Autonomic cardiac function, body composition and cardiorespiratory fitness changes in adolescents after a multidisciplinary obesity treatment program: a feasibility study

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Abstract:

Purpose: This feasibility study aimed to analyze the effects of a multidisciplinary (e.g., psychological, nutritional and water-based exercise interventions) obesity treatment program on resting heart rate variability (rHRV) indices according to the degree of excess body mass (overweight vs obesity) in adolescents. Additionally, we tested the association between changes in rHRV indices with changes in body composition and cardiorespiratory fitness. **Methods:** Twenty-five adolescents completed the study, 11 from the overweight group (OWG) and 14 from the obese group (OBG) classified according to body mass index. Anthropometric measures, autonomic cardiac function (measured by rate-to-rate interval analyses), lean mass and body fat, and cardiorespiratory fitness were assessed prior to and after the 16-week intervention period. **Results:** Both groups increased their parasympathetic indices (e.g., standard deviation 1) [OWG: Δ = 8.5 (1.7–15.3) ms; magnitude of change: “likely”; OBG: Δ = 11.4 (4.3–18.4) ms; “very likely”] and cardiorespiratory fitness [OWG: Δ = 2.0 (1.1–2.8) mL/kg/min; “likely”; OBG: Δ = 2.4 (1.5–3.3) mL/kg/min; “Almost certain”] with a slightly greater magnitude of change for the OBG. The OWG showed greater changes in body composition [e.g., body fat: Δ = −3.2 (–4.6 to −1.8) kg “Very likely”] when compared to the OBG [Δ = −2.8 (−4.4 to −1.3) kg “Possible”]. Inverse and large correlations were noted for changes in body fat markers (%) and changes in parasympathetic indices of rHRV (%) (i.e., rMSSD and SD1). **Conclusions:** These results provide evidence that a multidisciplinary program improves parasympathetic indices, body composition, and cardiorespiratory fitness independent of the degree of excess body mass.

Keywords: Pediatric obesity | Intervention studies | Parasympathetic indices | Body composition | Cardiorespiratory fitness

Article:

Abbreviations

BMI: Body mass index
HF: High frequency
HRrest: Resting heart rate
OBG: Obese adolescent group
OWG: Overweight adolescents group
rHRV: Resting heart rate variability
rMSSD: Square root of the mean of the squares of successive *R–R* interval differences
SD1: Standard deviation 1 of instantaneous beat-to-beat *R–R* interval variability measured from Poincare plots
VO_{2max} : Maximal oxygen consumption

Introduction

Autonomic cardiac function can be non-invasively evaluated by measuring resting heart rate variability (rHRV) [1]. Previous studies have demonstrated the relationship between low rHRV and increased risk of death following cardiac events [2], whereby the increase in rHRV represents an improvement in parasympathetic nervous system indices [1].

Excess body mass is associated with several cardiovascular risk factors, including low parasympathetic indices in children and adolescents [3,4,5]. Moreover, a decline in parasympathetic indices appears to be related to lower levels of moderate to vigorous physical activity participation, cardiorespiratory fitness, higher insulin resistance and higher systolic blood pressure in children and adolescents [3, 5, 6].

Given the complexity of obesity and its comorbidities, non-pharmacological multidisciplinary strategies (e.g., exercise and dietary modifications with psychological support) have been studied as a potential tool within a multidisciplinary program in Brazil [7, 8] to improve health-related parameters in overweight and obese youths [9]. Particularly, exercise may be performed in different environments (i.e., water- and land-based exercise), with greater adherence recently shown in a water-based exercise program compared to land-based exercise program [10]. Improvements in cardiorespiratory fitness and body composition may be related to improvements in rHRV after an exercise training program in overweight and obese adults [11]. However, the benefits of a multidisciplinary approach for overweight and obese adolescents on rHRV are not well understood [11, 12]. Furthermore, possible health markers (e.g., cardiorespiratory fitness and body composition) associated with rHRV changes in overweight and obese adolescents remain to be elucidated [6, 13, 14].

Although obesity is recognized as a public health issue in children and adolescents [15], there is still relevant discussion regarding the impact of degrees of excess body mass on health-related parameters changes after an intervention program [16,17,18]. It appears that with a greater degree of excess body mass there are increased risks for elevated blood pressure, metabolic syndrome risk factors, and declined physical fitness and health-related quality of life [16, 17]. However, the influence of the degree of excess body mass on autonomic cardiac function changes after an intervention program remains unclear [18]. These results may assist clinical practices by better targeting multidisciplinary interventions according to the degree of excess body mass with respect to autonomic cardiac function.

Thus, we aimed to study the effects of a multidisciplinary obesity treatment program combining psychological, nutritional and water-based physical exercise interventions on rHRV indices according to degree of excess body mass (overweight *vs* obese) in adolescents. Additionally, we tested the associations between changes in rHRV indices with changes in body composition and cardiorespiratory fitness markers following the intervention. We hypothesized that the multidisciplinary intervention program would improve rHRV regardless of the degree of excess body weight and that rHRV indices changes would be associated with changes in body composition and cardiorespiratory fitness.

Methods

Experimental design

This feasibility study is a pragmatic trial was designed to evaluate the effects of a multidisciplinary intervention in a real-life, outpatient setting (i.e., program offered on fixed days and set times by the local University and the University Hospital as a public health service to the community). Pragmatic trials designs are known to produce more generalized outcomes, which translates into a greater perspective of habitual routines and how they behave when outside a clinical setting [19, 20].

The study pediatrician completed the medical assessments prior to initiating the baseline assessments. Before beginning the intervention program, in the baseline assessment week, anthropometric measures, body composition, cardiorespiratory fitness and rHRV were assessed. After completing the 16-week program combining psychological, nutritional, and water-based exercises, the same assessments were repeated for all adolescents enrolled in the study.

Participants

We used the following inclusion criteria for the present study: aged 10–18 years, presence of excess body mass (overweight or obesity) according to the cut-off points presented by Cole and Lobstein [21], and participant self-identified availability to follow the schedule (days and times) of the intervention program during the treatment period. For the analysis, adolescents were allocated in two different groups: the overweight adolescents group (OWG) and the obese adolescent group (OBG). The exclusion criteria used were: metabolic, endocrine, or genetic abnormalities that were associated with the use of glucocorticoids or psychotropics, and compliance of less than 70% during the multidisciplinary intervention. Although the intervention program encouraged adolescents to be more physically active in their routines, those who opted to engage in systematic and regular exercise training programs were not included in the analysis to avoid possible influences in the results.

Thirty-five adolescents took part in the water-based exercise intervention as a component of the multidisciplinary intervention after the program was advertised by the University and University hospital in the local media. Of these, ten adolescents did not complete the study protocol due to transportation problems (3 adolescents), preference for other activities at the same time as the intervention (2 adolescents), or they did not attend the final rHRV assessment. The characteristics of the 25 adolescents who completed the study are: age = 12.7 ± 1.3 years; body mass index = 28.9 ± 5.2 kg/m^2; girls = 17 (68%); maturation stage = all in pubertal stage based on pubic hair self-assessment. Eleven adolescents were classified as overweight and 14 as obese.

The study was approved by the local Ethics Board (protocol 463/2009) registered at the Brazilian registry of clinical trials (RBR-95239p) and is in accordance with the guidelines in the Declaration of Helsinki. All the adolescents and their parents/guardians gave their written consent before starting the study protocol.

Description of the multidisciplinary obesity treatment program

Kinesiologists, nutritionists, psychologists, and a pediatrician composed the intervention team. The main objective of the team was to facilitate the establishment of proper and adequate eating and exercise behavior changes through cognitive behavioral therapy [22].

The intervention program is organized in weekly group meetings with the psychologists, nutritionists, and exercise professionals (physical activity-related educational program). Additionally, the participants took part in the water-based exercise program three times per week. More details of each intervention are described elsewhere [10].

In summary, the psychological intervention was conducted by a psychologist specialized in cognitive behavioral therapy, as well as psychology students in University and consisted in an hour of group session per week. The aim of these meetings was to discuss the following topics: (a) setting goals; (b) self-observation of own behaviors and consequences (immediate, short and long-term); (c) identification of feelings and emotional analysis; (d) body image discussion; (e) self-knowledge and analysis of internal events (thoughts) and their consequences; (f) aspects related to self-motivation and self-control; (g) interpersonal relationship (social skills). The nutritional intervention took place in 1 h weekly meetings with two nutritionists. The aim of these meetings was to encourage the adolescents to reduce their food consumption, each healthier foods, and guide the subjects on topics related to different nutritional aspects such as: (a) the food pyramid; (b) energy density of food; (c) importance of micro and macronutrients to healthy eating behavior; (d) the nutritional composition of food; (e) control of portion size; (f) strategies for eating out; (g) strict vs. flexible dietary restraint; (h) healthy food preparation; (i) frequency of feeding. The physical activity-related educational program also had 1 h weekly lectures, whose goal was to provide information about the practice of exercise and its benefits. The water-based physical activity program focused on exercising intensely in a playful and recreational way to increase the engagement, as recommended by the cognitive behavioral therapy [22]. They performed three session per week of 60 min each, in which they performed (1) immersed interval walking/running training; (2) immersed interval running training with water-based equipments (e.g., leggings and dumbbells)—both activities for about 30% of the session time; (3) to swim exercises (mainly crawl and backstroke) and diving to catch marbles and other objects (i.e., treasure hunt) for about 30% of the total time) and; (4) continuous recreational exercises for the rest of the session (40%).

Anthropometry and body composition evaluation

Height was determined using a wall-mounted stadiometer attached to the balance (accuracy: 0.1 cm) and body mass assessed with an electronic balance scale (Welmy, Sao Paulo, Brazil; scale: 0.05 kg). Body mass index was calculated as body mass (kg)/height $(m)^2$. Waist and hip circumference measurements were obtained using a non-extensive tape (WISO, Santa Catarina, Brazil; scale: 0.1 cm). All anthropometric measurements followed international standards proposed by Lohman et al. [23].

Body composition was assessed using a multifrequency bioelectrical impedance analyzer (Octapolar, InBody 520 model, Korea). The measurement in this equipment is performed on a scale in the upright position. We adopted the recommendations described by Heyward [24] for this type of evaluation: urinating ~30 min before the assessment, abstaining from the consumption of caffeinated and alcoholic beverages in the preceding 48 h, avoid intense physical activity 24 h and, avoiding diuretics 7 days prior to testing. Percentage body fat, absolute body fat and absolute lean mass were recorded.

Cardiorespiratory fitness evaluation

The 20-m shuttle run test as described by Leger et al. [25] was used to assess cardiorespiratory fitness. This maximal test started at 8.5 km/h with progressive increments of 0.5 km/h every minute until the subject reached volitional exhaustion. The participants were instructed to run in cadence with the beep for 20 m and were accompanied by an experienced assessor to help them stay in correct rhythm throughout the test. Relative maximal oxygen consumption ($VO_{2\max}$) was indirectly estimated according to the last attained stage [25].

Resting heart rate variability evaluation

Following blood pressure measurements, rHRV was analyzed, in the seated position, using a heart rate monitor (POLAR RS800cx, Kempele, Finland). This equipment has been previously validated for this measurement [26]. We chose not to control for respiratory rate because adolescents often have difficulty pacing their breathing with a predetermined cadence. We advised the participants to avoid the practice of any strenuous exercise, as well as the consumption of beverages containing caffeine for at least 24 h prior to this measurement. They were also asked not to consume any food for at least 2 h prior to this measurement.

R–*R* intervals were recorded for 10 min in a quiet room at a temperature of 23 °C between 4 and 5 pm. The last 5 min of each 10-min interval were used to assess rHRV variables. The data for *R*–*R* intervals were downloaded into a Polar Pro Trainer Software and expressed in milliseconds. All ectopic beats with deviation higher than 20% of adjacent intervals were identified and interpolated by adjacent *R*–*R* intervals, as recommended in the Task Force [1]. It worths to mention that the Task Force [1] also recommends short-term recording to avoid ectopy, as we followed.

The *R*–*R* intervals were analyzed using time-domain, frequency-domain, and non-linear-domain techniques to determine parasympathetic indices with the Kubios HRV analysis (University of

Eastern Finland). In the time-domain, we computed the square root of the mean of the squares of successive *R–R* interval differences (rMSSD). In the frequency-domain, we computed the frequency band of high frequency (HF: 0.15–0.4 Hz), in both milliseconds squared (ms^2) and normalized units (nu). The power spectral density was quantified using the fast Fourier transform algorithm of 1024 points, 50% overlap and Welch's periodogram method, and 256 s width (nature of the interval tachogram). This is within the recommendation for standardization of commercial equipment use in short-term recording presented in the Task Force [1]. In the non-linear-domain, we assessed standard deviation 1 of instantaneous beat-to-beat *R–R* interval variability measured from Poincare plots (SD1). Resting heart rate (HRrest) was also analyzed. The index rMSSD was chosen as reference due to its greater reliability compared to other rHRV indices [27]. Moreover, these variables seem to be the greater predictor of aerobic capacity [28, 29].

Statistical analysis

Data are presented as mean ± standard deviation. Normal distribution of the data was tested by the Shapiro–Wilk test. Baseline characteristics were compared between OWG and OBG through Independent *t* test and 2 × 2 Chi-square test. The adaptations to the multidisciplinary intervention were assessed by mixed-model ANOVA for repeated measures. When baseline was different between OWG and OBG, we applied mixed-model ANCOVA for repeated measures using the pre-intervention values as covariates, according to the recommendations of Vickers and Altman [30]. We applied Bonferroni post hoc adjustments.

Pearson's product-moment correlation was also used to test the association between percentage changes in rHRV indices with percentage changes in body composition and cardiorespiratory fitness. The *r* values were classified as per Hopkins et al. [31] as: trivial (<0.1), small (0.1 to <0.3), moderate (0.3 to <0.5), large (0.5 to <0.7), very large (0.7 to <0.9), and almost perfect (≥0.9).

Given the small sample size, analysis of practical inferences based on magnitudes [31] were applied in addition to the null hypothesis tests to complement the analyses of the effects of the intervention program on our outcomes. This analysis may minimize the chance of type II statistical error and is sometimes applied alone (i.e., with no traditional null hypothesis tests) [32]. Magnitude-based inferences were applied to identify the changes of a true observed effect being positive (increase), negative (decrease), or trivial. The smallest worthwhile change (0.2 times the pooled standard deviation of the participants at baseline) was determined [31]. Therefore, changes were assessed as: <1% almost certainly not; 1–5% very unlikely; 5–25% unlikely; 25–75% possible; 75–95% likely; 95–99% very likely; and >99% almost certainly. If both negative and positive values presented results >10%, the inference was considered unclear.

Results

Participants' age ranged from 10 to 15.9 years while the mean values were 12.9 ± 0.9 years in the OWG and 12.5 ± 1.5 years in the OBG, with no between-group difference ($p = 0.361$). The between-group comparison for the proportion of each sex was not different as well (OWG: 72.7% of girls vs. OBG: 64.3% of girls; $p = 0.653$). Pre- and post-intervention results regarding anthropometry, body composition and cardiorespiratory fitness are presented in Table 1. Body mass, BMI, and body fat (percentage and absolute values) were higher in OBG compared to OWG in the baseline, as expected. After controlling for these differences, we found no significant changes in body mass after the intervention (practical inferences based on magnitude: "unlikely" and "very unlikely"). On the other hand, both groups decreased BMI (OWG: "Likely"; OBG: "Possible"), percentage body fat (OWG: "Almost certain"; OBG: "Very likely"), absolute body fat (OWG: "Very likely"; OBG: "Possible"), as well as increased lean mass (OWG: "Very likely"; OBG: "Possible") and cardiorespiratory fitness (OWG: "Likely"; OBG: "Almost certain") following the intervention (Table 1).

Table 2 describes the results related to the parasympathetic indices of cardiac autonomic function. Only HRrest was different at baseline and was therefore, controlled for as a covariate. In the OWG, only SD1 increased after the intervention ("Likely"). Despite no significant changes, HRrest, rMSSD and HF (ms^2) showed a trend towards improvement ("Very likely", "Likely", and "Likely"). The OBG saw improvements in all rHRV indices, except HF (ms^2; "Likely"). The other practical inferences based on magnitude were all "Very likely" (Table 1).

The correlation test revealed inverse associations between percentage change in body fat (kg), BMI and body mass with percentage change in rMSSD (Fig. 1) that ranged from $r = -0.53$ to -0.63. The other associations are described in Table 3. The associations between cardiorespiratory fitness and rHRV indices were qualitatively classified as small (Fig. 1; Table 3).

Table 1. Anthropometry, body composition, and cardiorespiratory fitness

Variable	**OWG ($n = 11$)**					**OBG ($n = 14$)**				
	Pre Mean ± SD	**Post Mean ± SD**	**Δ difference (90% CI)**	**Inference: positive/trivial/negative**	**Result**	**Pre Mean ± SD**	**Post Mean ± SD**	**Δ difference (90% CI)**	**Inference: positive/trivial/negative**	**Result**
Body mass (kg)$^{\#}$	66.4 ± 8.9	65.6 ± 8.2	−0,9 (−0.2 to 0.7)	0/87/12	Unlikely	83.7 ± 18.2	82.3 ± 20.2	−1.4 (−3.7 to 0.8)	0/96/4	Very unlikely
BMI (kg m^{-2})$^{\#}$	25.3 ± 2.5	24.4 ± 2.4*	−0.9 (−1.5 to −0.4)	0/11/89	Likely	31.7 ± 5.1	30.5 ± 5.4*	−1.2 (−1.8 to −0.5)	0/44/56	Possible
Body fat (%)$^{\#}$	35.9 ± 7.5	31.5 ± 7.3*	−4.4 (−6.0 to −2.8)	0/0/100	Almost certain	44.2 ± 6.1	40.9 ± 7.7*	−3.2 (−4.6 to −1.8)	0/1/99	Very likely
Body fat (kg)$^{\#}$	24.1 ± 7.0	20.9 ± 6.3*	−3.2 (−4.6 to −1.8)	0/2/98	Very likely	37.5 ± 12.0	34.6 ± 13.0*	−2.8 (−4.4 to −1.3)	0/37/63	Possible
Lean mass (kg)	39.7 ± 5.0	41.9 ± 5.1*	2.2 (1.2 to 3.2)	97/3/0	Very likely	43.5 ± 7.8	45.2 ± 8.8*	1.8 (1.0 to 2.5)	62/38/0	Possible
VO_{2max} (mL kg^{-1} min^{-1})	24.6 ± 5.6	26.6 ± 5.9*	2.0 (1.1 to 2.8)	93/7/0	Likely	22.8 ± 3.6	25.1 ± 4.7*	2.4 (1.5 to 3.3)	100/0/0	Almost certain

BMI body mass index, VO_{2max} relative maximal oxygen consumption

* $p < 0.05$ compared to the pre-intervention

[a] Baseline used as covariate. $N = 13$ in OBG for VO_{2max}

Table 2. Parasympathetic indices

Variable	**OWG ($n = 11$)**					**OBG ($n = 14$)**				
	Pre Mean ± SD	**Post Mean ± SD**	**% difference (90% CI)**	**% changes: positive/trivial/negative**	**Result**	**Pre Mean ± SD**	**Post Mean ± SD**	**% difference (90% CI)**	**% changes: positive/trivial/negative**	**Result**
HRrest (bpm)^{a}	82.1 ± 1.8	78.7 ± 5.0	−3.4 (−6.2 to 0.6)	2/2/96	Very likely	79.5 ± 1.2	75.1 ± 1.7*	−6.9 (−4.5 to 2.0)	0/1/99	Very likely
rMSSD (ms)	29.9 ± 10.4	41.5 ± 18.4	11.0 (1.9 to 21.3)	94/4/2	Likely	33.2 ± 20.7	49.2 ± 28.2*	16.0 (6.0 to 26.0)	97/3/1	Very likely
HF (ms^2)	504.9 ± 303.2	1105.6 ± 1159.7	600.7 (23.0 to 1178.5)	94/3/3	Likely	717.0 ± 906.8	1131.8 ± 1142.0	414.8 (−116.4 to 936.0)	77/20/3	Likely
HF (nu)	36.8 ± 14.5	35.1 ± 14.4	−1.7 (−9.9 to 6.5)	15/47/38	Unclear	33.2 ± 16.3	43.7 ± 18.8*	10.5 (4.5 to 16.6)	97/3/0	Very likely
SD1	21.4 ± 7.4	29.9 ± 13.0*	8.5 (1.7 to 15.3)	95/4/1	Likely	23.7 ± 14.7	35.1 ± 20.0*	11.4 (4.3 to 18.4)	97/3/0	Very likely

HRrest resting heart rate, *rMSSD* square root of the mean of the squares of successive *R–R* interval differences, *HF* high frequency, *SD1* standard deviation 1 of instantaneous beat-to-beat *R–R* interval variability measured from Poincare plots

* $p < 0.05$ compared to the pre-intervention

[a] Baseline used as covariate

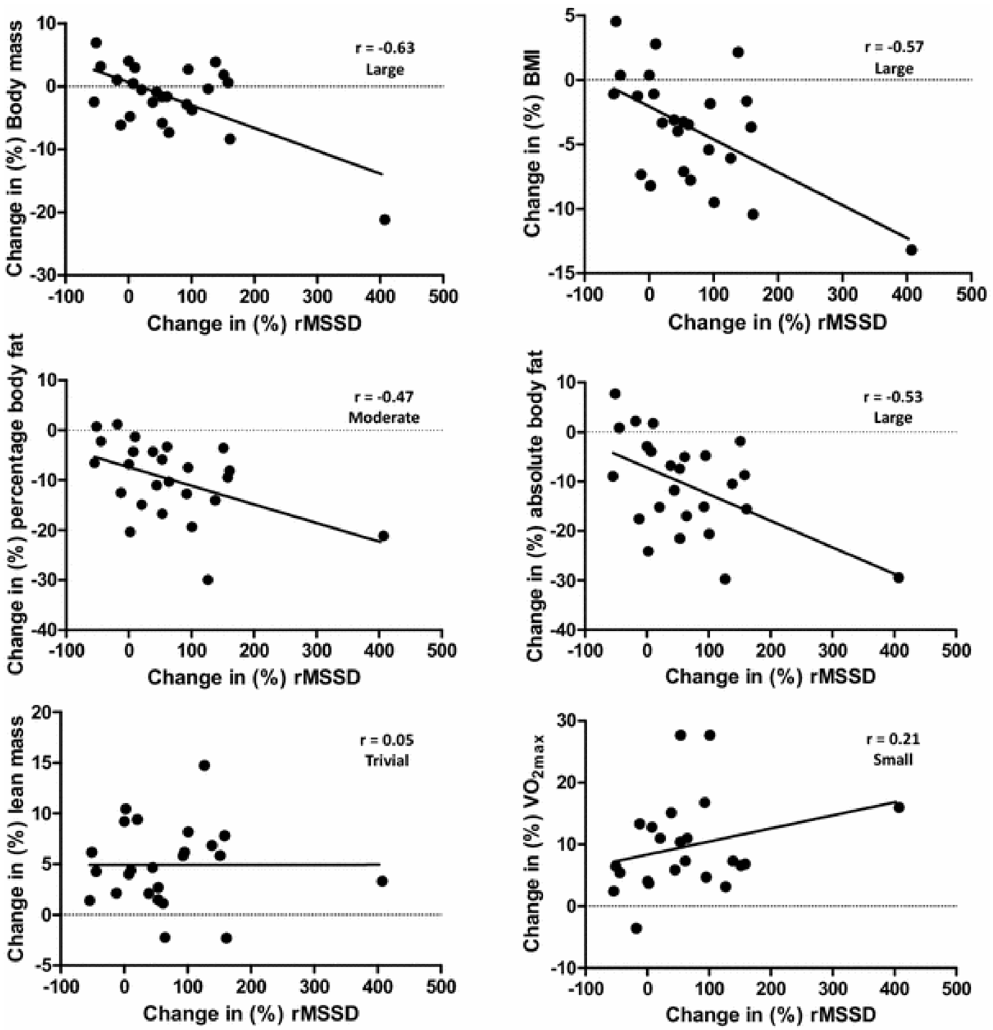

Fig. 1. Graphic representation of the correlation between percentage change in rMSSD and percentage change in body composition and cardiorespiratory fitness

Table 3. Correlations between parasympathetic indices (except rMSSD) and body composition, and cardiorespiratory fitness

	% change HRrest	**% change HF (ms^2)**	**% change HF (nu)**	**% change SD1**
% change body mass	0.38	−0.59	−0.21	−0.62
Qualitative analysis	Moderate	Large	Small	Large
% change BMI	0.45	−0.51	−0.30	−0.57
Qualitative analysis	Moderate	Large	Moderate	Large
% change body fat (%)	0.33	−0.34	0.08	−0.48
Qualitative analysis	Moderate	Moderate	Trivial	Moderate
% change body fat (kg)	0.41	−0.40	−0.04	−0.52
Qualitative analysis	Moderate	Moderate	Trivial	Large
% change lean mass (kg)	0.03	0.04	−0.26	0.06
Qualitative analysis	Trivial	Trivial	Small	Trivial
% change $VO_{2\max}$	−0.20	0.17	−0.24	0.21
Qualitative analysis	Small	Small	Small	Small

BMI body mass index, *VO* $_{2max}$ relative maximal oxygen consumption, *HRrest* resting heart rate, *HF* high frequency, *SD1* standard deviation 1 of instantaneous beat-to-beat *R–R* interval variability measured from Poincare plots

Discussion

This study aimed to assess the effects of a multidisciplinary intervention on rHRV and cardiorespiratory fitness in Brazilian adolescents with overweight and obesity. The main findings are that: (1) both groups (i.e., OWG and OBG) enhanced parasympathetic indices and cardiorespiratory fitness with slightly greater changes for the OBG; (2) OWG showed greater improvements in body composition vs the OBG (e.g., percentage and absolute body fat, and absolute lean mass), although both groups saw declines in these variables; (3) inverse associations were noted between percentage changes in body composition and percentage changes in parasympathetic indices of rHRV.

Recently, Matsuo et al. [33] showed that obese and severely obese adolescents responded similarly following a multidisciplinary intervention for hypertriglyceridemic waist phenotype and body composition; nevertheless, the effects on other important health-related markers (e.g., rHRV and cardiorespiratory fitness) were not studied. Impaired cardiac autonomic control is associated with increased risk of mortality for cardiovascular diseases [34] and high cardiorespiratory fitness is linked to improved health markers [35]. Moreover, the American Heart Association suggested the necessity of further exploring cardiovascular risk factors to better understand pathophysiological aspects and improve the management of cardiovascular diseases in young populations [36]. In this way, rHRV indices (e.g., parasympathetic indices) has been used as a marker of the effects of overweight and obesity intervention programs [11,12,13] on cardiovascular health.

Previous studies demonstrated that exercise training leads to improvements in parasympathetic indices [11, 12]. Prado et al. [12] observed a significant decrease in sympathovagal balance (i.e., low frequency [LF]/high frequency [HF]) after a 4-month period in obese children who engaged in a diet combined with exercise training program. Our findings corroborate these results, and reinforce the idea that pediatric obesity treatment may lead to improvements in parasympathetic indices of autonomic nervous system after a short-term intervention program (i.e., less than 1 year) [37]. Collectively, these improvements may be related to a reduced risk of various comorbidities, such as cardiovascular disease, type 2 diabetes, sleep disorders, and emotional issues [1, 38].

It is known that overweight and obesity are associated with lower parasympathetic indices in children and adolescents [3,4,5]. However, the association between body mass loss and changes in rHRV remained to be elucidated in this population. Tian et al. [11] found that rMSSD Ln (i.e., parasympathetic index) changes after aerobic exercise training were associated with changes in $\dot{V}O_{2max}$ and trunk fat percentage, and that the coefficient of correlations (i.e., r values) were similar. However, other studies failed to identify associations between fat loss and changes in rHRV [39]. Part of these inconsistences may be explained by the use of different protocols to determine rHRV, different populations studied, and different markers/equipment to measure body composition [11].

The analysis of the present study showed that changes in parasympathetic indices of rHRV (e.g., rMSSD and SD1) demonstrated a greater relationship with changes in body composition markers (e.g., body fat and BMI) compared to cardiorespiratory fitness changes in overweight and obese adolescents. These two indices have been highlighted as the most attractive ones to be applied in exercise-related practice [29]. However, there is still an unresolved issue related to which index should be preferred in clinical populations. Recently, Sala et al. [40] proposed a possible approach that aggregates autonomic indices into a comprehensive unitary proxy of autonomic regulation benchmarking individuals against a reference population. Although this study did not include children and adolescents, it is an innovative and potential approach that attempts to standardize autonomic regulation assessment and may be transferred to pediatric population in the near future.

Although the correlation between changes in $VO_{2\max}$ and changes in parasympathetic indices were only small in the present study, cardiorespiratory fitness and moderate to vigorous physical activity participation seem to be linked with rHRV (e.g., rMSSD) in children and adolescents [41]. By comparing the effects of diet alone *vs* diet combined with exercise training (i.e., land-based aerobic exercise), Prado et al. [12] found that only the combined intervention improved sympathovagal balance. It is suggested that the exercise component of the multidisciplinary intervention played an important role in the increase in parasympathetic indices after the intervention [42]. However, this is speculation and the relationship between physical activity and rHRV in overweight and obese adolescents needs to be further explored given the conflicting results of the few studies available [39, 43, 44].

Lopera et al. [10] demonstrated that the use of a water-based exercise program as a component of a multidisciplinary intervention led to similar effects on body composition, health-related quality of life, and physical fitness compared to a land-based exercise program as part of multidisciplinary intervention. Additionally, the water-based intervention group presented higher rates of compliance compared to the land-based intervention group [10]. It could be due to the decreased risk of injuries and improved thermoregulation [45, 46].

Regarding the comparison between OWG and OBG at baseline for rHRV, our findings suggested that there was no differences between these two groups, except for HRrest, which is limited in terms of representing parasympathetic nervous system. There is a link between increased cardiovascular risk factors (e.g., high blood pressure, insulin resistance) and reduced rHRV in children and adolescents [3, 5, 6]. Since overweight and obese adolescents may present similar prevalence of metabolic syndrome risk factors [47], it would be expected similar results for rHRV.

The main strength of the present study is related to the combined analysis of important markers associated with cardiovascular diseases (e.g., autonomic cardiac function, body composition and cardiorespiratory fitness) following a multidisciplinary intervention program for overweight and obese adolescents. Changes in these variables seem to be associated (i.e., body fat markers and parasympathetic indices). Despite these contributions, the present study also has limitations. We did not control for physical activity levels and energy intake, which might influence the parameters analyzed; however, it is assumed to have affected both groups equally. Adolescents had a large age range and maturation was noted as pubertal stage, which could affect the results; however, it was equally distributed between groups. The absence of a control group (i.e., no intervention participation) and the relatively small sample size, and the lack of randomization are considered limitations. However, the original goal of the present study is related to the effects of a multidisciplinary intervention program according to the degree of excess body mass (i.e., overweight *vs* obesity) in adolescents, which do not permit randomization and do not necessarily require a control group given the pragmatic design and goals of the study. Moreover, we also analyzed the adaptations to the multidisciplinary intervention using magnitude-based inferences [31], which provides a qualitative view of the outcomes and minimizes the impact of the small sample size [6]. Moreover, the percentage changes for traditional variables (e.g., body fat markers) observed after the intervention is in accordance with other similar intervention programs in Brazil [8, 10].

Conclusion

In summary, the present study demonstrated the benefits of a multidisciplinary program with psychological, nutritional, and water-based physical exercise interventions on autonomic cardiac function and cardiorespiratory fitness in both overweight and obese adolescents, with slightly greater improvements for OBG. On the other hand, body composition improved slightly more in OWG compared to OBG. Changes in parasympathetic indices of rHRV are inversely associated with changes in body fat markers. We suggest that future studies explore the potential mechanisms related to the association of rHRV changes and body fat markers changes as well as possible sex- and age-related effects on autonomic cardiac function.

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Ethics declarations

Funding

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethical standard

This study was approved by the local Ethics Committee (protocol 463/2009). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study as well as their guardians.

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