21	37	16	1.8	28	EKG	random	n.p.	62	57	63	63	-8.1
Krustrup et al. [85]	♀+♂	46	9.4	10	2.1	21	EKG	random	n.p.	70.4	69.9	70.6	71.2	-1.5
Lamina [86]	♂	112	58.63	8	3	24	ASP	random	double blind	82.25	70.78	82.6	80.5	-11.7
Linder et al. [87]	♂	21	11-17	8	4	32	n.p.	random	n.p.	72	74.8	69.7	75.7	-4.3
Loimaala et al. [88]	♂	26	46.8	22	5	110	EKG	random	n.p.	68	64	67	69	-8.6
Mahdiabadi [89]	♂	10	18.5	8	3	24	auscultation	random	n.p.	68.2	66.2	71.3	68.3	1.3
Melanson & Freedson [90]	♂	11	36.6	16	3	48	EKG	non random	n.p.	64.9	59.8	61	60.5	-7.1
Menezes-Cabral et al. [91]	♀	53	64.8	17	4	68	EKG	n.p.	n.p.	75.2	71.6	77.6	78.7	-6.1
Menezes-Cabral et al. [91]	♂	51	64.5	17	4	68	EKG	n.p.	n.p.	77.1	72.8	87	87.9	-6.5
Meucci et al. [92]	♀+♂	6	9.9	4	5	20	EKG	random	n.p.	97	80	104	99	-13.4

Table 1. Cont.

Author(s)	Sex	N (IG)	Age * (yr)	Exercise in the IG			Measurement of RHR	Randomization	Blinding	IG		CG		Rel. RHR Change IG/CG (%)
				Duration (/wk)	Frequency (/wk)	Overall Number of Units				Baseline RHR (/min)	Final RHR (/min)	Baseline RHR (/min)	Final RHR (/min)	
Miyai et al. [93]	♂	17	46.6	12	3	36	EKG	random	n.p.	68.5	57	66.7	63	-1.9
Mogharnesi et al. [94]	♂	12	14.32	8	3	24	n.p.	random	n.p.	76.4	69.75	74.6	75.6	-9.9
Mohr et al. [95]	♀	21	44	15	2.9	43.5	ASP	random	n.p.	78	73	77	74	-2.6
Molmen-Hansen et al. [96]	♀+♂	31	52.5	12	3	36	oscillometer	random	n.p.	73	69.5	73.4	73.7	-5.2
Moreau et al. [97]	♀	15	53	24	6	144	n.p.	random	n.p.	77	75	77	76	-1.3
Morgan et al. [98]	♀+♂	14	57.4	15	7	105	EKG	random	n.p.	75.64	71.21	71.6	72.13	-6.5
Nakamura et al. [18]	♀+♂	8	22.6	8	3	24	EKG	random	n.p.	78.7	73.4	71	70	-5.4
Nemoto et al. [99]	♀	31	64	22	4	88	EKG	random	n.p.	81	78	79	77	-1.2
Nemoto et al. [99]	♂	11	67	22	4	88	EKG	random	n.p.	75	74	80	77	2.5
Norris et al. [100]	♀+♂	14	16.7	10	2	20	n.p.	n.p.	n.p.	78.86	63.71	75.37	77.62	-21.6
Nualnim et al. [101]	♀+♂	24	58	12	7	84	EKG	random	n.p.	62	58	63	59	-0.1
Nybo et al. [102]	♂	8	37	12	2	24	EKG	n.p.	n.p.	55	52	60	61	-7.0
Ortega et al. [103]	♀+♂	7	24.8	2	5.5	11	EKG	random	n.p.	69	60	62	60	-10.1
Palmer [104]	♀	16	37.4	8	n.p.	n.c.	ASP	random	n.p.	74	72.2	71	72.7	-4.7
Patterson et al. [105]	♀	14	34.9	8	3	24	EKG	random	n.p.	74	66	72	72	-10.8
Pollock et al. [106]	♂	15	48.9	20	4	80	EKG	n.p.	n.p.	65	61.7	73.3	72.4	-3.9
Pollock et al. [107]	♂	9	38	20	3	60	EKG	random	n.p.	67.3	60	68	65.9	-8.0
Pollock et al. [108]	♂	22	55	20	3	60	EKG	n.p.	n.p.	62.9	56.1	67.6	65.6	-8.1
Racil et al. [109]	♀	14.20	17	12	3	36	EKG	random	n.p.	70	67	70	70	-4.3
Ray und Carter [110]	♀+♂	14	25	8	4	32	EKG	random	n.p.	66	64	76	75	-1.7
Richter et al. [111]	♂	10	45	9	3	27	EKG	random	n.p.	77	76.4	84	82	1.6
Ruoti et al. [112]	♀+♂	12	65	12	3	36	EKG	random	n.p.	72.21	67.12	71.32	72.32	-8.3
Sakai et al. [113]	♀+♂	19	56	4	3	12	ASP	random	n.p.	74	74	75	76	-1.3
Sakuragi u. Sugiama [114]	♀	8	19.4	4	6	24	EKG	random	n.p.	65.5	61.2	64	63.9	-6.4
Schmidt et al. [115]	♂	9	68	8	1.5	12	ASP	random	n.p.	64	56	61	59	-9.5
Seals et al. [116]	♀+♂	10	62	30.3	3.6	1098	EKG	n.p.	n.p.	68	67	62	66	-7.4
Seals u. Reiling [117]	♀+♂	9	63	6	3.6	21.6	n.p.	n.p.	n.p.	83	82	76	79	-5.0
Serwe et al. [118]	♀	20	37.1	8	5	40	n.p.	random	n.p.	68.4	68.6	72.7	72.9	0.0
Shiotani et al. [119]	♀+♂	16	young adults	9	3	27	EKG	random	n.p.	73.7	69.5	75	74.7	-5.3
Silie et al. [120]	♀	17	19.8	12	5	60	EKG	random	n.p.	82.3	78.7	82	81.8	-4.1
Spalding et al. [121]	♀+♂	15	22.2	6	4	24	EKG	random	n.p.	72.7	71.5	75.5	75.5	-1.7
Stefanick et al. [122]	♀+♂	43	30-64	52	3	156	n.p.	random	n.p.	67	66.2	67	68.1	-2.8
Stefanick et al. [122]	♀+♂	43	30-64	52	3	156	n.p.	random	n.p.	67	63.2	67	65.4	-3.4
Sugawara et al. [123]	♀	11	59	8	4.5	36	EKG	random	n.p.	59.5	58.5	65.5	64	.6
Suter et al. [124]	♂	39	38.8	17	4	68	EKG	random	n.p.	64.7	61.2	60.7	59.4	-3.3



Table 1. Cont.

Author(s)	Sex	N (IG)	Age * (yr)	Exercise in the IG			Measurement of RHR	Randomization	Blinding	IG		CG		Rel. RHR Change IG/CG (%)
				Duration (/wk)	Frequency (/wk)	Overall Number of Units				Baseline RHR (/min)	Final RHR (/min)	Baseline RHR (/min)	Final RHR (/min)	
Tanabe et al. [125]	♀+♂	21	50.9	10	3	30	n.p.	n. a	n.p.	75.7	73.2	69.1	70.6	−5.4
Tanaka et al. [126]	♀+♂	11	62	10	3	30	n.p.	n. a	n.p.	70	68	66	66	−2.9
Tanaka et al. [127–129]	♀+♂	12	47	10	3	30	palpation	n. a	n.p.	81	71	76	75	−11.2
Tsai et al. [130,131]	♀+♂	12	49.6	12	3	36	n.p.	n.p.	n.p.	83.8	79.2	80.4	79.7	−4.7
Tsai et al. [130,131]	♀+♂	22	45.5	12	3	36	n.p.	n.p.	n.p.	79	82.8	84.8	91	−2.3
Tsai et al. [132]	♀+♂	37	48.8	10	3	30	n.p.	random	n.p.	76.8	74.6	76.6	78.8	−5.6
Tully et al. [133]	♀+♂	42	46.37	12	3	36	ASP	random	n.p.	72	69.05	75	73.9	−2.7
Turner et al. [134]	♀+♂	11	65.2	30	4	120	n.p.	n.p.	n.p.	63.4	57.8	68	63	−1.6
Urata et al. [135]	♀+♂	10	51.4	10	3	30	n.p.	random	n.p.	74	72.1	73.3	71.2	.3
Vance et al. [136]	♂	19	n.p.	16	n.p.	n. c.	n.p.	n.p.	n.p.	76.71	67.6	73.18	76.05	−5.2
Wanderley et al. [137]	♀+♂	20	69.9	34	3	102	EKG	random	n.p.	67.5	64.1	68.4	65.5	−0.8
Whitehurst & Menendez [138]	♀	18	69	8	3	24	EKG	n.p.	n.p.	72.9	68.3	72.9	73.3	−6.8
Winter et al. [139]	♀+♂	24	31	10	3	30	EKG	ENV	n.p.	75	70	79	77	−4.2
Wolfe et al. [140]	♀	12	19–22	11	4	44	n.p.	n.p.	n.p.	68	68	67	71	−5.6
Wood et al. [141]	♂	48	45.3	52	4	208	EKG	random	n.p.	66.6	57.4	71.1	68.7	−10.8
Wood et al. [142]	♀+♂	11	69.1	12	3	36	EKG	n.p.	n.p.	67.8	62.2	64.1	64.8	−9.3
Wynne et al. [143]	♀	13	23.2	10	3	30	n.p.	n.p.	n.p.	76	68	70	67	−6.5
Yamamoto et al. [144]	♂	7	21	6	4	24	EKG	n.p.	n.p.	68.1	53.2	67.5	66.2	−20.3
Yoshizawa et al. [145]	♀	12	47	12	2	24	n.p.	random	n.p.	67	59	61	62	−13.4
<b>Combined endurance and strength training</b>														
Anek et al. [27]	♀	15	40.26	16	3	48	EKG	random	n.p.	79.4	75.2	79.13	79.56	−5.8
Byrne u. Wilmore [146]	♀	10	35.9	20	3	60	EKG	random	n.p.	66.5	59.3	63	62.2	−9.7
Cortez-Cooper et al. [147]	♀+♂	12	51	13	2	26	n.p.	random	n.p.	62	59	65	65	−4.8
Delecluse et al. [47]	♂	18	63.8	20	2.5	50	EKG	random	n.p.	76.2	71.4	73.3	73.9	−7.1
Deley et al. [148]	♀+♂	24	77.2	52	3	156	EKG	random	n.p.	73	75.5	74.3	70.1	9.6
Figueroa et al. [149]	♀	12	54	12	3	36	EKG	random	n.p.	66	62	68	67	−4.7
Frye et al. [150]	♀+♂	28	69.2	12	3	36	n.p.	random	n.p.	66.8	70	68.7	67.9	6.0
Karavirta et al. [75]	♂	29	55.6	21	2	42	EKG	random	n.p.	58	57	54	53	0.1
Karavirta et al. [76]	♀	21	49	21	2	42	EKG	random	n.p.	62	62	65	62	4.8
Masroor et al. [151]	♀	15	39.67	4	5	20	EKG	random	n.p.	75.5	71.2	80.3	83.2	−9.0
Ohkubo et al. [152]	♀+♂	22	60–81	25	2	50	ASP	random	n.p.	62.6	60.2	66.2	64	−0.5
Stewart et al. [153,154]	♀+♂	51	63	26	3	78	ASP	random	n.p.	69.8	65.9	71.9	69.7	−2.6
Svensen et al. [155]	♀	48	53.8	12	3	36	n.p.	random	n.p.	73	64	74	69	−6.0

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Author(s)	Sex	N (IG)	Age * (yr)	Exercise in the IG			Measurement of RHR	Randomization	Blinding	IG		CG		Rel. RHR Change IG/CG (%)
				Duration (/wk)	Frequency (/wk)	Overall Number of Units				Baseline RHR (/min)	Final RHR (/min)	Baseline RHR (/min)	Final RHR (/min)	
Tsuda et al. [156]	♂	8	46.2	6	2	12	ECG	random	n.p.	69	68	72	70	1.4
Wood et al. [142]	♀+ ♂	9	66.1	12	3	36	ECG	n.p.	n.p.	79.8	73.7	64.1	64.8	-8.6
<b>Strength training</b>														
Badrov et al. [157]	♀	11	27	8	5	40	ECG	random	n.p.	64	64	66	65	1.5
Baross et al. [158]	♂	10	55	8	3	24	ECG	random	n.p.	71	66	69	68.2	-6.0
Beck et al. [32,33]	♀+ ♂	15	21.1	8	3	24	n.p.	random	n.p.	63	61	60	58	0.2
Byrne u. Wilmore [146]	♀	9	39.1	20	4	80	ECG	random	n.p.	63.4	60.5	63	62.2	-3.3
Carter et al. [159]	♀+ ♂	12	21	8	3	24	ECG	non random	n.p.	65	63	61	67	-11.8
Cononie et al. [45]	♀+ ♂	12	72	26	3	78	ECG	random	n.p.	61	65	68	67	8.1
Cononie et al. [45]	♀+ ♂	6	72	26	3	78	ECG	random	n.p.	65	69	66	65	7.8
Cortez-Cooper et al. [147]	♀+ ♂	13	52	13	3	39	n.p.	random	n.p.	60	61	65	65	1.7
Fripp et al. [160]	♂	14	15.2	9	3	27	n.p.	n.p.	n.p.	76	78	79	79	2.6
Gelecek et al. [161]	♀	24	54.33	12	3	36	palpation	random	single blinded	80.08	78.41	77.76	80.47	-5.4
Gerage et al. [162]	♀	15	65.5	12	3	36	ECG	random	n.p.	73.86	71.89	78.37	81.14	-6.0
Giannaki et al. [163]	♂	20	16	8	2	16	ECG	random	n.p.	78.8	77.6	76.8	78.5	-3.7
Gorjao et al. [164]	♀	10	66	8	3	24	ECG	random	n.p.	75.7	77.4	76.6	74.7	4.8
Harris und Holly [165]	♂	10	32.7	9	3	27	ECG	random	n.p.	75.7	76.5	73.9	72.3	3.3
Ibrahim et al. [166]	♂	12	21	12	3	36	ASP	random	n.p.	71.7	71.2	72.9	72.6	-0.3
Ibrahim et al. [166]	♂	10	22	12	3	36	ASP	random	n.p.	72.4	68.3	72.2	68.5	-0.6
Kanegusuku et al. [167]	♀+ ♂	13	63	16	2	32	ECG	random	n.p.	83	87	81	78	8.9
Karavirta et al. [75]	♂	25	55.6	21	2	42	ECG	random	n.p.	59	59	54	53	1.9
Karavirta et al. [76]	♀	26	52	21	2	42	ECG	random	n.p.	62	61	65	62	3.1
Lovell et al. [168]	♂	12	71.4	16	3	48	n.p.	random	n.p.	69	68	68	66	1.5
Marinda et al. [169]	♀	25	66.12	8	3	24	n.p.	random	n.p.	68.8	73.2	62.48	74.92	-1.3
Menezes-Cabral et al. [91]	♀	51	64.8	17	4	68	n.p.	n.p.	n.p.	75.7	72	77.6	78.7	-6.2
Menezes-Cabral et al. [91]	♂	53	64.5	17	4	68	n.p.	n.p.	n.p.	82.6	77.1	87	87.9	-7.6
Millar et al. [170]	♀+ ♂	13	65	8	3	24	ECG	non random	n.p.	58	56	62	63	-5.0
Miyachi et al. [171]	♂	14	22	17	3	51	n.p.	random	n.p.	55	54	57	56	-0.1
Mogharnesi et al. [94]	♂	12	13.71	8	3	24	auscultation	random	n.p.	76.5	70.33	74.6	75.6	-9.3
Nybo et al. [102]	♂	8	36	12	2	24	ASP	n.p.	n.p.	57	56	60	61	-3.4
Okamoto et al. [172]	♀	10	19.1	8	3	24	n.p.	random	n.p.	68.4	67.1	67.6	62.4	6.3
Okamoto et al. [173]	♀+ ♂	13	18.5	10	2	20	n.p.	random	n.p.	66	66	63	62	1.6
Schmidt et al. [115]	♂	9	69.1	12	1.9	22.8	ASP	random	n.p.	63	61	61	59	0.1
Shaw et al. [174]	♀	19	60.44	6	2	12	auscultation	random	n.p.	69.05	63.8	71.26	71	-7.3
Spalding et al. [121]	♀+ ♂	15	22.2	6	4	24	pulse monitor	random	n.p.	72.9	73	75.5	75.5	0.1

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Author(s)	Sex	N (IG)	Age * (yr)	Exercise in the IG			Measurement of RHR	Randomization	Blinding	IG		CG		Rel. RHR Change IG/CG (%)
				Duration (/wk)	Frequency (/wk)	Overall Number of Units				Baseline RHR (/min)	Final RHR (/min)	Baseline RHR (/min)	Final RHR (/min)	
Stiller-Moldovan et al. [175]	♀+ ♂	11	60	8	3	24	pulse monitor	random	n.p.	71.3	71	66.2	64.4	2.4
Taylor et al. [176]	♀+ ♂	9	69.3	10	3	30	EKG	random	n.p.	70	68	70	76	−10.5
Terra et al. [177]	♀	20	66.8	12	3	36	ASP	non random	n.p.	72.2	72.7	74.1	74	0.8
Thomas et al. [178]	♀+ ♂	65	69.1	12	3	36	ASP	random	n.p.	67	65	67	65	0.0
Vincent et al. [179]	♀+ ♂	24	66.6	24	3	72	auscultation	random	n.p.	82	80	77	84	−10.6
Wanderley et al. [137]	♀+ ♂	11	67.3	34	3	102	EKG	random	n.p.	62.2	60.3	68.4	65.5	1.2
Wiley et al. [21]	n.p.	10	20–35	8	3	24	EKG	random	n.p.	78	76	77	82	−8.5
Wilmore et al. [180]	♀	12	n.p.	10	3	30	EKG	random	n.p.	65.4	59.4	61.5	59.6	−6.3
Wilmore et al. [180]	♂	16	n.p.	10	3	30	EKG	random	n.p.	63.6	58.4	61.8	55.3	2.6
Wood et al. [142]	♀+ ♂	10	69.8	12	3	36	EKG	n.p.	n.p.	67.3	63.5	64.1	64.8	−6.7
Yoshizawa et al. [145]	♀	11	47	12	2	24	n.p.	random	n.p.	67	63	61	62	−7.5
<b>Unspecified sports activities</b>														
Edwards et al. [181]	♀+ ♂	25	46.5	12	5	60	EKG	random	n.p.	77.2	73.3	75.4	78.5	−8.8
García-Ortiz et al. [182]	♀+ ♂	1456	51.47	52	4	208	n.p.	random	n.p.	75.8	75.42	75.27	74.89	0.0
<b>Additional school sports</b>														
Hansen et al. [183]	♀	17	9–11	8	3	24	EKG	random	n.p.	91.8	85.9	96	88	2.1
Nogueira et al. [184]	♀	71	10.6	35	3	105	auscultation	random	n.p.	71.8	66.6	67.2	66	−5.6
Rautela et al. [185]	♀	30	n.p.	6	6	36	EKG	random	n.p.	80.9	80.73	81.1	81	−0.1
Walther et al. [186]	♀+ ♂	141	11	104	3	312	n.p.	ENV	n.p.	103	98.3	102	98	−0.7
Wong et al. [187]	♂	12	13.75	12	2	24	EKG	random	n.p.	78	71	76	76	−9.0
<b>Qigong</b>														
Lee et al. [188]	♀+ ♂	29	55.8	10	3	30	ASP	random	n.p.	73.82	72.27	73.55	76.2	−5.5
Li et al. [189]	♀+ ♂	101	20.63	12	5	60	n.p.	PLAN	n.p.	83.61	82.61	80.49	82.22	−3.3
Sousa et al. [190]	♀	8	11.5	7	7	49	n.p.	non random	n.p.	107	96	81	86	−15.5
<b>Tai chi</b>														
Frye et al. [150]	♀+ ♂	23	69.2	12	3	36	n.p.	random	n.p.	70.95	70.77	68.7	67.9	0.9
Logghe et al. [191]	♀+ ♂	138	77.5	13	2	26	n.p.	random	n.p.	71	68.3	70.6	67.8	0.2
Nguyen und Kruse [192]	♀+ ♂	48	69.23	26	2	52	n.p.	random	n.p.	84.48	76.72	83.08	82.86	−8.9
Thomas et al. [178]	♀+ ♂	64	68.9	52	3	156	ASP	random	n.p.	70	67	67	65	−1.3
Tsai et al. [193]	♀+ ♂	37	51.6	12	3	36	EKG	random	n.p.	77.8	75.8	78.2	76.6	−0.5

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				Duration (/wk)	Frequency (/wk)	Overall Number of Units				Baseline RHR (/min)	Final RHR (/min)	Baseline RHR (/min)	Final RHR (/min)	
<b>Yoga</b>														
Bezerra et al. [194]	♀	18	63.1	12	3	36	oximeter	random	n.p.	76.39	74.61	77.28	79.78	-5.4
Blumenthal et al. [35,36]	♀+ ♂	32	67	17	2	34	ECG	random	n.p.	75	70	70	69	-5.3
Cheema et al. [195]	♀+ ♂	18	37	10	3	30	ECG	random	n.p.	62	65	68	67	6.4
Cohen et al. [196]	♀+ ♂	46	48.2	6	3	18	n.p.	random	n.p.	70	68	69	67	0.0
Hewett et al. [197]	♀+ ♂	29	38.2	16	4	64	ECG	random	n.p.	64.1	62.9	65.4	62.2	3.2
Kanojia et al. [198]	♀	25	18.6	13	6	78	ECG	random	n.p.	79.84	72.96	75.72	81.92	-15.5
Kim et al. [199]	♀	16	45.7	6	5	30	pulse monitor	random	n.p.	65.9	65.9	65.8	66.1	-0.5
Krishna et al. [200]	♀+ ♂	44	49.34	12	1	12	ECG	random	n.p.	96.36	81.48	96.33	92.04	-11.5
Lau et al. [201]	♀	53	51.64	12	3	36	ECG	non random	n.p.	69.11	66.81	70.61	71.39	-4.4
Lau et al. [201]	♂	34	53.68	12	3	36	ECG	non random	n.p.	67.53	66.32	66.77	68.73	-4.6
Madanmohan et al. [202]	♀+ ♂	23	17-20	6	6	36	ASP	n.p.	n.p.	70	67	75	73	-1.7
McCaffrey et al. [203]	♀+ ♂	27	56.7	8	3	24	n.p.	random	n.p.	85.59	73.74	80.85	85.07	-18.1
Mehrotra et al. [204]	♀	36	18-21	13	7	91	ECG	non random	n.p.	86.84	72.97	81.68	82.35	-16.7
Mehrotra et al. [204]	♂	36	18-21	13	7	91	ECG	non random	n.p.	77.08	70.14	80.59	79.76	-8.1
Murugesan et al. [205]	♀+ ♂	11	35-65	11	6	66	palpation	random	n.p.	92.61	64.62	90.53	88.25	-28.4
Ray et al. [206]	♀	5	22.6	22	3	66	auscultation	random	n.p.	77.6	70.2	80.2	73.2	-0.9
Ray et al. [206]	♂	23	23.6	22	3	66	auscultation	random	n.p.	74.91	73.61	74.85	75.45	-2.5
Sieverdes et al. [207]	♀+ ♂	14	12.1	13	2.5	32.5	ASP	random	n.p.	74.8	72.8	78.5	82.64	-7.5
Tew et al. [208]	♀	25	73.8	12	0.8	9.6	n.p.	random	n.p.	79	74	80	80	-6.3
Thiyagarajan et al. [209]	♀+ ♂	51	44.08	12	3	36	n.p.	c.r.	n.p.	75	72	77	74	-0.1
Udupa et al. [210]	♂	31	14.5	13	5	65	ASP	random	n.p.	73.58	67.42	76.15	74.64	-6.5

Notes: ♀+ ♂= males and females; ♀= females only; ♂= males only; adol. = adolescents; ASP = automatic sphygmanometer; CG = control group; c.r. = cluster randomization; ECG = electrocardiography; ENV = choosing an envelope which contained the allocation towards the treatment or control group; IG = intervention group; min = minute(s); IVRS = interactive voice response system; N = number of participants; n.c. = not calculable; n.p. = not presented; PLAN = PLAN sentences of the statistical software SAS9.1; PMP = postmenopausal; rel. = relative; RHR = resting heart rate; wk = week(s); y = year(s); \* mean, median, or range.

### 3.2. Effects of Exercise on RHR by Considering Different Types of Sports/Exercise

The mean baseline and post-interventional RHR according to the different forms of sports and/or exercise are presented in Table 2. Under consideration of all comparisons, the RHR significantly decreased more in the exercising groups (intervention groups) compared to the control groups (all studies:  $-4.7\%$  and  $-3.3$  bpm resp., females only:  $-4.8\%$  and  $-3.4$  bpm, resp., males only:  $-6.4\%$  and  $-4.3$  bpm, resp., studies including both females and males:  $-3.6\%$  and  $-2.6$  bpm, resp.). The meta-analyses on specific types of sports and exercise also revealed significant higher decreases in RHR in the intervention compared to the corresponding control groups for endurance training (all groups), yoga (females and males only), strength training (females only), and combined endurance and strength training (females only, not Hartung-Knapp CI).

### 3.3. Additional Analyses

The extents of decrease of the RHR due to the interventions were significantly associated with the initial RHR (all studies:  $r = 0.30$ ,  $n = 215$ ,  $p < 0.001$ ; women:  $r = 0.28$ ,  $n = 65$ ,  $p = 0.024$ ; men:  $r = 0.22$ ,  $n = 59$ ,  $p = 0.09$ ; both sexes:  $r = 0.39$ ,  $n = 91$ ,  $p < 0.001$ ). The average age of the study participants was not related with the baseline RHR of the participants ( $r = -0.14$ ,  $n = 194$ ,  $p = 0.052$ ; 21 trials did not mention the mean age of the participants), but with the sport/exercise-induced decrease of the RHR ( $r = 0.15$ ,  $n = 194$ ,  $p = 0.037$ ). The higher the average age the smaller was the decrease of the RHR. The average age of the exercising participants was not significantly associated with the number of training sessions throughout the intervention ( $r = 0.133$ ,  $n = 194$ ,  $p = 0.064$ ). The number of exercise sessions throughout the interventions did not significantly influence the changes in the RHR ( $r = 0.088$ ,  $n = 215$ ,  $p = 0.20$ ).

### 3.4. Risk of Bias in Individual Studies

The characteristics of the samples and the results of the risk of bias assessment included in the present review are shown in Table 1. In 178 (82.8%) samples, the participants were randomly assigned to the exercising and control groups with 10 articles presenting detailed information about the mode of randomization. Nine (4.2%) samples were based on non-randomized collectives. In the remaining 27 (12.6%) samples, no information about randomization was given.

In only two studies [86,161], the researchers were blinded regarding the assignment of the participants to the intervention and control group.

In 153 (71.2%) samples, the method used for measuring the RHR was described: conventional or long-term electrocardiography or sport tester heart rate monitors ( $n = 111$ ), automatic sphygmomanometer ( $n = 25$ ), auscultation ( $n = 8$ ), pulse monitor ( $n = 4$ ), palpation ( $n = 3$ ), oscillometer ( $n = 1$ ), and oximeter ( $n = 1$ ). 62 studies gave no information regarding the measurement methods of the RHR.

**Table 2.** Effects of regular exercise/sports on RHR according to type of sports/exercise.

Types of Sports/Exercise Participants' Sex, Number of Comparisons (c), Participants in the Intervention (N <sub>IG</sub> ), and Control Groups (N <sub>CG</sub> )	Meta-Analytic SMD +95%-CI +95%-HK-CI	Heterogeneity	IG		CG		Correlation between Baseline RHR and Change of RHR After Intervention *
			Baseline RHR (M(SE))	Final RHR: rel. Change (M(SE))	Baseline RHR (M(SE))	Final RHR: rel. Change (M(SE))	
<b>All types of sports</b>							
all c = 215, N <sub>IG</sub> = 6763, N <sub>CG</sub> = 6189	SMD = -0.29 (95%-CI: -0.35--0.24, p < 0.001) (95%-HK-CI: -0.35--0.24, p < 0.001)	Q = 381.06, p < 0.001, I <sup>2</sup> = 43.8%	72.4 (0.5)	68.7 (0.5) -5.2 (0.4)%	72.3 (0.6)	71.9 (0.6) -0.5 (0.2)%	-0.36 (95%-CI: -0.47--0.24, p < 0.001)
females only c = 65, N <sub>IG</sub> = 1366, N <sub>CG</sub> = 1268	SMD = -0.35 (95%-CI: -0.43--0.26, p < 0.001) (95%-HK-CI: -0.43--0.26, p < 0.001)	Q = 67.17, p = 0.305, I <sup>2</sup> = 7.7%	73.2 (0.8)	69.5 (0.9) -5.1 (0.6)%	73.2 (1.0)	72.9 (0.9) -0.3 (0.2)%	-0.32 (95%-CI: -0.52--0.08, p = 0.009)
males only c = 58, N <sub>IG</sub> = 1208, N <sub>CG</sub> = 1036	SMD = -0.40 (95%-CI: -0.51--0.29, p < 0.001) (95%-HK-CI: -0.52--0.28, p < 0.001)	Q = 79.35, p = 0.018, I <sup>2</sup> = 30.7%	70.3 (1.2)	65.4 (1.1) -7.0 (0.6)%	70.5 (1.6)	69.9 (1.6) -0.6 (0.4)%	-0.22 (95%-CI: -0.46--0.04, p = 0.094)
females and males c = 92, N <sub>IG</sub> = 4189, N <sub>CG</sub> = 3885	SMD = -0.21 (95%-CI: -0.29--0.13, p < 0.001) (95%-HK-CI: -0.30--0.12, p < 0.001)	Q = 185.24, p < 0.001, I <sup>2</sup> = 50.3%	73.1 (0.7)	70.0 (0.7) -4.3 (0.6)%	72.7 (0.9)	72.3 (0.9) -0.6 (0.4)%	-0.49 (95%-CI: -0.63--0.32, p < 0.001)
<b>Endurance training</b>							
all c = 121, N <sub>IG</sub> = 2924, N <sub>CG</sub> = 2533	SMD = -0.33 (95%-CI: -0.40--0.26, p < 0.001) (95%-HK-CI: -0.40--0.26, p < 0.001)	Q = 157.16, p = 0.013, I <sup>2</sup> = 23.6%	72.4 (0.6)	68.0 (0.7) -6.0 (0.4)%	72.3 (0.8)	71.9 (0.8) -0.1 (0.3)%	-0.19 (95%-CI: -0.36--0.01, p = 0.042)
females only c = 35, N <sub>IG</sub> = 698, N <sub>CG</sub> = 620	SMD = -0.38 (95%-CI: -0.49--0.26, p < 0.001) (95%-HK-CI: -0.50--0.26, p < 0.001)	Q = 37.06, p = 0.330, I <sup>2</sup> = 8.3%	73.6 (1.2)	69.8 (1.1) -5.2 (0.6)%	73.4 (1.5)	73.3 (1.3) -0.2 (0.4)%	-0.26 (95%-CI: -0.55--0.08, p = 0.132)
males only c = 36, N <sub>IG</sub> = 792, N <sub>CG</sub> = 656	SMD = -0.49 (95%-CI: -0.63--0.35, p < 0.001) (95%-HK-CI: -0.64--0.34, p < 0.001)	Q = 45.18, p = 0.077, I <sup>2</sup> = 27.0%	70.3 (1.6)	64.0 (1.6) -9.0 (0.7)%	70.8 (2.1)	70.3 (2.2) 0.0 (0.6)%	-0.18 (95%-CI: -0.49--0.17, p = 0.320)
females and males c = 50, N <sub>IG</sub> = 1434, N <sub>CG</sub> = 1277	SMD = -0.19 (95%-CI: -0.28--0.11, p < 0.001) (95%-HK-CI: -0.28--0.10, p < 0.001)	Q = 53.85, p = 0.294, I <sup>2</sup> = 9.0%	72.8 (0.7)	69.4 (0.8) -4.6 (0.7) %	72.4 (0.8)	71.9 (0.9) -0.0 (0.5)%	-0.33 (95%-CI: -0.56--0.05, p = 0.022)

Table 2. Cont.

Types of Sports/Exercise Participants' Sex, Number of Comparisons (c), Participants in the Intervention (N <sub>IG</sub> ), and Control Groups (N <sub>CG</sub> )	Meta-Analytic SMD +95%-CI +95%-HK-CI	Heterogeneity	IG		CG		Correlation between Baseline RHR and Change of RHR After Intervention *
			Baseline RHR (M(SE))	Final RHR: rel. Change (M(SE))	Baseline RHR (M(SE))	Final RHR: rel. Change (M(SE))	
<b>Strength training</b>							
all c = 43, N <sub>IG</sub> = 720, N <sub>CG</sub> = 689	SMD = -0.18 (95%-CI: -0.32--0.04, p = 0.011) (95%-HK-CI: -0.32--0.04, p = 0.014)	Q = 64.98, p = 0.013, I <sup>2</sup> = 35.4%	69.1 (1.2)	67.8 (1.2) -2.5 (0.7)%	68.9 (1.3)	69.0 (1.4) 0.1 (0.8)%	-0.04 (95%-CI: -0.34-0.27, p = 0.817)
females only c = 13, N <sub>IG</sub> = 243, N <sub>CG</sub> = 229	SMD = -0.26 (95%-CI: -0.44--0.08, p = 0.005) (95%-HK-CI: -0.44--0.09, p = 0.007)	Q = 9.07, p = 0.697, I <sup>2</sup> = 0%	69.7 (1.6)	68.1 (1.8) -3.7 (1.0)%	69.4 (1.9)	70.0 (2.1) 1.3 (1.6)%	0.19 (95%-CI: -0.43-0.69, p = 0.565)
males only c = 14, N <sub>IG</sub> = 225, N <sub>CG</sub> = 214	SMD = -0.23 (95%-CI: -0.48-0.03, p = 0.081) (95%-HK-CI: -0.48-0.03, p = 0.075)	Q = 21.39, p = 0.066, I <sup>2</sup> = 39.2%	69.4 (2.6)	67.3 (2.4) -4.2 (0.9)%	69.1 (3.1)	68.1 (3.4) -1.7 (1.0)%	-0.21 (95%-CI: -0.67-0.36, p = 0.465)
females and males c = 16, N <sub>IG</sub> = 252, N <sub>CG</sub> = 246	SMD = -0.06 (95%-CI: -0.34-0.23, p = 0.704) (95%-HK-CI: -0.40-0.29, p = 0.737)	Q = 28.95, p = 0.011, I <sup>2</sup> = 51.6%	67.6 (1.9)	67.4 (2.1) -0.1 (1.0)%	67.6 (1.5)	68.0 (1.8) 0.5 (1.9)%	0.15 (95%-CI: -0.39-0.61, p = 0.597)
<b>Combined endurance and strength training</b>							
all c = 15, N <sub>IG</sub> = 322, N <sub>CG</sub> = 279	SMD = -0.18 (95%-CI: -0.35--0.01, p = 0.041) (95%-HK-CI: -0.37-0.01, p = 0.061)	Q = 15.30, p = 0.358, I <sup>2</sup> = 8.5%	69.1 (1.5)	66.3 (1.8) -4.8 (0.8)%	69.2 (2.0)	68.1 (2.4) -1.5 (0.8)%	-0.35 (95%-CI: -0.73-0.19, p = 0.195)
females only c = 6, N <sub>IG</sub> = 121, N <sub>CG</sub> = 117	SMD = -0.38 (95%-CI: -0.72--0.03, p = 0.031) (95%-HK-CI: -0.83-0.08, p = 0.086)	Q = 7.70, p = 0.174, I <sup>2</sup> = 35.1%	70.5 (3.4)	65.7 (3.2) -5.9 (1.5)%	71.6 (3.4)	70.6 (3.8) -1.4 (1.5)%	-0.37 (95%-CI: -0.91-0.63, p = 0.475)
males only c = 3, N <sub>IG</sub> = 55, N <sub>CG</sub> = 37	SMD = -0.10 (95%-CI: -0.52-0.32, p = 0.654) (95%-HK-CI: -0.61-0.41, p = 0.503)	Q = 0.61, p = 0.736, I <sup>2</sup> = 0.0%	67.5 (6.0)	65.3 (4.7) -2.7 (2.5)%	66.1 (7.5)	65.5 (6.9) -1.4 (2.7)%	
females and males c = 6, N <sub>IG</sub> = 146, N <sub>CG</sub> = 125	SMD = -0.06 (95%-CI: -0.29-0.19, p = 0.679) (95%-HK-CI: -0.32-0.22, p = 0.653)	Q = 3.76, p = 0.584, I <sup>2</sup> = 0%	68.4 (2.0)	67.3 (2.5) -4.3 (1.3)%	68.4 (1.8)	67.4 (1.2) -1.5%	-0.18 (95%-CI: -0.86-0.74, p = 0.738)
<b>Additional school sports</b>							
all c = 5, N <sub>IG</sub> = 271, N <sub>CG</sub> = 216	SMD = -0.26 (95%-CI: -0.63-0.10, p = 0.154) (95%-HK-CI: -0.92-0.39, p = 0.328)	Q = 12.19, p = 0.016, I <sup>2</sup> = 67.2%	84.8 (3.9)	80.4 (4.1) -5.2 (2.3)%	84.3 (4.8)	81.6 (4.4) -1.4 (1.0)%	-0.09 (95%-CI: -0.90-0.86, p = 0.883)

Table 2. Cont.

Types of Sports/Exercise Participants' Sex, Number of Comparisons (c), Participants in the Intervention (N <sub>IG</sub> ), and Control Groups (N <sub>CG</sub> )	Meta-Analytic SMD +95%-CI +95%-HK-CI	Heterogeneity	IG		CG		Correlation between Baseline RHR and Change of RHR After Intervention *
			Baseline RHR (M(SE))	Final RHR: rel. Change (M(SE))	Baseline RHR (M(SE))	Final RHR: rel. Change (M(SE))	
<b>Unspecified sports activities</b>							
all c = 2, N <sub>IG</sub> = 1481, N <sub>CG</sub> = 1414	SMD = -0.13 (95%-CI: -0.52-0.26, p = 0.523)	Q = 2.3, p = 0.130, I <sup>2</sup> = 56.4%	75.8 (0.3)	75.1 (0.7) -0.9 (1.0)%	75.4 (0.3)	76.3 (1.8) 0.7 (2.2)%	
<b>Yoga</b>							
all c = 21, N <sub>IG</sub> = 597, N <sub>CG</sub> = 589	SMD = -0.37 (95%-CI: -0.58--0.16, p < 0.001) (95%-HK-CI: -0.60--0.14, p = 0.003)	Q = 59.32, p < 0.001, I <sup>2</sup> = 66.3%	76.1 (2.5)	70.4 (1.3) -7.2 (1.6)%	76.7 (2.4)	75.9 (2.1) -2.0 (0.7)%	-0.87 (95%-CI: -0.94--0.69, p < 0.001)
females only c = 7, N <sub>IG</sub> = 178, N <sub>CG</sub> = 181	SMD = -0.44 (95%-CI: -0.76--0.13, p = 0.006) (95%-HK-CI: -0.84--0.04, p = 0.036)	Q = 8.36, p = 0.138, I <sup>2</sup> = 40.2%	76.9 (3.6)	71.4 (2.6) -7.2 (2.3)%	77.1 (3.4)	76.2 (3.2) -1.7 (1.6)%	-0.89 (95%-CI: -0.99--0.28, p = 0.018)
males only c = 4, N <sub>IG</sub> = 124, N <sub>CG</sub> = 117	SMD = -0.24 (95%-CI: -0.50--0.01, p = 0.063) (95% HCI: -0.38--0.10, p = 0.013)	Q = 0.36, p = 0.949, I <sup>2</sup> = 0%	73.2 (2.3)	69.6 (1.7) -4.8 (2.1)%	74.4 (3.0)	74.5 (2.7) 0.7 (2.0)%	
females and males c = 10, N <sub>IG</sub> = 295, N <sub>CG</sub> = 291	SMD = -0.41 (95%-CI: -0.77--0.05, p = 0.028) (95%-HK-CI: -0.86--0.04, p = 0.069)	Q = 49.28, p < 0.001, I <sup>2</sup> = 79.7%	76.8 (4.4)	70.2 (2.1) -7.9 (2.7)%	77.3 (4.0)	76.3 (3.7) -2.6 (1.0)%	-0.87 (95%-CI: -0.97--0.58, p < 0.001)
<b>Tai chi</b>							
all c = 5, N <sub>IG</sub> = 310, N <sub>CG</sub> = 317	SMD = -0.26 (95%-CI: -0.68--0.16, p = 0.228) (95% HCI: -0.89--0.38, p = 0.327)	Q = 24.03, p < 0.001, I <sup>2</sup> = 83.4%	74.9 (3.2)	71.9 (2.1) -4.7 (1.8)%	73.6 (3.5)	72.1 (4.2) -1.1 (0.8)%	-0.78 (95%-CI: -0.99--0.31, p = 0.115)
<b>Qigong</b>							
all c = 3, N <sub>IG</sub> = 138, N <sub>CG</sub> = 142	SMD = -0.23 (95%-CI: -0.47--0.00, p = 0.054)	Q = 1.66, p = 0.437, I <sup>2</sup> = 0%	84.6 (5.1)	81.6 (4.9) -1.9 (1.5)%	78.1 (2.7)	81.2 (2.6) 3.0 (1.7)%	
<b>All Asian sports</b>							
all c = 29, N <sub>IG</sub> = 1045, N <sub>CG</sub> = 1038	SMD = -0.34 (95%-CI: -0.50--0.18, p < 0.001) (95%-HK-CI: -0.52--0.16, p < 0.001)	Q = 87.81, p < 0.001, I <sup>2</sup> = 68.1%	76.8 (1.8)	71.6 (1.0) -6.2 (1.2)%	76.3 (1.7)	75.8 (1.6) -1.3 (0.6)%	-0.75 (95%-CI: -0.88--0.54, p < 0.001)
females and males c = 17, N <sub>IG</sub> = 735, N <sub>CG</sub> = 732	SMD = -0.35 (95%-CI: -0.57--0.12, p = 0.002) (95%-HK-CI: -0.61--0.08, p = 0.013)	Q = 76.90, p < 0.001, I <sup>2</sup> = 76.6%	77.5 (2.4)	72.1 (1.3) -6.2 (1.6)%	76.5 (2.3)	76.0 (2.1) -1.3 (0.7)%	-0.74 (95%-CI: -0.89--0.43, p < 0.001)

\* At least 5 trials; c = number of comparisons; CI = confidence interval; HK-CI = Hartung–Knapp confidence interval; I<sup>2</sup> = Higgins–Thompson I<sup>2</sup>; M = mean; N<sub>CG</sub> = participants in the control groups; N<sub>IG</sub> = participants in the intervention groups (exercising participants); Q = Cochran’s Q; rel. change = relative change as compared to baseline; RHR = resting heart rate; s = studies (publications); SE = standard error; SMD = standardized mean difference.



## 4. Discussion

### 4.1. General Discussion of Findings

The present meta-analysis is the first determining the effects of any regular physical activity, exercise, or sports on RHR of healthy people by considering different types of sports and exercise as well as differences between males and females. The literature search in six data bases and additional sources revealed a total of 191 primary studies suitable for inclusion that overall encompassed 215 samples, resulting in a comprehensive evaluation of existing studies on the effects of sports and exercise on RHR in males and females.

### 4.2. Effects of Different Types of Sports on RHR

In the meta-analysis of 16 trials by Huang et al. [6], the magnitude of net change of RHR due to endurance training in older adults averaged  $6.16 \pm 0.97$  bpm, representing a mean reduction of 8.4%. The mean effect of yoga identified in the meta-analysis of nine trials by Cramer et al. [8] was very similar (M:  $-6.59$  bpm, 95%-CI:  $-12.89$  to  $-0.28$  bpm). This meta-analysis included both healthy and diseased participants. Zou et al. [15] combined four trials and described a significant decrease of the RHR due to qigong (SMD:  $-0.87$ , no absolute difference of RHR presented). Tai chi exercise reduced the RHR by 0.72 (SMD: CI =  $-1.27$  to  $-0.18$ ,  $n = 6$  trials) [7].

Our meta-analyses indicate that endurance training as well as yoga decrease the RHR. After endurance training, the mean decrease of RHR of the exercising participants as compared to the non-exercising was depending on the sexes of the participants (4.5% to 9.0% and 2.7 to 5.8 bpm, resp.). These results are a little bit smaller than those found by Huang et al. [6] who meta-analytically combined 13 studies with a total of 410 exercising individuals. Their overall net change in RHR amounted to  $-6.16 \pm 0.97$  bpm (M  $\pm$  SE, 95%-CI:  $-8.15$  to  $-4.18$ ,  $p < 0.001$ ). Our results on effects occurring after a yoga program indicate a mean decrease of the RHR due to the exercise (4.1% to 5.5% and  $-5.2$  to  $-5.5$  bpm, resp.). However, the reduction found in our study was slightly smaller than that found by Cramer et al. [8] in controlled clinical trials (M =  $-6.59$  bpm, 95%-CI:  $-12.89$  to  $-0.28$  bpm). The results of Zheng et al. [7], indicating a significant decrease of RHR due to tai chi could not be confirmed in the present meta-analysis. However, in contrast to our approach, the authors included only two randomized controlled trials, eight non-randomized controlled trials, three self-controlled trials, and seven cohort studies. Thus, the basis of their meta-analysis differed considerably with the present one.

The meta-analysis of the five RCTs on strength training included in our review did not yield significant effects: our results indicate that strength training has no significant impact on the RHR. Nevertheless, by stratification of sexes strength training ( $-5.0\%$  and  $-2.2$  bpm) and a combined endurance and strength training ( $-4.5\%$  and  $-3.8$  bpm) significantly decreased the RHR in females, but not in males.

All other sports types also resulted in a decrease of the RHR. However, the effects did not reach significance, due possibly to insufficient statistical power caused by too small sample sizes and/or only few available trials. The higher the initial RHR, the more the RHR decreased due to exercise. The effect occurs after only a few months—on average, three months with three training sessions per week. Furthermore, the participants' age was negatively associated with the exercise-induced decrease of the RHR, although the elderly participants did not exercise less than their younger counterparts.

### 4.3. Possible Mechanisms of the Heart Rate-Decreasing Effect of Sports and Physical Activity

Bahrainy et al. [211] suggest that neither an increase in resting parasympathetic tone nor a decrease in response to beta-adrenergic stimulation contribute to the decrease in RHR after regular exercise or physical activity in humans. The effect may be due to a decrease in the intrinsic heart rate via mechanisms which have not yet been fully understood. In the case of yoga, lower RHR may also be caused by an enhanced parasympathetic output [212].

#### 4.4. Possible Relevance of Exercise-Induced Reductions of the RHR for Mortality

Recently, Aune et al. [10] calculated that an increase of the RHR by 10 bpm increases all-cause mortality by 17%. The evidence regarding negative influence of elevated RHR on cardiovascular and thus all-cause death is constantly increasing. The mechanisms of this relationship are still not completely known. Possible mechanisms may be endothelial dysfunction, reduced artery compliance and distensibility, and consequently increased arterial wall stress and elevated pulsed wave velocity, which is further associated with increased after load and ultimately systemic hypertension [213]. However, the RHR does not fulfil all criteria for being an independent risk factor, as scientific evidence proving that treating an elevated RHR reduces mortality is still lacking [214]. Thus, it cannot be excluded that the relationship between the RHR and mortality may be non-causative. If there is a causative relationship assuming a persistently reduced RHR due to lifelong endurance—according to the results of our meta-analysis—exercise and yoga could reduce mortality by about 4.4% to 8.9% and about 6.0% to 8.7%, respectively, depending on the sex of the athlete.

#### 4.5. Risk of Bias

The majority of studies randomly assigned the participants to the intervention and controls groups. It is possible that the percentage may be even considerably higher, since only nine studies have been declared as non-randomized, whereas the remaining 27 studies did not report on randomization. However, including non-randomized interventional studies in the analysis probably does not affect the results, since the RHR as an autonomic function is unlikely to be influenced by the participants wills.

In only two studies, the researcher was blinded regarding the assignment of the participants to the intervention or control group. Double blinded exercise and sport studies are difficult to perform. However, this could substantially influence the measurements of the RHR. Additionally, the accuracy of the RHR measurements might be lower for physical assessments (like palpation or auscultation) than for electrocardiography. Thus, the accuracy of measuring the RHR differs between the studies that used different methods. However, a systematic error due to different measurement methods applied in the included studies is rather unlikely, given that within each study the method did not change. Furthermore, the RHR is not a stable construct and may vary within short time periods. Consequently, the point in time the measurements were conducted could have influenced the identified values. Nevertheless, it is hardly imaginable that any systematic errors occurred which influenced only the training or only the control group.

In the excluded studies, outcome reporting bias and publication bias may exist: for example, several studies examining the relationship between physical activity and/or sport and health-related outcomes probably involved and measured RHR but did not report the results. However, as in the studies included in the present meta-analysis, only in one study was RHR the primary outcome [204]—hence we assume that non-reporting of RHR does not distort our results for RHR.

Only studies presenting complete outcome parameters (RHR before and after the intervention as well as scattering data) were included in the meta-analysis. Several studies do not present the mean or median age of their participants as well as the corresponding scattering data. Lacking detailed information on the participants' ages and gender as in the study of Wiley et al. [21] also do not affect the effect of training on the RHR.

#### 4.6. Strength and Limitations

A strength of this systematic review and meta-analysis is the systematic search of primary studies employing six search engines and encompasses more than 200 samples. Additionally, types of sports and exercise performed in the intervention were considered to enable the identification of sport-specific effects on RHR. However, this meta-analysis also consists of several limitations. First, the duration and frequency of the sports and exercise conducted during the intervention programs varied considerably—even when summarizing interventions of the same types of sports. Second,

the effects of the different types of sport and exercise (endurance or strength training, Asian sports activities) cannot be compared to each other due to different physiological effects. Thus, the results of our analysis only showed if the different types of sports and exercise had an impact on the RHR or not. Third, the number of studies examining school sports, tai chi, and qigong was too low to draw final conclusions, resulting in the impossibility of calculating the effects associated with these activities.

## 5. Conclusions

Our meta-analyses indicate that both endurance sports as well as yoga decrease the RHR. These types of sports activities—after exclusion of otherwise treatable disease such as anemia, cardiac or endocrine disorders (e.g., hyperthyroidism)—could be used as a treatment in case of unfavorable high RHRs. The positive correlation between the RHR-decreasing effect and the initial RHR indicates that this therapeutic approach could be especially interesting in case of tachycardia. However, further studies are needed focusing on effects of Tai Chi and Qigong which have only been considered in a few studies. Furthermore, future studies could use shorter time intervals between measurements of RHR to get insights into the underlying processes, contributing to the reductions in RHR.

In summary, exercise-related decrease of RHR may contribute to—or at least indicate—increasing life expectancy. However, this has not been investigated in the current meta-analysis and should therefore be a topic of further studies.

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