Review

Physical Exercise Improves Heart-Rate Variability in Obese Children and Adolescents: A Systematic Review

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Abstract: Background: Childhood obesity has negative impact on heart-rate variability (HRV) and, thereby, on the cardiovascular health of children and adolescents. Thus, physical-exercise interventions were proposed to increase HRV. The present systematic review aims to provide an up-to-date analysis of research on the effect of physical-exercise interventions on HRV in obese children and adolescents. Methods: An electronic search of the literature was performed, and 10 articles were included. PRISMA guideline methodology was employed. Results: Physical-exercise interventions predominantly involved aerobic training; however, alternative training programs, including judo or recreational soccer, were found. The duration of intervention ranged from 6 to 24 weeks, with a training frequency of between 2 and 7 times per week. The duration of sessions typically ranged from 40 to 60 min. Conclusions: Results of the included articles indicated that physical-exercise intervention increased the HRV and thereby the autonomic modulation of obese children and adolescents. This is significant, as HRV is associated with cardiovascular health. Such physical-exercise interventions are crucial to reduce weight and improve cardiovascular health in children and adolescents, thereby achieving a sustainable future.

Keywords: HRV; autonomic modulation; physical activity

1. Introduction

Global obesity prevalence among children has increased in recent decades. It is estimated that 124 million children and adolescents between 5 and 19 years of age are obese, and more than 213 million are overweight [1]. Obesity has enormous health consequences. For instance, obesity during childhood increases cardiovascular risk [2,3] and cognitive decline in terms of executive function [4]. Furthermore, childhood obesity has enormous economic impact [5]. In this regard, one goal of sustainable development is to ensure healthy lives and promote wellbeing at all ages [6]. Since childhood obesity dramatically compromises health, physical-exercise interventions are crucial to reduce weight, improve cardiovascular health in children and adolescents, and achieve a sustainable future [7–9].

The World Health Organization recommends performing at least 60 min of vigorous physical activity per day, and strengthening muscle and bone through games, jumps, and sprints in order to counteract obesity [10]. As a result, aerobic exercise emerged as a relevant component of physical-activity intervention to reduce obesity. Such training can effectively decrease body fat [11], improve cardiorespiratory fitness [12,13], or reduce cardiovascular risk factors [14–16]. Despite the benefits of physical activity, Guthold, Stevens [17] revealed that the overall prevalence of insufficient physical activity among adolescents is higher than 80%.

Heart-rate variability (HRV) is a noninvasive measure of the autonomic nervous system that is based on the study of successive RR intervals. This measure provides

information about the balance between the sympathetic and parasympathetic nervous systems [18]. Low HRV is associated with increased risk of mortality from several causes [19] and increased obesity status or central adiposity [20]. Furthermore, obese adolescents show cardiac autonomic dysfunction (indicated by reduced HRV), which leads to poor cardiovascular health and decreased parasympathetic function [21,22]. However, higher HRV values are typically present in individuals with high fitness levels or after exercise [23]. In this regard, physical activity such as aerobic training [24], recreational soccer [25], high-intensity training [26], or judo [27] are used as interventions to increase HRV and thereby decrease sympathetic modulation.

To our knowledge, neither systematic reviews nor meta-analyses have explored the effect of physical-exercise interventions on HRV in obese adolescents and children. Therefore, the present review provides up-to-date analysis of studies published in scientific journals that are indexed in well-known databases on the effects of physical-exercise interventions on HRV in obese children and adolescents, and offers future directions.

2. Materials and Methods

This systematic review was conducted following the PRISMA guidelines [28].

2.1. Data Sources and Searches

Two well-known databases, PubMed and Web of Science (WOS) (including Current contents connect, Derwent innovations index, Korean journal database, Medline, Russian science citation index and, SciELO citation index), were used to extract eligible articles. The used search term string was: (child* OR adolescen* OR kid) AND (obes* OR overweight) AND (exer* OR "physical therapy") AND ("heart rate variability" OR HRV OR "autonomic modulation").

The article selection process is shown in Figure 1. The search was conducted by SV and supervised by JLLL. In cases of disagreement, DCM directed a consensus discussion. The search ended on 5 January 2021, and only articles published after 1970 were potentially included.

Studies were included if they met the following inclusion criteria: (a) quantitative randomized controlled trial or observational designs focused on exercise interventions, (b) samples comprising adolescents or children, (c) adolescents or children suffering from obesity, and (d) the article reported HRV outcomes. Furthermore, articles that met any of the following criteria were excluded: (a) studies not written in Spanish, Portuguese, English, Italian, or French; (b) summaries of conferences or seminars; and (c) commentaries, editor letters, dissertations, or theses.

2.2. Risk of Bias

The Evidence Project risk of bias tool [29] was used to assess the risk of bias in the selected articles. Eight criteria were assessed as: yes, no, not applicable, or not reported. These criteria were: (1) cohort, (2) control or comparison group, (3) pre-/postintervention data, (4) random assignment of participants to the intervention, (5) random selection of participants for assessment, (6) follow-up rate of 80% or more, (7) comparison groups equivalent on sociodemographics, and (8) comparison groups equivalent at baseline on outcome measures. This information is summarized in Table 1.
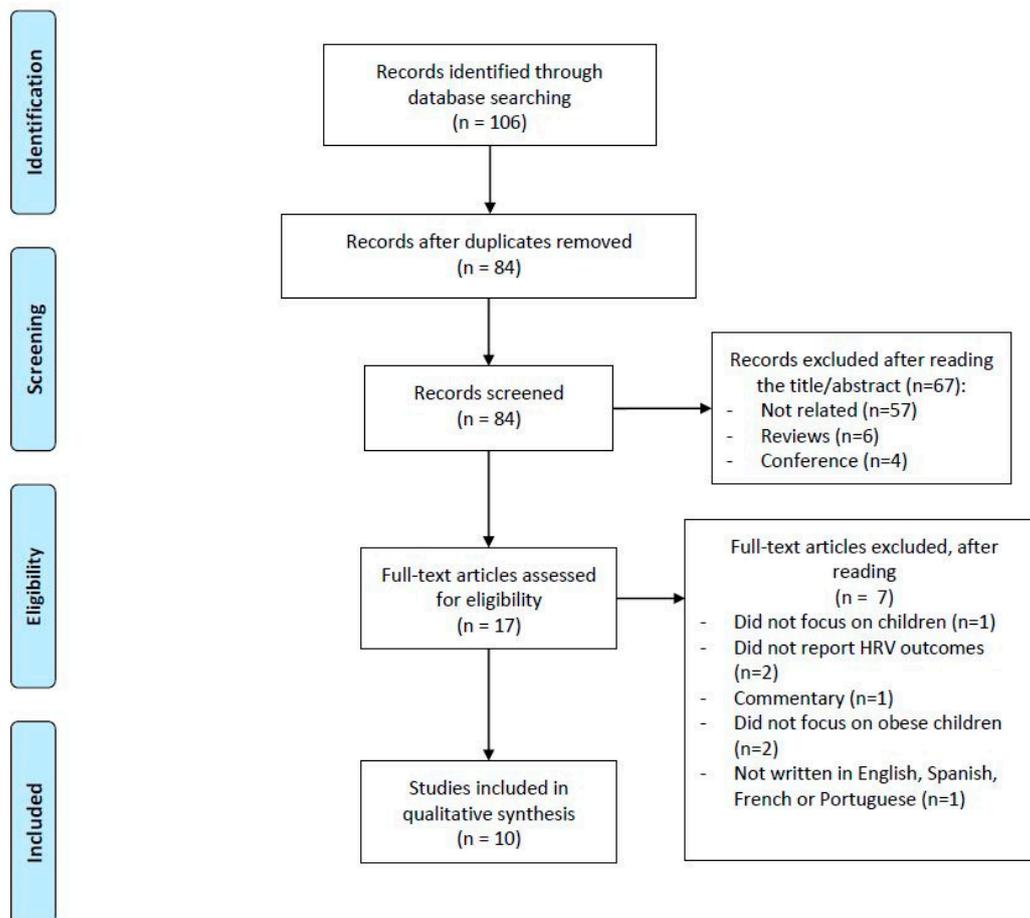
Figure 1. Article selection process flow diagram.

2.3. Data Extraction

The Participants, Intervention, Comparison, Outcome, and Study (PICOS) design strategy, as recommended by the PRISMA methodology, was used to extract data from articles [28]. This information is summarized in Tables 2–4.

Table 1. Risk of bias in randomized and nonrandomized controlled trials using Evidence Project risk of bias tool.

Study	Cohort	Control or Comparison Group	Pre-/Postintervention Data	Random Assignment of Participants to Intervention	Random Selection of Participants for Assessment	Follow-Up Rate of 80% or More	Comparison Groups Equivalent on Sociodemographics	Comparison Groups Equivalent at Baseline on Disclosure
Brasil (2020)	green	green	red	red	red	red	red	red
Chen (2016)	green	green	green	green	red	green	green	green
Farah (2012)	green	green	green	green	red	red	green	green
Farinatti (2016)	green	green	red	red	red	green	green	red
Faulkner (2013)	green	green	green	red	red	red	green	orange
Gutin (2000)	green	green	green	green	red	green	green	green
Hamila (2017)	green	green	green	green	red	green	green	green
Huang (2019)	green	red	green	red	red	green	white	white
Prado (2010)	green	green	green	green	red	orange	green	green
Vasconcellos (2015)	green	green	green	green	red	green	green	green

Evidence Project risk of bias tool criteria assessed as: yes, no, not applicable, or not reported. Green, yes; red, no; orange, not reported; white, not applicable.

3. Results

3.1. Article Selection

The article selection process is depicted in Figure 1. A total of 106 articles were identified in electronic databases WOS (65 articles) and PubMed (41 articles). Twenty-two articles were duplicates. Furthermore, 67 articles were excluded after reading the title or abstract (reasons detailed in Figure 1). Of the remaining 17 articles, 7 were excluded as per the exclusion criteria. Therefore, 10 articles were included in the qualitative synthesis.

3.2. Risk of Bias

Table 1 shows the results of the risk of bias assessment. Random assignment of participants to intervention (40% of articles did not fulfill this criterion) [27,30–32], random selection of participants for assessment (0% of articles fulfilled this criterion), and follow-up rate of 80% or more (30% of articles did not fulfill this criterion) [26,27,31] were the most important sources of bias detected in the selected articles.

3.3. Participants

Table 2 displays the participants´ characteristics in each study. Three articles were focused on obese children [27,33,34], whereas 7 were focused on obese adolescents [25,26,30–32,35,36]. Sample sizes ranged between 7 and 79 participants per study, a total of 335 participants (49.25% girls). Participants´ ages ranged from 9 to 15 years.

Table 2. Characteristics of samples and study designs of included articles.

Study (Year)	Participants	Sample Size (N)	Age (SD)	Study Design	Control Group Protocol
Brasil (2020)	Obese children Nonobese children	20 (10 g) 15 (7 g)	11.1 (1.1) 10.7 (1.6)	Non-RCT	Usual life
Chen (2016)	Obese adolescents	25 (13 g) 25 (9 g)	EG: 12.64 (0.70) CG: 12.84 (0.75)	RCT	Usual life
Farah (2012)	Obese adolescents	9 (5 g) 10 (5 g)	HIT: 15.4 (0.4) LIT: 14.8 (0.4)	RCT	Light-intensity training
Farinatti (2016)	Obese adolescents Nonobese adolescents	24 (17 g) 20 (7 g)	13–17	Non-RCT	Usual life
Faulkner (2013)	Obese adolescents Type II DM adolescents	10 (6 g) 9 (8 g)	14.6 (1.6) 14.7 (1.8)	Non-RCT	Personalized aerobic training
Gutin (2000)	Obese children	79 (53 g)	9.5 (1)	Crossover	Usual life
Hamila (2017)	Obese adolescents	7 (4 g) 8 (5 g)	EG: 14.5 (1) CG: 14.5 (0.9)	RCT	Usual life
Huang (2019)	Obese adolescents	21 (10 g)	10–16	Observational	-
Prado (2010)	Obese children	18 15	EG: 10.3 (0.2) CG: 10.2 (0.3)	RCT	Diet
Vasconcellos (2015)	Obese adolescents	10 (4 g) 10 (2 g)	EG: 14.3 (1.3) CG: 14.8 (1.4)	RCT	Usual life

g, girls; DM, diabetes mellitus; RCT, randomized controlled trial; EG, experimental group; CG, control group; HIT, high-intensity training; LIT, light-intensity training; N, sample size; SD, standard deviation.

3.4. Study Design

Table 2 presents the study design. Five (50% of total) articles were classified as randomized controlled trials [25,26,34–36]. Three articles were classified as nonrandomized controlled trials [27,30,31] (two groups with pre- and postassessments but without randomization). Furthermore, one article had a crossover design [33], whereas another had an observational design [32] (the experimental group was only assessed once at the end of the intervention).

3.5. Intervention

Table 3 summarizes the intervention protocols of the treatment groups in each study. All interventions included an experimental group comprising participants who performed exercise. The duration of interventions ranged from 6 to 24 weeks with a training frequency of between 2 and 7 times per week. Session durations typically ranged between 40 and 60 min except for one intervention that required a total of 5 h/day of physical activity [32].

Table 3. Frequency, duration, and intensity of physical-exercise interventions included in this systematic review.

Study (Year)	Intervention Duration (Weeks)	Session Duration (Minute)	Weekly Frequency (Days)	Intensity	Activities Included in Session
Brasil (2020)	12	60	2	65–75% maximal heart rate	Sessions consisted of 60 min of judo training for beginners (including 10 min warmup and 10 min cooldown).
Chen (2016)	12	40	4	60–70% maximal heart rate	Participants were free to choose one of the provided exercise types (e.g., fast walking, stair climbing, jumping rope, or aerobic dancing).
Farah (2012)	24	Not fixed	31	HIT: at ventilatory threshold I. LIT: 20% below ventilatory threshold I.	Treadmill.
Farinatti (2016)	12	30–40	3	50–85% 10 RM, progressively	One set of 10–15 repetitions (reps) with 50–70% of load corresponding to 10 RM for first 2 weeks; two sets of 8–12 reps with 60–80% 10 RM in weeks 3–6, and three sets of 6–10 reps with 70–85% 10 RM in weeks 7–12.
Faulkner (2013)	16	60	7	65–75% maximal heart rate	Personalized training (based on participant interest) where participants performed activities such as calisthenics, kickboxing, dancing, cycling, walking, and Dance Dance Revolution (Konami, Japan). Activities could be conducted at gym facilities, parks, schools, participants' homes, or all of the above.
Gutin (2000)	16	40	5	-	First 20 min were spent on machines (e.g., treadmill, cycle, Nordic ski machine), and next 20 min were devoted to games modified to maintain a high rate of energy expenditure.
Hamila (2017)	8	50	3	70% maximal aerobic speed	Each session included a 10 min collective warmup based on ball games followed by 2 × 20 min periods of walking, interspersed by 10 maximal sprints on a cycle ergometer against a braking force equal to 0.75 g/kg body mass.
Huang (2019)	6	5 h/day	6	-	Program primarily comprised various types of aerobic exercise such as bicycling, walking, running, dancing, and ball games for 5 h/day. It was supplemented by strength training. Endurance exercises involved moderate- (70–85% of maximal heart rate) and high-intensity (~90% of maximal heart rate) training. Strength training was conducted 2–3 times per week at 40–50% maximal strength for 2–3 sets of 12–15 repetitions maximum, with 2–3 min of rest between sets. Furthermore, participants were provided with calorie-restricted but nutritionally complete diet based on their age.
Prado (2010)	16	60	3	Ventilatory anaerobic threshold	Each exercise session consisted of 30 min of walking and/or jogging (aerobic exercise) on a jogging track, and 30 min of recreational exercise.
Vasconcellos (2015)	12	60	3	-	Each session consisted of a 10 min warmup followed by 40 min of games performed in small pitch areas (such as 2 vs. 2, 3 vs. 3, and 4 vs. 4), and a 10 min cooldown.

A total of 6 articles conducted aerobic training in the range of 60–75% of maximal heart rate [27,31,35], at the first ventilatory threshold [26], at 70% of the maximal aerobic speed [36], or at the ventilatory anaerobic threshold [34]. One article conducted resistance training at 50–85% 10 repetition maximum (RM) [30]. The three remaining articles did not report intensity; however, their interventions were based on aerobic training [33], aerobic plus resistance training [32], and recreational soccer [25].

3.6. Comparison Groups

Table 2 provides the protocol followed by the comparison groups. Two articles included a nonobese adolescent group [27,30], 1 Type II diabetes mellitus group [31], 1 did not include a comparison group [32], and the 6 other articles included obese children or adolescents as a comparison group [25,26,33–36].

Among studies with a control group, 6 articles encouraged the control group to follow their usual life [25,27,30,33,35,36]. In contrast, the control group of one study performed light-intensity training [26], that of another article performed personalized aerobic training [31], and a third control group followed a diet (see Table 2) [34].

3.7. Outcomes

HRV results from the selected articles are summarized in Table 4. Time- and frequency-domain variables were the most studied variables. Eight articles reported within- or between-group differences after physical training on HRV variables. Only 1 article did not report any significant differences [31].

Table 4. Results analysis of selected articles.

Authors	Recording Protocol and Instrument	Outcome Measure	EG Baseline	EG after Treatment	CG Baseline	CG after Treatment	Reported Effect
Brasil (2020)	5 min (Polar RS800cx, Polar™, Kempele, Finland)	RR (ln ms)	2.85 (0.02)	2.88 (0.02)	2.88 (0.02)	-	WG
		SDNN (ln ms)	1.66 (0.06)	1.64 (0.07)	1.66 (0.05)	-	-
		Rmssd (ln ms)	1.64 (0.07)	1.63 (0.07)	1.67 (0.07)	-	-
		Pnn50 (ln %)	1.16 (0.12)	1.19 (0.11)	1.24 (0.12)	-	-
		LF (ln ms^2)	1.75 (0.03)	1.72 (0.02)	1.71 (0.02)	-	-
		HF (ln ms^2)	1.63 (0.02)	1.70 (0.03)	1.66 (0.03)	-	WG
		LF/HF (ln ms^2)	0.13 (0.05)	0.02 (0.03)	0.06 (0.04)	-	BG (pre)/WG
Chen (2016)	5 min Handheld device (CheckMyHeart 3.0, DailyCare BioMedical, Inc., Taoyuan, Taiwan)	Lf (nu)	57.82 (15.64)	62.85 (18.27)	52.09 (16.3)	48.56 (15.46)	BG
		Hf (nu)	42.27 (13.38)	42.37 (13.38)	42.27 (13.38)	42.37 (13.38)	EG (WG)/BG
Farah (2012)	7 min (Polar RS800cx, Polar™, Kempele, Finland)	Mean RR (ms)	757 (55)	-	810 (31)	-	EG (WG)/BG
		SDNN (ms)	75 (16)	-	88 (9)	-	
		rMSSD (ms)	57 (18)	-	66 (9)	-	
		Pnn50 (%)	26 (10)	-	33 (5)	-	EG (WG)/BG
		LF (ms^2)	3941 (1320)	-	5090 (1000)	-	
		HF (ms^2)	1602 (1014)	-	1842 (392)	-	EG (WG)
Farinatti (2016)	15 min Noninvasive device (Finometer, Finapres Medical Systems, Amsterdam, The Netherlands)	Mean RR (ms)	746.2 (71.4)	-	862.4 (126)	-	WG
		SDNN (ms)	58.3 (25.5)	-	79.8 (35.9)	-	WG
		rMSSD (ms)	46 (18.4)	-	74.3 (21.5)	-	BG (pre)/WG
		Pnn50 (%)	24.8 (16)	-	44.6 (13.6)	-	BG (pre)/WG
		LF (nu)	50.4 (16.3)	-	31.4 (17.2)	-	
		Total power	-	-	-	-	WG
		HF (nu)	49.6 (16.3)	-	68.6 (17.2)	-	BG (pre)/WG
		LH/HF ratio	1.3 (0.9)	-	0.59 (0.6)	-	BG (pre)

Table 4. *Cont.*

Authors	Recording Protocol and Instrument	Outcome Measure	EG Baseline	EG after Treatment	CG Baseline	CG after Treatment	Reported Effect
Faulkner (2013)	24 h Vision Premier Holter Analysis System Software, (Cardiac Science, Bothell, WA).	Total Power (ln ms^2)	8.3 (0.9)	8.0 (1)	7.6 (0.6)	7.6 (0.8)	-
		HF (ln ms^2)	6.8 (1)	6.5 (1.1)	6 (0.8)	6.1 (0.8)	-
		LF (ln ms^2)	7 (1)	6.7 (1.1)	6.4 (0.5)	6.3 (0.6)	-
		SDNN (ms)	150 (46)	148 (57)	108 (22)	110 (35)	-
		SDANN (ms)	127 (37)	127 (52)	94 (22)	95 (32)	-
		Pnn50 (%)	23 (15)	19 (12)	11 (6)	12 (9)	-
		rMSSD (ms)	72 (37)	62 (36)	41 (15)	46 (25)	-
Gutin (2000)	10 min Schiller ECG system(Baar, Switzerland)	rMSSD (ms)	54.3 (26.3)	Change = 6.1 (27.8)	-	-	BG
Hamila (2017)	5 min (Polar S-810, Polar^{TM}, Kempele, Finland)	Mean RR (ms)	644 (40.6)	670.4 (64.1)	611 (30.5)	621.7 (30.5)	-
		ln rMSSD	1.58 (0.2)	1.78 (0.2)	1.53 (0.19)	1.62 (0.33)	-
		HF (nu)	24.6 (14.4)	34.5 (15.1)	27.02 (8.98)	28.1 (6.46)	EG (WG)
		HF (ln ms^2)	2.5 (0.5)	2.6 (0.5)	2.3 (0.51)	2.37 (0.81)	-
		LF (nu)	72.2 (12.8)	48.1 (23.9)	71.8 (22.34)	71.17 (19.56)	EG (WG)/BG
		LF (ln ms^2)	2.9 (0.5)	2.5 (1.3)	2.59 (0.35)	2.83 (0.55)	-
		LF/HF	4 (2.3)	2.6 (1.6)	2.81 (0.9)	2.91 (1.28)	-
		SD1 (ms)	34.8 (10.5)	45.7 (15.6)	34.5 (8.16)	35.29 (17.5)	EG (WG)
		SD2 (ms)	75.5 (32.1)	98.21 (23.59)	69.3 (10.5)	77.57 (12.8)	-
Huang (2019)	10 min SphygmoCor system (AtCor Medical, Sydney, Australia)	SDNN (ms)	65.2 (18.98)	88.3 (28.36)	-	-	WG
		rMSSD (ms)	65.8 (27.49)	100.5 (37.68)	-	-	WG
		Pnn50 (%)	37.8 (17.05)	57.8 (12.31)	-	-	WG
		Total Power (ms^2)	4012.8 (2272.3)	4633.7 (1978.1)	-	-	-
		LF (ms^2)	1172.8 (1189.5)	1882.8 (2465.1)	-	-	-
		HF (ms^2)	1372.5 (908.8)	1988 (983.3)	-	-	-
		LF/HF	1 (0.55)	0.7 (0.43)	-	-	WG
Prado (2010)	3 min 12-lead ECG (Marquette Medical Systems, CardioSoft, Wisconsin, USA)	LF (ms^2)	-	-	-	-	BG/EG (WG)
		HF (ms^2)	-	-	-	-	BG/EG (WG)
		LF (nu)	-	-	-	-	BG/EG (WG)
		HF (nu)	-	-	-	-	BG/EG (WG)
		LF/HF	-	-	-	-	BG/EG (WG)
Vasconcellos (2015)	5 min (Polar RS800cx, Polar^{TM}, Kempele, Finland)	LF (nu)	-	-	-	-	WG
		HF (nu)	-	-	-	-	WG
		LF/HF	-	-	-	-	

RR, R to R interval; SDNN, standard deviation of all normal-to-normal RR intervals, pNN50, percentage of intervals > 50 ms different from the previous interval; RMSSD, square root of mean of squares of successive differences of interval RR; LF/HF, low frequency (LF) (ms^2)/high frequency (HF) (ms^2) ratio; total power (sum of all spectra); nu, normalized units; ln, natural logarithm; SD1, standard deviation of points perpendicular to axis of line of identity in Poincaré plot; SD2, standard deviation of points along axis of line of identity in Poincaré plot; WG, within-group; BG, between-group.

Between-group differences were detected in 7 articles [26,27,30,33–36]. Four of them were randomized controlled trials [26,34–36], 2 [27,30] were classified as nonrandomized controlled trials (as groups were not randomly allocated), and 1 [33] had a crossover design. Only 1 randomized controlled trial [25] did not report between-group differences (although within-group differences were reported).

4. Discussion

The present systematic review performed up-to-date analysis of studies focused on the effects of physical-exercise interventions on HRV in obese children and adolescents. Physical-exercise interventions mainly focused on aerobic training, but alternative exercise activities, including judo and recreational soccer, were found. The duration of interventions ranged from 6 to 24 weeks with training frequency between 2 and 7 times per week. The duration of sessions typically ranged from 40 to 60 min. From intervention results, HRV increased after physical-exercise interventions in obese children and adolescents, leading to a reduction in sympathetic modulation. However, while 10 articles were included in this systematic review, the heterogeneity of the procedures and methodological concerns may have increased the risk of bias. As such, this interpretation of results must be considered with caution.

Previous studies confirmed that childhood obesity induced abnormal autonomic modulation (presentation of reduced HRV), which is related to poor cardiovascular health [21,22]. This is relevant, as cardiovascular health and, thereby, childhood lifestyle can compromise health in adulthood [37]. In this regard, previous studies indicated that high HRV could be considered a health biomarker [38] for critical illness in children [39]. Thus, considering the effects of physical-exercise interventions on HRV in obese children and adolescents, the autonomic modulation of these populations could be enhanced.

One sustainable development goal is to ensure healthy lives and promote wellbeing at all ages [6]. Considering both the negative impact of obesity on health and the large global prevalence, childhood obesity dramatically affects the achievement of this goal. Of all the negative consequences of obesity, cardiovascular health can be highlighted due to the high health-related costs [40,41] and the relationship between cardiovascular health and mortality [42,43]. Thus, physical-exercise interventions that aim to reduce weight and improve cardiovascular health in children and adolescents are crucial to achieving a sustainable future [7–9].

Results of the articles included in this systematic review showed that between-group differences (experimental vs. control) were found in 7 of the 10 articles [26,27,30,33–36]. Among them, 4 were randomized controlled trials [26,34–36] (only 1 randomized controlled trial did not observe between-group differences), 2 [27,30] were classified as nonrandomized controlled trials (as groups were not randomly allocated), and 1 [33] had a crossover design. These results reinforce the hypothesis of physical exercise's utility as a tool to restore the correct functioning of autonomic modulation in obese children and adolescents. However, future studies should focus on how obesity can impair autonomic modulation. In this regard, obesity disrupts the normal maturation of cardiac autonomic control [44] and would, therefore, favor a reduction in autonomic activity [45,46] or an increase in sympathetic activity [45,47].

One of the main problems in physical-exercise intervention in obese children and adolescents is adherence. Adolescents are not typically motivated by physical-exercise intervention [48], which may lead to ineffective exercise [30]. Taking into account these relevant concerns, some articles included in this systematic review [25,27,31] conducted alternative physical-exercise interventions (compared with traditional aerobic interventions), such as customized training (based on participant interest), judo, or recreational soccer, in order to increase motivation and adherence to programs. These interventions were based on a previous study that indicated that adolescents are more interested in physical activities that are social, outdoors, and competitive. Results from these three interventions demonstrated that judo [27] obtained 74.07% adherence, recreational soccer [25] 62.5% adherence, and personalized aerobic training [31] 78% adherence. However, comparing the adherence of these interventions with the mean adherence of the rest of the program (86.38%) reveals that adherence in these three intervention programs was lower. Thus, future randomized controlled trials should address this topic in order to better understand these controversial results.

Limitations in this systematic review should be noted. First, only articles in English, French, Italian, Portuguese, and Spanish were included. Thus, relevant articles in other languages could have not been found. Second, the heterogeneity of the procedures did not allow for meta-analysis to clarify the extent of HRV improvement after physical-exercise interventions. Third, the results of the systematic review must be considered with caution due to the identified risk of bias sources in the included articles.

5. Conclusions

Physical-exercise intervention increased the HRV and thereby improved the autonomic modulation of obese children and adolescents. This is relevant, as HRV is associated with cardiovascular health. The duration of interventions ranged from 6 to 24 weeks, with training frequency between 2 and 7 times per week. The duration of sessions typically ranged from 40 to 60 min. Physical-exercise interventions mainly focused on aerobic training (60%–75% of maximal heart rate), but also included alternative interventions such as judo, personalized aerobic training, or recreational soccer. However, extracted evidence from this systematic review did not confirm that these alternative interventions improve adherence to physical exercise.

Conflicts of Interest: The authors declare no conflict of interest.

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