

**CLINICAL RESEARCH ARTICLE**


# Influence of physical fitness and weight status on autonomic cardiac modulation in children

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**BACKGROUND:** This study provides reference values for cardiovascular modulation at rest, during maximal exercise test and recovery after exercise in Caucasian children according to weight status and cardiorespiratory fitness (CRF) level. Additionally, the current study analyzed several correlations between autonomic cardiovascular modulation, cardiorespiratory performance and cardiometabolic risk. The principal goal of this study was to analyze cardiac function at rest, during maximum exercise, and during the recovery phase in children grouped according to weight status and CRF level.

**METHODS:** One hundred and fifty-two healthy children (78 girls) 10–16 years of age were divided into three groups: soccer and basketball players (SBG), endurance group (EG), and sedentary people with overweight and obesity (OOG). A cardiac RR interval monitor recorded the cardiac data and specific software analyzed the cardiac autonomic response through heart rate (HR) and HR variability. The study analyzed resting HR (RHR), HR<sub>peak</sub>, and HR recovery (HRR).

**RESULTS:** OOG showed significant poorer performance in the Léger test lower  $\dot{V}O_{2\max}$  and higher values of blood pressure at rest and post-exercise than sport groups. The EG presented the best results in CRF and cardiometabolic risk (CMR) in relation to SBG and OOG. The OOG showed higher percentage of HR values, compatible with an unhealthy cardiovascular autonomic modulation than the sport groups, with significant differences in bradycardia, HR reserve, and HRR 5 min.

**CONCLUSIONS:** Aerobic performance, vagal activity, blood pressure, chronotropic competence, and HRR have significant associations with CMR parameters.

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**IMPACT:**

- The current study presents reference values of autonomic cardiac function in Caucasian children according to weight status and cardiorespiratory fitness level.
- Aerobic performance, vagal activity, blood pressure, chronotropic competence, and heart rate during the recovery period after exercise have significant associations with cardiometabolic risk parameters.
- Children with overweight and obesity show signs of autonomic dysfunction reflected as low cardiac vagal activity and poor chronotropic competence.

**INTRODUCTION**

Currently, the relevance of physical activity (PA) for health cannot be questioned, indeed, children have shown both physical and psychological benefits following PA.<sup>1</sup> However, it has been shown that larger levels of inactive lifestyles are related with the following health problems in children and adolescents: cardiometabolic risk (CMR), low cardiopulmonary fitness (CRF), minor functioning of the cardiac autonomic nervous system and increased adiposity.<sup>2</sup> In this regard, the predominance of obesity (OB) between children and adolescents (aged 2–18 years) is a major public health issue,<sup>3</sup> leading to malnutrition with lower levels of PA.<sup>4</sup> Obese children show breathing difficulties, hypertension, early markers of cardiovascular disease, and insulin

resistance.<sup>4</sup> Especially, autonomic dysfunction, in combination with poor physical fitness, may be a mechanism associated with early glucose dysmetabolism and the development of diabetes.<sup>5</sup> It seems that the development of autonomic dysfunction starts at an early age, and is related to metabolic syndrome prevalence that is growing in younger populations.<sup>6</sup> Adolescents and young adults with severe OB have a more adverse cardiovascular risk profile and poorer cardiac and vascular structure and function.<sup>7</sup>

One of the diseases that has the greatest influence on morbidity and mortality trends worldwide is cardiovascular disease, and indeed, some of it may originate in early childhood.<sup>8</sup> Throughout development, from infancy to adulthood, there are changes in cardiac autonomic neural regulation that affect heart rhythm.

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Indeed, these modifications could be used as a diagnostic method in those individuals at greater risk of suffering some type of alteration that could lead to a severe cardiovascular disorder.<sup>9</sup> As a matter of fact, several childhood diseases, such as OB<sup>10</sup> and diabetes, are related to cardiac autonomic dysfunction.<sup>11</sup>

PA is a protective factor for autonomic dysfunction, above all, vigorous PA is most strongly related with cardiac vagal modulation in young adults.<sup>12</sup> Regardless of sex, a physically active life was associated with better cardiovascular autonomic modulation in adolescents.<sup>13</sup> Therefore, engaging in sports practice should be encouraged to improve cardiac autonomic function in obese adolescent boys.<sup>14</sup> Similarly, physical fitness is recognized as an essential marker of health across the life stages, because it has been shown to be a powerful marker of health in early childhood and later in life.<sup>15,16</sup> It seems important to assess the function of the respiratory systems, since negative CRF in these stages is associated with adverse cardiovascular indicators (e.g., hypertension).<sup>17</sup> Indeed, the evidence have established cut points of CRF to avoid cardiovascular disease risk in children and adolescents, identifying CRF as an important indicator of cardiometabolic health.<sup>18</sup>

From early childhood, heart rate (HR) could be a helpful further measure to detect subtle alterations in cardiovascular health during PA through simple clinical measurements.<sup>8</sup> It should be noted that the balance of the autonomic nervous system could be determined by analyzing various values of the cardiopulmonary stress trial, such as the rest period, HR response to dynamic exercise, HR recovery (HRR) from the exercise test, and HR variability (HRV).<sup>19</sup> Indeed, CRF evaluation could supply significant evidence about the state of health and way of life of the child population, difficult to identify at rest.<sup>20</sup> While positive relationships between PA and CRF with resting HRV have been established in childhood, additional understanding about the possible relationships of PA and CRF to cardiac autonomic function during recovery following exercise is required. Moreover, the effects of PA intensity on HRV and HRR is not clear, when measures of cardiac autonomic function with CMR factors are analyzed.<sup>21</sup> Additional studies are needed to clarify the role of PA and CRF on HRV in children and adolescents,<sup>22</sup> especially, in children with overweight (OW) and OB.

Therefore, to propose realistic and medically safe exercise interventions for obese adolescents, it remains to be determined whether exercise tolerance is altered and whether anomalous cardiopulmonary responses during maximal exercise testing are present.<sup>23</sup> Since exercise dysfunction precedes resting abnormalities, exercise testing could be a tool for early detection of cardiac dysfunction in children.<sup>24</sup> Therefore, studies are needed to examine the cardiopulmonary response during a maximal exercise test in OW and OB children. For clinical purposes, cardiovascular autonomic function has been studied in depth in children<sup>25</sup>; however, limited studies<sup>22,26,27</sup> have considered the effect that CRF and weight status have on HR response to maximal exercise and following recovery. Therefore, the principal goal was to examine cardiac function at rest, during maximum exercise, and during the recuperation stage to define sex reference values of RHR, HRV, HR<sub>peak</sub>, and HRR in child population considering weight status and CRF level.

## METHODS

### Participants

This cross-sectional research required a group of 152 healthy children (78 girls) aged 10–16 years (age=12.71±1.72 years old) and they were selected by convenience from several schools and athletic clubs in southern Spain. Any physical or intellectual disability was taken as a criterion for exclusion; indeed, it was necessary to receive from the parents of the children included in the study a certificate declaring that their children were free of physical and intellectual disabilities. The participants

were divided into three groups: soccer and basketball players (SBG) ( $n = 76$ , 46.1% girls), endurance group (EG) ( $n = 45$ , 57.8% girls), and those who did not participate in any sport and showed OW and OB (OOG) ( $n = 31$ , 54.8% girls). Both EG and SBG made 4 weekly training sessions. For this study, an informed consent form was voluntarily signed by the parents so that their children could participate. The study was carried out respecting the standard of the Declaration of Helsinki (2013 version) and was consented by the Ethics Committee of the University of Jaen (SEPT.20/9.TES).

### Materials and testing

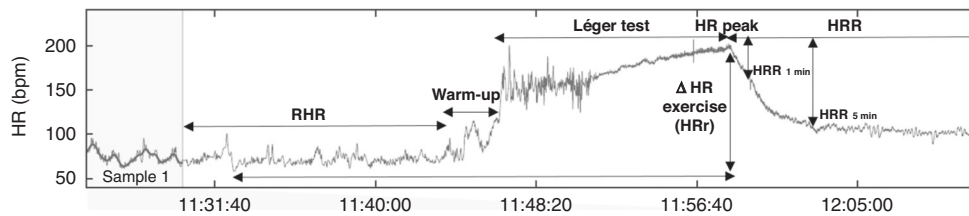
**Anthropometric variables.** The body mass index (BMI) was calculated by dividing body mass (kg) by body height<sup>2</sup> (in meters). The 85th and 95th percentiles of the study by Sobradillo et al.<sup>28</sup> were considered in classifying children as OW or OB, respectively, in relation to BMI. Waist circumference (WC) and waist-to-height ratio (WHR) were measured as previously described by Latorre-Román.<sup>29</sup>

**Cardiorespiratory fitness.** The 20-m shuttle run test (20Mstrt) was used to measure the CRF.<sup>30</sup> A high value in the number of stages performed, indicates a better result, which showed a high CRF. Additionally, the maximum volume of oxygen uptake ( $\dot{V}O_{2\max}$ ) was calculated with the equation below:  $\dot{V}O_{2\max} = (31.025) + (3.238 \times V) - (3.248 \times A) + (0.1536 \times A \times V)$ , where  $V$  = speed in km/h and  $A$  = age in years.<sup>30</sup> Moreover, to gain more evidence about the perceived exertion after the completion of the Léger test, the rate of perceived exertion (RPE) was documented on a scale from 0 to 10.<sup>31</sup>

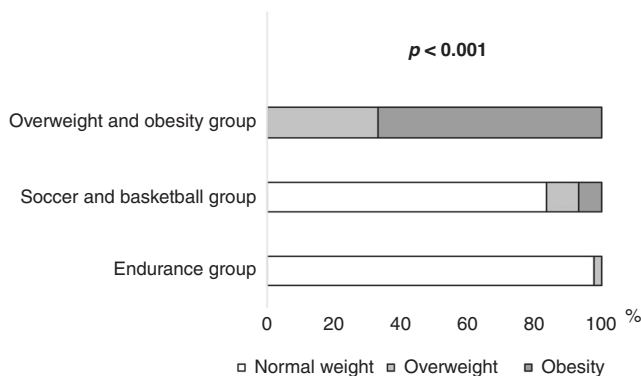
**Heart rate recording.** In terms of HR control, we used a Firstbeat Bodyguard 2 of Firstbeat Technologies Ltd. (Jyväskylä, Finland) to record the RR intervals. The monitor measures at a sample rate of 1000 Hz and has been calibrated with standard electrocardiogram apparatus.<sup>32,33</sup> The program includes the HRV algorithms supplied by the European Society of Cardiology<sup>34</sup> (Firstbeat Uploader, Firstbeat Technologies Ltd. Yliopistonkatu, Jyväskylä; Version 3.3.4.0) and a signal filter which is based on the artifact compensation algorithm defined in Saalasti's study.<sup>35</sup> The frequency domain of HRV involves the measurement of the high-frequency (HF) (0.15–0.4 Hz) and low-frequency (LF) spectrum in ms<sup>2</sup> (0.04–0.15 Hz), and also allows for an LF/HF ratio. Parasympathetic activity may be reflected by HF, in addition a combination of sympathetic and parasympathetic input may be indicated by LF and sympathovagal balance by the ratio of LF/HF.<sup>36</sup> Furthermore, the time domain analysis comprises statistical metrics that reflect parasympathetic activity, such as the root-mean-square differences of successive heartbeat intervals (RMSSD) and the average standard deviation of the NN interval (normal RR) (SDNN).<sup>34,37</sup>

The maximal predicted HR of reserve (HRr) attained was indicated as the chronotropic index (CI); HRr is the difference between HR<sub>peak</sub> and HR at rest. Particularly, the CI was consequently explained as  $CI = (HR_{\text{peak}} - RHR) / [(220 - \text{age}) - RHR]$ <sup>38</sup> and chronotropic incompetence was said to be show when amounts of the chronotropic index were <0.80.<sup>38</sup> Additionally, based on earlier studies,<sup>39,40</sup> HR was also registered at 1 (HRR1) and 5 min (HRR5) after the end of the test and the HRR was determined as the difference among the HR<sub>peak</sub> and HR at these recuperation spots, represent the fast and slow points of recovery time, correspondingly.<sup>41</sup> According to earlier studies, we used HR references at rest, during exercise, and in the recovery time related to an enhance in the risk of death.<sup>42,43</sup> Mostly showed in people with a RHR that was more than 75 beats per minute (bpm); individuals with a raise in HRr during exercise that was less than 89 bpm; and in subjects with a HRR1 and HRR5 of less than 25 beats and 75 beats per minute after the end of test respectively.<sup>42,43</sup> Also, an OMRON® digital electronic monitor model HEM 7114 (Illinois) was used to analyze blood pressure (BP).

**Procedure.** In the morning time, this study was carried out in the school's athletic installations, at a minimum of 3 h after the last feeding. In addition, participants were asked to avoid any strenuous PA the day before the test. Before stress test, it was registered BP, RHR and HRV together with anthropometric variables, which were determined after 10 min in a sitting posture and with spontaneous breathing according to Young et al.<sup>44</sup> Prior to the measurements, participants were commanded that talking or moving during the test was strictly forbidden. Seated short-term resting HRV determinations can be performed in the field (i.e., outside lab-controlled settings) in children.<sup>45</sup> Successively, the children completed a standard warm-up. Using the Léger test, HR was constantly monitored in



**Fig. 1** Heart rate profile at rest, during exercise, and during recovery time. HR heart rate, RHR resting HR, HRr heart rate reserve, CI chronotropic index, HRR HR recovery.



**Fig. 2** Weight status of participants. Weight status with respect to the groups analyzed.

order to determine the  $HR_{peak}$ . The HR was also recorded at the first (HRR1) and the fifth (HRR5) minute after the end of the test). Based on Buchheit et al.,<sup>46</sup> at the end of the Léger test, the participants were instantly seated passively on a chair next to the track. Time duration among the end of exercise and sitting was less than 5 s. Consequently, pre- and post-exercise measures of HR were performed in the sitting posture for at least 10 min (Participants had to remain seated, breathe naturally and not join in any dialog) in conformity with Bentley et al.<sup>47</sup> Figure 1 shows an example of HR profile at rest, during exercise, and recovery times.

### Statistical analysis

The results were examined using SPSS software, v.22.0 for Windows (SPSS Inc, Chicago). Tests of normal distribution and homogeneity (Kolmogorov–Smirnov and Levene's test, respectively) were conducted on all data periods after the analyses. Descriptive data are described in terms of means and standard deviations (SD) and percentage (%). The differences in the different parameters between sex and groups were analyzed using an analysis of covariance adjusted for age, and post hoc analysis by Bonferroni test was performed. Moreover, in nonparametric variables the Kruskal–Wallis test and post hoc analysis by the Mann–Whitney *U*-test were used. Furthermore, to validate the association between anthropometric variables, HR parameters, and CRF, partial correlation analysis and a simple linear regression analysis (adjusted by age and sex) were used. The size of correlation between outcome variables was denoted as: <math>< 0.1</math> (trivial), 0.1–0.3 (small), 0.3–0.5 (moderate), 0.5–0.7 (large), 0.7–0.9 (very large), and 0.9–1.0 (almost perfect).<sup>48</sup> The significance level was set at  $p < 0.05$ .

### RESULTS

Figure 2 indicated the weight status with respect to the groups analyzed. Table 1 illustrates anthropometric characteristics, CMR factor, and Léger test performance according to sex and groups. OOG showed significantly poorer performance in the Léger test ( $p < 0.001$ ), lower  $\dot{V}O_{2max}$  ( $p < 0.001$ ) than sport groups, and higher values of WtHR and BP at rest and post-exercise than EG. EG presented the best results in CRF and CMR in relation to SBG and OOG.

Table 2 indicates HR and HRV at rest, HR during the Léger test and during the recovery period after exercise testing relating to sex and groups. OOG exhibit higher values of RHR and lower values of  $HR_{peak}$ , HRr, RMSSD and HRR5 than EG ( $p < 0.001$ ,

$p = 0.005$ ,  $p < 0.001$ ,  $p = 0.004$ ,  $p = 0.006$ , respectively) and SBG ( $p < 0.001$ ,  $p < 0.001$ ,  $p < 0.001$ ,  $p = 0.002$ ,  $p < 0.001$ , respectively). In addition, EG showed the highest CI values with significant differences compared to the OOG ( $p = 0.004$ ).

Controlling for age and sex, it is noteworthy that we found a very large and inverse correlations between Léger performance and BMI and WtHR. In additions, a very large positive correlation between HRR5 and HRr, and a large and inverse correlation between Léger performance and WC, between RHR and HRR5, between RHR and RMSSD. Finally, a large positive correlation between HRR5 and  $HR_{peak}$  (Table 3).

Figure 3 shows the percentage of children within each HR references values (at rest, during maximal exercise, and at recovery time) associated with a healthy cardiovascular system. In all cardiovascular risk parameters, OOG showed significant differences with respect to EG and SBG in bradycardia, HRr, and HRR5. Finally, simple linear regression analysis revealed that RHR and HRr were the main variables that showed influence on  $\dot{V}O_{2max}$  and CMR parameters (Table 4).

### DISCUSSION

The principal goal was to examine cardiac autonomic function at rest, during maximum exercise, and during the recovery phase to determine sex reference values of RHR, HRV,  $HR_{peak}$ , and HRR in children 'according to weight status and CRF level. Based on our information, this is the first study that conducted this comparison between children trained in endurance sports, in soccer and basketball, and children with OW and OB who do not train in any sport. The principal outcomes of this study show that there are significant differences between these groups in cardiac autonomic modulation and in the cardiac response to maximal exercise. Children who practice competitive sports displayed low RHR, and higher values of RMSSD, chronotropic competence, and HRR than OOG. These values are associated with the highest performance in the Léger test by sport groups and lower values of CMR.

#### Cardiac autonomic function at rest

With respect to RHR, we reported that weight status and aerobic capacity influences RHR; thereby, high RHR is associated with low aerobic performance and OW and OB. Furthermore, no sex difference was found in RHR. In this regard, RHR shows significant correlations with BMI, WC and WtHR. As regards weight status, the outcomes of this study, align with those of Kwok et al.,<sup>49</sup> which detected an association between RHR and OB. In addition, Kwok et al.,<sup>49</sup> indicated that high RHR is related, among other factors to elevated BP and physical inactivity in children, moreover, RHR is more closely linked to obesity than body size, and with increased WC in boys but not girls.<sup>49</sup> In addition, previous studies showed that a  $RHR \geq 86$  bpm is associated with an increased likelihood for high BP values in both non-obese and obese children,<sup>50</sup> furthermore, school children with a higher RHR (91 bpm) displayed higher values of LDL cholesterol.<sup>51</sup> Finally, a longitudinal study showed a causal association between RHR and myocardial dysfunction, this association was independent of other risk factors, including BP, BMI, and fitness level.<sup>52</sup>

**Table 1.** Anthropometric characteristics, cardiometabolic risk factor, and Léger test performance according to sex and groups.

	Endurance group			Soccer and basketball group			Overweight and obesity group		
	Total	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls
Age (years)	12.51 (1.81)	12.44 (2.17)	12.56 (1.55)	12.87 (1.74)	12.85 (1.85)	12.90 (1.62)	12.50 (1.84)	12.87 (1.78)	12.85 (1.88)
Height (cm)	154.81 (13.14) <sub>a</sub>	155.61 (16.99)	154.24 (9.85) <sub>a</sub>	161.52 (12.93) <sub>b</sub>	162.21 (14.92)	160.66 (10.08) <sub>b</sub>	155.51 (9.04) <sub>a</sub>	160.25 (9.07)	152.75 (9.65) <sub>a</sub>
Body mass (kg)	43.56 (10.53) <sub>a</sub>	43.34 (12.12) <sub>a</sub>	43.72 (9.49) <sub>a</sub>	53.25 (13.73) <sub>b</sub>	52.06 (14.34) <sub>b</sub>	54.73 (12.99) <sub>b</sub>	67.15 (14.69) <sub>b</sub>	73.81 (15.66) <sub>c</sub>	60.48 (10.45) <sub>b,c</sub>
BMI (kg/m <sup>2</sup> ) <sup>a</sup>	17.86 (2.23) <sub>a</sub>	17.54 (2.11) <sub>a</sub>	18.10 (2.32) <sub>a</sub>	20.11 (3.43) <sub>b</sub>	19.40 (3.06) <sub>b</sub>	20.98 (3.70) <sub>b</sub>	27.13 (3.35) <sub>c</sub>	28.50 (3.85) <sub>c</sub>	25.76 (2.14) <sub>c</sub>
WC (cm) <sup>a</sup>	62.29 (5.78) <sub>a</sub>	63.33 (6.00) <sub>a</sub>	61.63 (5.70) <sub>a</sub>	72.78 (10.85) <sub>b</sub>	74.10 (10.05) <sub>b</sub>	71.10 (11.76) <sub>b</sub>	90.86 (10.05) <sub>c</sub>	95.80 (8.38) <sub>c</sub>	84.26 (8.23) <sub>b,c</sub>
WTHR <sup>a</sup>	0.41 (0.03) <sub>a</sub>	0.43 (0.03) <sub>a</sub>	0.40 (0.02) <sub>a</sub>	0.45 (0.06) <sub>b</sub>	0.45 (0.07) <sub>a</sub>	0.44 (0.06) <sub>b</sub>	0.58 (0.06) <sub>c</sub>	0.60 (0.05) <sub>b</sub>	0.55 (0.06) <sub>b,c</sub>
Léger test (Bouts) <sup>a</sup>	7.76 (2.26) <sub>a</sub>	8.87 (1.92) <sub>a</sub>	6.87 (2.10) <sub>b</sub>	6.41 (2.10) <sub>b</sub>	7.04 (2.31) <sub>b</sub>	5.69 (1.55) <sub>b</sub>	2.77 (1.26) <sub>c</sub>	2.54 (1.32) <sub>c</sub>	2.97 (1.21) <sub>c</sub>
RPE (0–10) <sup>a</sup>	5.58 (1.71) <sub>a</sub>	5.79 (1.51)	5.42 (1.85)	6.89 (1.91) <sub>b</sub>	7.96 (1.37)	5.63 (1.68) <sub>b</sub>	7.81 (1.49) <sub>c</sub>	7.71 (1.20)	7.88 (1.73)
VO <sub>2 max</sub> (ml/kg/min)	52.43 (5.74) <sub>a</sub>	55.82 (3.06) <sub>a</sub>	49.95 (6.02) <sub>a</sub>	48.14 (5.11) <sub>b</sub>	49.74 (5.26) <sub>b</sub>	46.26 (4.27) <sub>b</sub>	39.47 (3.11) <sub>c</sub>	38.58 (3.02) <sub>c</sub>	40.20 (3.07) <sub>c</sub>
SBP at rest (mmHg)	106.86 (13.60) <sub>a</sub>	107.70 (15.24) <sub>a</sub>	106.16 (12.61) <sub>a</sub>	116.42 (12.68) <sub>b</sub>	117.07 (14.83) <sub>b</sub>	115.58 (9.37) <sub>b</sub>	117.39 (11.90) <sub>b</sub>	123.58 (11.90) <sub>b</sub>	112.75 (9.87) <sub>b</sub>
DBP at rest (mmHg)	70.59 (8.84) <sub>a</sub>	68.94 (7.05) <sub>a</sub>	71.72 (9.85)	75.50 (9.20) <sub>b</sub>	77.20 (8.30) <sub>b</sub>	73.32 (9.97)	74.67 (9.54) <sub>b</sub>	76.58 (10.65) <sub>b</sub>	73.25 (8.70)
SBP post exercise (mmHg)	114.70 (17.32) <sub>a</sub>	118.76 (18.00) <sub>a</sub>	111.83 (16.61) <sub>a</sub>	125.67 (15.93) <sub>b</sub>	128.12 (17.75) <sub>a,b</sub>	122.51 (12.80) <sub>b</sub>	133.32 (15.76) <sub>c</sub>	137.16 (15.55) <sub>b</sub>	130.43 (15.79) <sub>c</sub>
DBP post exercise (mmHg)	72.22 (11.20) <sub>a</sub>	71.00 (14.65) <sub>a</sub>	73.08 (8.18)	77.25 (10.79) <sub>b</sub>	79.20 (9.37) <sub>b</sub>	74.74 (12.08)	78.39 (15.14) <sub>b</sub>	86.41 (13.22) <sub>b</sub>	72.37 (13.95) <sub>b</sub>
ΔSBP (mmHg)	7.90 (21.63)	11.05 (24.35)	5.66 (19.71) <sub>a</sub>	9.25 (14.27)	11.05 (15.35)	6.93 (12.60) <sub>a</sub>	15.92 (17.70)	13.58 (17.51)	17.68 (18.17) <sub>b</sub>
ΔDBP (mmHg)	1.46 (14.17)	2.05 (16.59)	1.04 (12.53)	1.74 (12.46)	2.00 (9.57)	1.41 (15.58)	3.71 (18.05)	9.83 (17.34)	−0.87 (17.71) <sub>b</sub>

Data are represented by mean and SD (standard deviation).

VO<sub>2 max</sub> maximal oxygen consumption, BMI body mass index, WC waist circumference, WTHR waist-to-height ratio, RPE rate of perceived exertion, SBP systolic blood pressure, DBP diastolic blood pressure, Δ increment of rest-post.

<sup>a</sup>Chi-squared test.

<sup>b</sup>Significant differences ( $p < 0.05$ ) with boys. Different subscript letters indicate significant differences ( $p < 0.05$ ) in interaction between sex and groups.

**Table 2.** HR and HRV at rest, HR during the Léger test and during the recovery period after exercise testing relating to sex and groups.

	Endurance group			Soccer and basketball group			Overweight and obesity group		
	Total	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls
RHR (bpm) <sup>a</sup>	69.86 (9.90) <sub>a</sub>	67.94 (7.74) <sub>a</sub>	71.26 (11.15) <sub>a</sub>	68.65 (12.73) <sub>a</sub>	66.51 (11.79) <sub>a</sub>	71.17 (13.48) <sub>a</sub>	85.36 (14.62) <sub>b</sub>	86.38 (13.34) <sub>b</sub>	84.58 (15.89) <sub>b</sub>
Average HR exercise (bpm)	173.75 (16.23) <sub>a</sub>	174.21 (18.09) <sub>a</sub>	173.42 (15.09) <sub>a</sub>	169.01 (16.16) <sub>a,b</sub>	165.70 (17.08) <sub>a,b</sub>	172.88 (14.28) <sup>b</sup>	166.56 (12.30) <sub>b</sub>	163.10 (13.57) <sub>b</sub>	169.23 (11.02)
HR-peak (bpm)	203.33 (10.14) <sub>a</sub>	202.31 (11.82) <sub>a</sub>	204.07 (8.89) <sub>a</sub>	205.89 (9.40) <sub>b</sub>	203.31 (6.62) <sub>b</sub>	208.91 (11.23) <sup>b</sup>	195.90 (11.40) <sub>c</sub>	201.00 (9.23) <sub>c</sub>	191.70 (11.54) <sup>b,c</sup>
HR (bpm) <sup>a</sup>	133.46 (14.80) <sub>a</sub>	134.36 (13.67) <sub>a</sub>	132.80 (15.81) <sub>a</sub>	137.23 (15.10) <sub>a</sub>	136.80 (12.35) <sub>a</sub>	137.74 (17.97) <sub>a</sub>	110.10 (19.42) <sub>b</sub>	114.00 (15.00) <sub>b</sub>	107.11 (22.21) <sub>b</sub>
Chronotropic index <sup>a</sup>	0.97 (0.07) <sub>a</sub>	0.98 (0.07) <sub>a</sub>	0.97 (0.08) <sub>a</sub>	0.92 (0.25) <sub>a</sub>	0.85 (0.32) <sub>ab</sub>	1.00 (0.09) <sub>a</sub>	0.90 (0.11) <sub>b</sub>	0.91 (0.08) <sub>b</sub>	0.90 (0.13) <sub>b</sub>
HRR 1 min (bpm) <sup>a</sup>	41.91 (14.75) <sub>a</sub>	45.52 (15.63) <sub>a</sub>	39.26 (13.77) <sub>a</sub>	45.81 (23.18) <sub>a</sub>	43.95 (24.77) <sub>a</sub>	47.94 (21.37) <sub>a</sub>	40.00 (15.21) <sub>a</sub>	38.00 (14.73) <sub>a</sub>	41.50 (15.87) <sub>a</sub>
HRR 5 min (bpm)	89.02 (10.43) <sub>a</sub>	90.15 (11.22) <sub>a</sub>	88.19 (9.96) <sub>a</sub>	93.11 (12.30) <sub>a</sub>	91.43 (9.34) <sub>a</sub>	95.08 (14.95) <sub>b</sub>	80.33 (10.64) <sub>b</sub>	79.22 (9.61) <sub>b</sub>	81.16 (11.69) <sub>a</sub>
RMSSD (ms), at rest <sup>a</sup>	44.97 (17.64) <sub>a</sub>	51.00 (17.64) <sub>a</sub>	40.57 (16.61) <sup>b</sup>	54.84 (38.92) <sub>a</sub>	63.76 (44.62) <sub>a</sub>	44.40 (28.12) <sup>b</sup>	32.89 (13.96) <sub>b</sub>	31.66 (11.19) <sub>b</sub>	33.76 (15.91) <sub>b</sub>
SDNN (ms), at rest <sup>a</sup>	67.95 (26.29) <sub>a</sub>	74.31 (29.82) <sub>a</sub>	63.30 (22.87) <sub>a</sub>	77.83 (56.82) <sub>a</sub>	79.90 (58.45) <sub>a</sub>	75.40 (55.59) <sub>a</sub>	71.10 (37.79) <sub>a</sub>	68.33 (40.61) <sub>a</sub>	73.05 (36.82) <sub>a</sub>
HF (ms <sup>2</sup> ), at rest <sup>a</sup>	1742.25 (1524.60) <sub>a</sub>	2027.20 (1684.20) <sub>a</sub>	1534.01 (1393.50) <sub>a</sub>	1670.88 (2064.07) <sub>a</sub>	1901.19 (1997.47) <sub>a</sub>	1401.09 (2136.60) <sub>a</sub>	1681.05 (1297.08) <sub>a</sub>	1790.82 (1329.48) <sub>a</sub>	1597.12 (1306.32) <sub>a</sub>
LF (ms <sup>2</sup> ), at rest <sup>a</sup>	2600.22 (1669.09) <sub>a</sub>	3047.34 (1961.34) <sub>a</sub>	2273.48 (1367.64) <sub>a</sub>	2329.84 (1732.90) <sub>a</sub>	2347.20 (1785.06) <sub>a</sub>	2309.50 (1695.46) <sub>a</sub>	2926.67 (2128.42) <sub>a</sub>	3413.33 (2225.40) <sub>a</sub>	2554.51 (1659.02) <sub>a</sub>
LF/HF, at rest <sup>a</sup>	2.18 (1.33) <sub>a</sub>	1.98 (1.02) <sub>a</sub>	2.34 (1.53) <sub>a</sub>	2.31 (1.46) <sub>a</sub>	1.92 (1.34) <sub>a</sub>	2.76 (1.48) <sup>b</sup>	2.16 (1.17) <sub>a</sub>	2.24 (1.17) <sub>a</sub>	2.09 (1.21) <sub>a</sub>

Data are represented by mean and SD (standard deviation).

RHR resting heart rate, CI chronotropic index, HRR heart rate reserve, RMSSD square root of the mean squared differences of successive RR intervals, SDNN standard deviation of all normal

R-R intervals, HF high-frequency band, LF low-frequency band, LF/HF ratio of LF and HF frequency band powers.

<sup>a</sup>Chi-squared test.

<sup>b</sup>Significant differences ( $p < 0.05$ ) with boys. Different subscript letters indicate significant differences ( $p < 0.05$ ) in interaction between sex and groups.

**Table 3.** Partial correlations of heart rate parameters with cardiorespiratory fitness and anthropometric variables controlled by age and sex.

Variables	<i>r</i>	<i>p</i> value
Leger Bouts vs. BMI	-0.729	<0.001
Leger Bouts vs. WC	-0.686	<0.001
Leger Bouts vs. WtHR	-0.704	<0.001
Leger Bouts vs. RHR	-0.353	<0.001
Leger Bouts vs. HRr	0.319	<0.001
RHR vs. BMI	0.321	0.001
RHR vs. WC	0.313	0.001
RHR vs. WtHR	0.358	<0.001
RHR vs. HRr	-0.849	<0.001
RHR vs. HRR5	-0.555	<0.001
RHR vs. RMSSD	-0.572	<0.001
HR <sub>peak</sub> vs. HRr	0.708	<0.001
HRr vs. WC	-0.352	<0.001
HRr vs. WtHR	-0.362	<0.001
HRr vs. RMSSD	0.472	<0.001
HRR1 vs. HRR5	0.301	<0.001
HRR5 vs. HR <sub>peak</sub>	0.538	<0.001
HRR5 vs. HRr	0.710	<0.001
HRR5 vs. RMSSD	0.372	<0.001
BMI vs. SBP posttest	0.372	<0.001
WC vs. SBP pretest	0.348	<0.001
WC vs. SBP posttest	0.443	<0.001
WC vs. DBP posttest	0.320	0.001
WtHR vs. SBP posttest	0.328	0.001

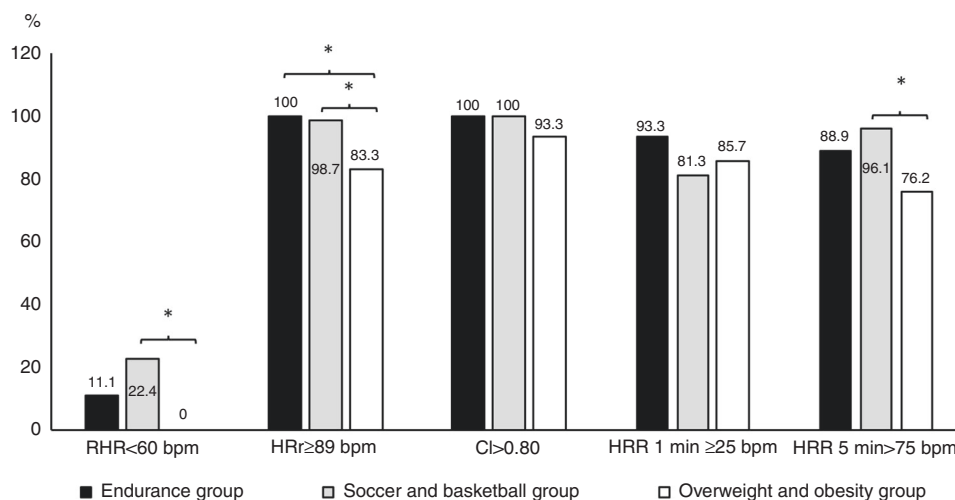
BMI body mass index, WC waist circumference, WtHR waist-to-height ratio, SBP systolic blood pressure, DBP diastolic blood pressure, RHR resting heart rate, CI chronotropic index, HRr heart rate reserve, HRR heart rate recovery, RMSSD square root of the mean squared differences of successive RR intervals.

Regarding aerobic capacity, these results match those observed in earlier studies that have reported strong correlations between RHR and aerobic performance in children and adolescents.<sup>53,54</sup> Concerning sex, these outcomes are contrary to those examined in prior to studies that propose that girls present higher RHR values than boys.<sup>49,54,55</sup>

Moreover, bradycardia, a RHR < 60 bpm, may be joined by exercise intolerance in older children.<sup>56</sup> However, regular PA stimulates bradycardia<sup>57,58</sup> showing that the RHR of endurance athletes children is 11 bpm lower than age-matched non-athletes.<sup>59</sup> This event would suggest that it is caused to cardiac adaptations led by a vagal predominance, sinus bradycardia, and increased HRV,<sup>60</sup> and is not linked with cardiovascular risk factors. In the current study, the prevalence of bradycardia was 11.1%, 22.4%, and 0% in EG, SBG and OOG groups, respectively. The RHR of children who play sports was 16 bpm lower than age-matched non-athlete. In the EG and SBG, the RHR values found in the present study were in accordance with the values of international references, however, the OOG showed high values in relation to these references.<sup>61</sup>

### Cardiac autonomic function at maximum exercise

Overall, in the current study, no sex difference was found in HR<sub>peak</sub>. This finding is in agreement with previous studies,<sup>62-64</sup> in the OW and OB group, girls present lower HR<sub>peak</sub> values than boys,



**Fig. 3 Percentage of children within each heart rate (HR) references (at rest, HR reserve and at recovery time) associated with a healthy cardiovascular system.** RHR resting HR, HRr heart rate reserve, CI chronotropic index, HRR HR recovery, bpm beats per minute. \* $p < 0.05$ .

which could indicate that obese girls do not perform maximum effort or show intolerance to exercise. In fact, according to clinical guidelines,<sup>65</sup> a usual measure to conclude whether the child gave a maximum effort is a peak HR approaching 200 bpm (may not be attained in children with chronotropic or other limitations to exercise). OB girls achieved a  $HR_{peak} \sim 191$  bpm.

Additionally, in our study is interesting to observe that  $HR_{peak}$  exhibited a low correlation with age. This outcome is in accord with Van Brussel et al.,<sup>66</sup> which shows that average  $HR_{peak}$  remains relatively stable, around 200 bpm (treadmill) in children and adolescents. Contemplating the narrow range of  $HR_{peak}$  in youth, Gelbart et al.,<sup>67</sup> proposed using 197 bpm as the mean  $HR_{peak}$  in children and adolescents, with 180 bpm as the minimum threshold value. The current findings agree with the earlier work regardless of the group analyzed.

In addition, chronotropic incompetence has proven to be a useful predictive instrument for patients with coronary heart disease and an effective indicator of all-cause mortality, and has been reported in various heart diseases in the pediatric community.<sup>68</sup> However, data involving chronotropic response during exercise in children and adolescents is reduced.<sup>38</sup> In the present research, chronotropic competence analyzed by CI and HRr was better in children who practice sport than children with OW and OB; 100% vs. 93% achieve a  $CI > 0.80$ , which could indicate a healthy HR response to exercise. Therefore, according to a recent report,<sup>69</sup> chronotropic incompetence was found to be highly prevalent in OOG and related to poor cardiometabolic health as well as exercise intolerance. Likewise, Nikolaidis et al.<sup>70</sup> observed lower  $HR_{peak}$  among OW and OB children.

Nevertheless, Von Scheidt et al.<sup>38</sup> showed values of  $CI < 0.80$  in healthy children related with children with congenital heart diseases, so it is advisable not to use the threshold of 0.8 for the identification of chronotropic incompetence using treadmill exercise testing in children, most likely due to an overestimation of the maximal HR using the Karvonen  $HR_{max}$  formula (220 – age of subject).<sup>71</sup> However, HRr is also higher in child athletes and these parameters showed significant correlations with parameters of metabolic risk. In this sense, other significant outcome of the present study was that BMI, WC and WtHR were negatively correlated not only with the HRr, also with the  $\dot{V}O_{2max}$  and performance in Léger test. In this regard, Delgado-Flody et al.<sup>72</sup> noted that children aged 11 to 13 years with OB showed a lower  $\dot{V}O_{2max}$ , recorded by Léger's test, than children with normal weight and OW. Therefore, chronotropic incompetence is more frequent in obese adolescents compared to their lean

counterparts and is related to exercise intolerance,<sup>69</sup> although, in a review,  $HR_{peak}$  was not reduced in obese adolescents.<sup>73</sup> More research on this topic needs to be undertaken before the association between  $HR_{peak}$  and OB in children is more clearly understood.

#### Cardiac autonomic function in recovery after exercise

Metabolic risks are inversely associated with HRR in healthy children and adolescents.<sup>74</sup> In the current study, it is noteworthy that HRR5 was more sensitive than HRR1, revealing differences between groups and showing several associations with other cardiac variables such as RHR, HRV, HRr and  $HR_{peak}$ . In accordance with Lin et al.,<sup>74</sup> a simple linear regression analysis, indicates that WC and WtHR were the only parameters associated with HRR parameters, in particular with HRR5. However, these findings are not coherent with those showed by Easley et al.,<sup>39</sup> who note that OB alone does not seem to considerably impact HRR. Similarly, a current study noted that there are no differences in autonomic function during recovery (HRR1) from maximal exercise in lean and obese 8- to 12-year-old children.<sup>75</sup> Conversely, Laguna et al.<sup>76</sup> observed that HRR was inversely associated with OB traits and related CMR factors mainly in healthy boys.

Concerning sex differences, girls displayed high values of HRR5 than boys in SBG and OOG. These outcomes are contrary to those detected by Guilkey et al.,<sup>77</sup> who observed no significant differences in HRR following maximal and submaximal exercise between boys and girls, reporting that parasympathetic modulation was related between boys and girls at rest and during recovery from exercise. Furthermore, HRR is associated with some cardiovascular fitness indices such as  $\dot{V}O_{2max}$ .<sup>78</sup> However, the present study has been unable to demonstrate strong relationships between  $\dot{V}O_{2max}$  and HRR. Similarly, Fernando et al.<sup>79</sup> showed that no relationship between aerobic fitness and HRR1 after a three minutes modified Harvard's step test in children 7 to 11 years of age.

#### Heart rate variability

BMI and PA are the main factors that can influence HRV between 12 and 17 years.<sup>80</sup> Thereby, the obese children displayed modifications in HRV, characterized by a reduction in both sympathetic and parasympathetic activity.<sup>81</sup> In this regard, another outcome of this research is that HRV differs between groups; OOG showed the lowest values of RMSSD at rest, in particular in boys; furthermore, only in this parameter did the boys show higher values than the girls in the groups that participated

**Table 4.** Simple linear regression between variables.

	$\dot{V}O_{2\max}$		BMI		WC		WtHR		Systolic pressure		Diastolic pressure		
	B	p value	B	p value	B	p value	B	p value	B	p value	B	p value	
RHR	Adjusted	-0.346	<0.001	0.318	<0.001	0.304	0.001	0.352	<0.001	-0.058	0.485	-0.002	0.980
	Raw	-0.367	<0.001	0.283	0.001	0.247	0.007	0.344	<0.001	-0.128	0.134	-0.051	0.550
HR <sub>peak</sub>	Adjusted	0.098	0.240	-0.057	0.512	-0.211	0.023	-0.170	0.072	-0.119	0.149	-0.008	0.930
	Raw	0.081	0.323	-0.115	0.173	-0.275	0.003	-0.149	0.107	-0.203	0.016	-0.058	0.492
HRr	Adjusted	0.305	<0.001	-0.269	0.001	-0.337	<0.001	-0.351	<0.001	-0.030	0.714	0.001	0.994
	Raw	0.318	<0.001	-0.283	0.001	-0.344	<0.001	-0.348	<0.001	-0.032	0.708	-0.003	0.969
CI	Adjusted	0.141	0.078	-0.140	0.092	-0.216	0.016	-0.180	0.049	-0.151	0.059	-0.104	0.212
	Raw	0.133	0.104	-0.135	0.111	-0.237	0.010	-0.209	0.024	-0.154	0.070	-0.106	0.211
HRR1	Adjusted	-0.006	0.941	-0.090	0.302	-0.097	0.304	-0.103	0.280	-0.162	0.050	-0.091	0.294
	Raw	-0.010	0.900	-0.143	0.096	-0.142	0.131	-0.061	0.518	-0.245	0.004	-0.138	0.107
HRR5	Adjusted	0.126	0.124	-0.102	0.247	-0.180	0.059	-0.208	0.026	-0.001	0.992	-0.030	0.728
	Raw	0.108	0.203	-0.113	0.200	-0.211	0.029	-0.213	0.027	-0.041	0.644	-0.053	0.548
RMSSD	Adjusted	0.218	0.008	-0.143	0.095	-0.189	0.042	-0.248	0.008	0.033	0.692	0.005	0.954
	Raw	0.265	0.001	-0.139	0.103	-0.114	0.225	-0.195	0.036	0.083	0.333	0.044	0.602
SDNN	Adjusted	0.159	0.046	-0.059	0.483	-0.104	0.255	-0.170	0.064	-0.008	0.919	0.014	0.870
	Raw	0.174	0.033	-0.063	0.459	-0.073	0.437	-0.153	0.101	0.003	0.972	0.023	0.790
HF	Adjusted	0.093	0.250	0.024	0.774	-0.003	0.973	-0.051	0.583	0.018	0.820	-0.043	0.605
	Raw	0.121	0.140	0.012	0.889	0.021	0.819	-0.006	0.951	0.019	0.821	-0.039	0.650
LF	Adjusted	0.046	0.572	0.068	0.422	0.083	0.364	0.033	0.720	0.045	0.579	-0.047	0.572
	Raw	0.070	0.393	0.083	0.330	0.137	0.142	0.046	0.623	0.085	0.317	-0.021	0.805
LF/HF	Adjusted	-0.108	0.189	0.038	0.659	0.016	0.873	0.044	0.652	0.047	0.564	0.073	0.394
	Raw	-0.145	0.075	0.084	0.325	0.005	0.961	-0.052	0.575	0.071	0.406	0.078	0.359

$\dot{V}O_{2\max}$  maximal oxygen consumption, BMI body mass index, WC waist circumference, WtHR waist-to-height ratio, RHR resting heart rate, CI chronotropic index, HRr heart rate recovery, RMSSD square root of the mean squared differences of successive RR intervals, SDNN standard deviation of all normal R-R intervals, HF high-frequency band, LF/HF ratio of LF and HF frequency band powers. Statistically significant p values are in bold.

in sports. This outcome is in concert, in part, with the outcomes from Jarrin et al.,<sup>82</sup> which show significantly greater HRV values in boys in comparison to girls. These differences can be partly explained by lower HR in boys,<sup>83</sup> differences in level of training,<sup>80</sup> more in boys (which we have not measured), or that the kind of training may have different influence on girls and boys (which requires further research). Nonetheless, more recently, bibliography has developed that offers inconsistent outcomes concerning the sex influence on HRV.<sup>84</sup> In this sense, Sharma et al.,<sup>80</sup> found significant differences in HRV between girls and boys in non-athletes, but not in athletes, which lead to the hypothesis that physical training in boys could have improved their HRV similar to that of girls, therefore, irrespective of sex, athletic level training had positive influence on HRV in terms of increased resting parasympathetic activity and decreased sympathetic activity.<sup>80</sup>

Furthermore, there is no correlation between HRV with BMI, WC and WtHR. The current outcomes appear to be consistent with other study that has not found a clear association between weight status and CMR with HRV.<sup>75</sup> Likewise, Kaufman et al.,<sup>85</sup> showed no significant differences in HRV measures between the normal weight and OW children; the most prominent differences were observed between normal weight children and children at the extreme levels of OB (BMI 95th percentile).<sup>85</sup> Although, a recent study indicated that higher CMR was associated with smaller HRV, mainly indicating lower parasympathetic activity in young children.<sup>86</sup> In this regard, in the current study, simple linear regression showed that RMSSD is inversely associated with WC and WtHR.

Additionally, taking into account CRF, the findings of the current study further support the idea that there is an association between CRF and HRV,<sup>22</sup> simple linear regression showed that both RMSSD and SDNN are positively associated with  $\dot{V}O_{2\max}$ . The current outcomes appear to be coherent with other study that indicated that there was a trend for higher baroreflex sensitivity in athletes, thus HRV (total power and SDNN) was higher in athletes. In the same way, the parasympathetic tone was higher in terms of higher RMSSD, and higher HF power.<sup>87</sup> In this same way, a recent review indicated that high PA level was associated with significant cardiac autonomic control in children and adolescent, in particular, PA and HRV were significantly positive correlated.<sup>88</sup>

However, it was recently noted that HR is a better predictor of CRF than HRV parameters and the complex concept of HRV might not provide additional information to the prediction of CRF in OW and OB children.<sup>27</sup> In the same way, Grant et al.<sup>89</sup> emphasize that during an investigation of aerobic capacity, quantification of HRV may not add significant value. Gamelin et al. reported that after 7 weeks of high intermittent exercise training increased aerobic fitness. Conversely, this training did not generate substantial changes in HRV in prepubertal children.<sup>90</sup> Furthermore, Da Silva et al.<sup>91</sup> support the theory that physical training does not enhance HRV in healthy children. Therefore, future studies, which take these variables into account, will need to be undertaken.

### Relationship between the different HR behaviors

Significant correlations were found between aerobic performance with RHR and HRr. In addition, following the present results, an earlier study has shown that RHR is adversely correlated to HRR.<sup>92</sup> In turn, we found significant correlation between HRR and HRr, in this regard, a previous study noted that the main portion of the abnormality in HRR after exercise can be explained by CI.<sup>93</sup> Moreover, these findings add to past research that observes no relation between aerobic fitness and HRR after a 20-m shuttle test in children aged 7–11 years.<sup>79</sup> Moreover, in the current study, lower values of HRr and higher values of RHR and BP could be indicators of CMR. In this sense, in accordance with the present results, previous studies have demonstrated that children and adolescents with high total or central OB had higher BP at rest.<sup>94,95</sup> Finally, according to Proudfoot et al.<sup>96</sup> engagement in more

intense PA programs as they were performed in EG and SBG, results in greater cardiovascular fitness, better autonomic function and provides additional benefits because it is associated with lower values of CMR.

The present study has some limitations that should be mentioned. First, we used a cross-sectional design, therefore, both cardiac function at rest and during maximum exercise and recovery in growing children should have been measured in a long-term longitudinal study. Second, Since the sample included Caucasian Spaniards, we should be cautious when generalizing these results to other populations. Third, the HR response must take into account the mode of the stress test (i.e., treadmill vs. cycling). Fourth, in our study, the menstrual cycle was not tracked. In spite of these limitations, this current study is the first study to observe the correlations of PA and CRF with cardiac function along with traditional CMR risk factors in this population. Therefore, our results present some insights into cardiovascular autonomic modulation in children and adolescent populations during typical field tests, such Léger test, reinforcing the ecological validity of this study.

From a practical point of view and considering the lack of reference values for assessing the autonomic cardiac function during maximal exercise and recovery in children concerning weight status and CRF level, the values obtained in this study might play a key role for teachers, coaches, and physicians who work with children aged 10–16 years. It will enable the development of individualized health programs based on measurable values of HR. In addition, assessing HR has a minimal cost and its ease of use allows the test to be employed in both sports and clinical practice.

### CONCLUSIONS

In conclusion, aerobic performance, vagal activity, BP, chronotropic competence, and HRR have significant associations with CMR. In accordance with Dangardt et al.,<sup>97</sup> children with OW and OB show signs of autonomic dysfunction reflected as low cardiac vagal activity and poor chronotropic competence. Therefore, weight reduction and increased PA may, in concert or independently of each other, restore cardiac autonomic control back to normal operating balance in children who are OW and OB, and possibly helping to maintain their normal cardiac autonomic function long term.<sup>97</sup> The age- and sex-specific reference range at rest, during and post-exercise HR, determined by Léger test, provides the assessment and monitoring of exercise-induced adaptations in the cardiovascular system and the potential to detect children with poor exercise tolerance or abnormal hemodynamic responses to exercise.

### DATA AVAILABILITY

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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## AUTHOR CONTRIBUTIONS

All the authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; drafted the article or revised it critically for important intellectual content; and gave final approval of the version to be published.

## COMPETING INTERESTS

The authors declare no competing interests.

## ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Parents voluntarily signed an informed consent for the participation of their children in this study.

## ADDITIONAL INFORMATION

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