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ORIGINAL ARTICLE

Physical Activity and Heart Rate Variability in Adolescents with Abdominal Obesity

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Abstract Physical activity is a protective factor for autonomic dysfunction. However, whether this occurs in adolescents with abdominal obesity is still unclear. Thus, the aim of this study was to analyze the association between physical activity and heart rate variability (HRV) in adolescents with and without abdominal obesity. This cross-sectional study included 1152 boys (age: 17 ± 1 years). HRV measures of time (root mean square of the squared differences between adjacent normal RR intervals—RMSSD and the percentage of adjacent intervals over 50 ms—PNN50) and frequency domains (balance sympathetic–vagal—LF/HF) were evaluated, as well as total physical activity, commuting physical activity, leisure-time physical activity, and abdominal obesity. All physical activity domains were associated with better RMSSD, PNN50, and LF/HF in normal weight adolescents ($p < 0.05$), whereas in adolescents with abdominal obesity only leisure-time physical activity was associated with better PNN50 ($b = 0.174$, $p = 0.035$) independent of age, period of the day, body mass index, and blood pressure. In conclusion, higher leisure-time physical activity, but not total and commuting physical activity levels, was associated with improved HRV in adolescents with abdominal obesity.

Keywords Autonomic nervous system · Adolescents · Physical activity · Obesity

Introduction

Adolescent obesity is a global public health issue and once established in childhood seem to track into adulthood [1, 2], enhancing the risk of developing chronic metabolic

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and cardiovascular disorders [3]. Autonomic cardiac modulation is a strong and independent predictor of cardiovascular diseases and mortality [4], and it is reduced in adolescents with obesity [5]. Thus, sympathetic nervous system should be a target to improve cardiometabolic risk in obesity.

Physical activity is a well-recognized factor that improves the autonomic cardiac modulation, measured by heart rate variability (HRV), in overweight children [6, 7] or obese adults [8, 9]. Previous studies in normal weight adolescents [10, 11] observed that adolescents who were physically active had greater HRV compared with insufficient active adolescents. However, these studies have small samples and analyze only one type of physical activity. In fact, some studies [8, 9] evaluated just total physical activity, while others used the leisure-time physical activity [6, 7, 10]. Furthermore, none of the previous studies [6–11] analyzed this association between HRV and adolescents with abdominal obesity, which is more related with autonomic cardiac dysfunction compared to general obesity in adolescents [12].

Thus, this study aimed to investigate the association between physical activity and HRV in adolescents with abdominal obesity. A significant association may provide further support for targeted interventions to enhance cardiac autonomic function and reduce cardiovascular risk in adulthood.

Materials and Methods

Design and Subjects

This is a cross-sectional study conducted in the Department of Physical Education, University of Pernambuco, Pernambuco, Brazil. After obtaining approval of the ethics committee of the university in compliance with the Brazilian National Research Ethics System Guidelines, the participants were sampled from the students of the Public School System in the State of Pernambuco (northeast Brazil), as previously described [13]. Adolescents and their guardians were informed about methodological procedures and we obtained signed written consent form to have their children participating.

The target population was limited to high school students between 14 and 19 years old. Exclusion criteria were as follows: (a) known diabetes mellitus, cardiovascular disease, and neurologic or mental disabilities; (b) consumption of caffeinated beverages 12 h prior to the HRV evaluation; (c) use of alcohol, any form of tobacco, and/or other illicit drugs; and (d) participation in any physical exercise training 24 h before evaluations.

Data Collection

The data collections were conducted from May to October in 2011. The period of the day that the adolescents were in class (morning, afternoon, and evening) was obtained. Demographic data and physical activity were obtained using an adapted version of the Global School-based Student Health Survey.

Heart Rate Variability (HRV)—Outcome

HRV was assessed from the RR intervals obtained by a heart rate monitor (POLAR, RS 800CX, USA). Adolescents remained in the supine position for 10 min, after approximately 30 min at rest, being used to analysis at least 5 min stationary period. All analyses were performed with Kubios HRV software (Biosignal Analysis and Medical Imaging Group, Joensuu, Finland) by a single evaluator blinded to the other study variables. Intraclass correlation coefficient of this evaluator ranged from 0.990 to 0.993 [14]. All procedures for HRV analysis followed the recommendations of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [4].

The time-domain variables, such as root mean square of the squared differences between adjacent normal RR intervals (RMSSD) and the percentage of adjacent intervals over 50 ms (PNN50) were obtained. The frequency-domain variables were analyzed using the spectral analysis of HRV. Stationary periods of the tachogram were broken down into bands of low (LF) and high (HF) frequencies, using the autoregressive method with a fixed model order of 12 by Akaike's information criterion.

Frequencies between 0.04 and 0.4 Hz were considered as physiologically significant, where the LF component was represented by oscillations between 0.04 and 0.15 Hz and HF was represented by oscillations between 0.15 and 0.4 Hz. The power of each spectral component was normalized by dividing the power of each spectrum band by the total variance, minus the value of very low-frequency band (< 0.04 Hz), and multiplying the result by 100. For analysis, the ratio between these bands (LF/HF) was defined as the cardiac sympathovagal balance [4]. In a subsample of 27 adolescents, the reliability of HRV parameters was assessed after one week. Intraclass correlation coefficient ranged from 0.68 to 0.91 [14].

Physical Activity—Predictors

Physical Activity Level Total physical activity level was assessed by the question "During the past 7 days on how many days were you physically active for a total of at least 60 min per day?" Reproducibility indicators (i.e., test-

retest consistency, 1-week apart) showed the kappa coefficient to be 0.60 and Spearman's rank correlation coefficient to be 0.82 [15].

Commuting Physical Activity Commuting physical activity was assessed by the question: 'During the past seven days, how many days have you walked or cycled to and from school?' The adolescents who responded that they got to and from school on foot or by bicycle three days or more were considered active. Reproducibility indicators showed intraclass correlation coefficient 0.64 [16].

Leisure-Time Physical Activity Leisure-time physical activity was assessed by the question: "Do you regularly perform some sort of physical activity in your free time, such as exercise, sports, dance or martial arts?" The adolescents were classified as active (if the answer was yes) or not active. Reproducibility indicators showed intraclass correlation coefficient 0.77.

Demographic Data, High Blood Pressure, and Obesity Indicator—Confounders

Age, ethnic background, place of residence were obtained. Waist circumference (WC) was measured in the standing position at the level of the umbilicus using a constant tension tape. High blood pressure was defined as systolic and/or diastolic blood pressure equal or higher than the reference sex, age, and height-specific 95th percentile [17]. Overweight was determined by Cole's criteria [18]. Abdominal obesity was determined by waist circumference above the 80th percentile for sex and age [19].

Statistical Analysis

All statistical analyses were performed using SPSS/PASW version 20 (IBM Corp, NY, USA). Continuous variables were summarized as mean and standard deviation, whereas categorical variables were summarized as relative frequency. HRV parameters between normal weight adolescents and adolescents with abdominal obesity were compared using independent t test.

Crude and adjusted analyses were performed by linear regression to analyze the relationship between HRV parameters and physical activity levels in normal weight and adolescents with abdominal obesity. In multiple linear regressions, the fully adjusted model included age, period of the day (diurnal and nocturnal), body mass index, and high blood pressure. In both analyses, each HRV parameter was included in a separate regression analysis. Residual analysis was performed and adherence to the normal distribution was tested using the Kolmogorov–Smirnov test. Statistical significance was set at $p < 0.05$.

Results

From the 1212 enrolled in the present study, sixty were excluded due to poor signal quality (stationary periods of the tachogram lower than five minutes), therefore, 1152 boys were included in the analyses. The general characteristics of the sample according to abdominal obesity are summarized in Table 1. Adolescents with abdominal obesity presented higher body mass, body mass index, WC, and high blood pressure prevalence as compared to the normal weight ones.

Comparisons of HRV parameters between normal weight adolescents and adolescents with abdominal obesity are presented in Fig. 1. Adolescents with abdominal obesity presented lower values of RMSSD (55.5 ± 29.0 vs 49.8 ± 28.4; $p = 0.026$) and PNN50 (30.3 ± 20.5 vs 25.2 ± 19.6; $p = 0.005$) than normal weight, while LF/HF were higher in adolescents with abdominal obesity (1.4 ± 1.0 vs 1.6 ± 1.2; $p = 0.006$).

The associations between HRV parameters and physical activity level in normal weight adolescents and adolescents with abdominal obesity are shown in Tables 2 and 3, respectively. In normal weight adolescents, all physical activity domains were associated with better HRV parameters, while it only occurred for leisure-time physical activity and PNN50 in adolescents with abdominal obesity ($p = 0.036$). These associations remained significant after adjustment for age, the period of the day (diurnal and nocturnal), body mass index, and high blood pressure.

Discussion

The main findings of this study were that total and commuting physical activities were positively associated with HRV in normal weight, but not in boys with abdominal obesity. Leisure-time physical activity was positively associated with HRV in both normal weight and obese adolescents.

In accordance to the previous studies [5, 20, 21], the current study showed worse HRV in adolescents with abdominal obesity compared to normal weight adolescents. The proposed mechanisms underlying the low HRV and obesity present a bidirectional pathway. Adipokines secreted by adipocytes, especially leptin, activate neural pathways increasing sympathetic activity and reducing parasympathetic activity [22, 23]. Others studies suggested that low HRV leads to lower levels of energy expenditure, and, consequently, to a positive energy balance and weight gain [24, 25].

Positive and significant associations between physical activity and better HRV were previously reported in

Table 1 General characteristics of adolescents with abdominal obesity ($n = 1152$)

Variable	Normal weight ($n = 933$)	Obese ($n = 149$)	p value
Age (years)	17 ± 1	17 ± 1	0.161
Weight (kg)	59.3 ± 7.5	87.1 ± 11.8	< 0.001
Height (cm)	171.4 ± 6.9	173.6 ± 7.1	< 0.001
Waist circumference (cm)	73.2 ± 4.8	95.9 ± 8.3	< 0.001
Body mass index (kg/m^2)	20.2 ± 2.0	28.9 ± 3.5	< 0.001
High blood pressure (%)	6.5	27.5	< 0.001
Total physical activity (day/week)	4.3 ± 2.3	4.0 ± 2.2	0.290
Commuting physical activity (day/week)	4.1 ± 2.9	3.8 ± 2.9	0.347
Leisure-time physical activity (% of active)	79.3	71.8	0.039

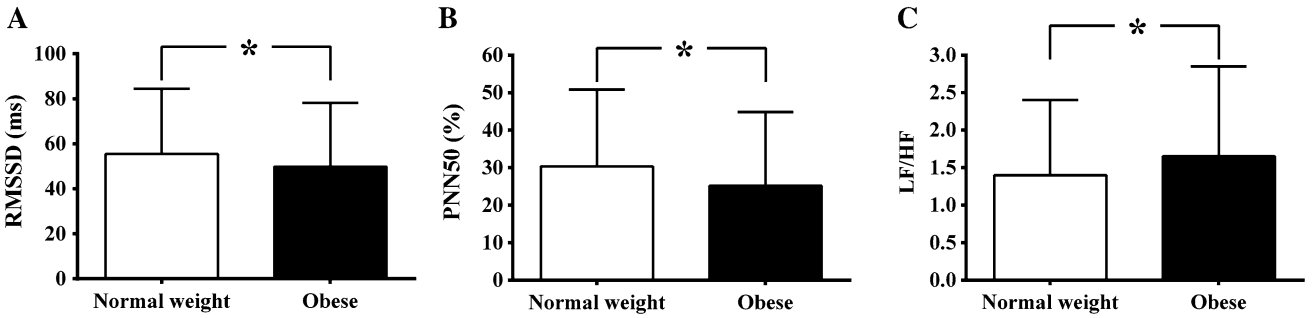

Fig. 1 Comparison of root mean square of the squared differences between adjacent normal RR intervals (RMSSD, Painel **A**), the percentage of adjacent intervals over 50 ms (PNN50, Painel **B**), and low-frequency/high-frequency ratio (LF/HF, Painel **C**) between normal weight and obese adolescent

Table 2 Relationship between heart rate variability (HRV) parameters and physical activity in normal weight adolescents ($n = 933$)

HRV parameters	(Crude analysis)				(Adjusted analysis)			
	β	SE	b	p	β	SE	b	p
Total physical activity (day/week)								
RMSSD (ms)	1.511	0.412	0.119	< 0.001	1.514	0.413	0.120	< 0.001
PNN50 (%)	0.950	0.292	0.106	0.001	0.941	0.292	0.105	0.001
LF/HF	− 0.021	0.015	− 0.045	0.165	− 0.022	0.015	− 0.049	0.136
Commuting physical activity (day/week)								
RMSSD (ms)	1.061	0.325	0.106	0.001	1.046	0.325	0.105	0.001
PNN50 (%)	0.560	0.231	0.079	0.015	0.545	0.230	0.077	0.018
LF/HF	− 0.033	0.012	− 0.092	0.005	− 0.033	0.012	− 0.091	0.005
Leisure-time physical activity (0 = not active; reference)								
RMSSD (ms)	7.098	2.332	0.099	0.002	6.898	2.330	0.097	0.003
PNN50 (%)	5.671	1.647	0.112	0.001	5.502	1.641	− 0.109	0.001
LF/HF	− 0.171	0.084	− 0.066	0.043	− 0.178	0.084	0.069	0.036

β regression coefficient, *SE* standard error, *b* standard coefficient, *SDNN* standard deviation of all RR intervals, *RMSSD* root mean square of the squared differences between adjacent normal RR intervals, *PNN50* the percentage of adjacent intervals over 50 ms, *LF* low frequency, *HF* high frequency; *Adjusted model* adjusted for age, high blood pressure, body mass index, and time of day

adolescents [10] and normal weight adult individuals [26]. A previous study in healthy adults [26] observed a high significant correlation between HRV indices and physical activity. Furthermore, recently, Sharma et al. [10] observed that 451 normal weight adolescents who practiced sports had greater HRV when compared with their insufficient active counterparts, which is in agreement with the current study that showed association between physical activity and HRV in normal weight adolescents.

Table 3 Relationship between heart rate variability (HRV) parameters and physical activity in adolescents with abdominal obesity (n = 149)

HRV parameters	(Crude analysis)				(Adjusted analysis)			
	B	SE	*b*	*p*	β	SE	*b*	*p*
Total physical activity (day/week)								
RMSSD (ms)	1.694	1.047	0.132	0.118	1.392	1.051	0.109	0.187
PNN50 (%)	1.423	0.718	0.161	0.049	1.241	0.723	0.141	0.088
LF/HF	− 0.034	0.043	− 0.066	0.425	− 0.025	0.043	− 0.049	0.557
Commuting physical activity (day/week)								
RMSSD (ms)	− 0.029	0.825	− 0.003	0.972	0.241	0.851	0.024	0.778
PNN50 (%)	− 0.322	0.566	− 0.047	0.570	− 0.155	0.587	− 0.023	0.792
LF/HF	− 0.009	0.033	− 0.022	0.792	− 0.019	0.034	− 0.048	0.577
Leisure-time physical activity (0 = not active; reference)								
RMSSD (ms)	8.405	5.137	0.134	0.104	8.792	5.161	0.140	0.091
PNN50 (%)	7.296	3.521	0.168	0.040	7.553	3.548	0.174	0.035
LF/HF	− 0.374	0.208	− 0.146	0.075	− 0.386	0.210	− 0.151	0.069

β regression coefficient, *SE* standard error, *b* standard coefficient, *SDNN* standard deviation of all RR intervals, *RMSSD* root mean square of the squared differences between adjacent normal RR intervals, *PNN50* the percentage of adjacent intervals over 50 ms, *LF* low frequency, *HF* high frequency; *Adjusted model* adjusted for age, high blood pressure, body mass index, and time of day

Total physical activity and commuting did not counteract the cardiac autonomic dysfunction in adolescents with abdominal obesity. A possible explanation for this response is the larger pro-inflammatory state compared to their normal weight counterparts [14, 27, 28]. Different inflammatory markers, such as C-reactive protein [29–31], leukocyte [31, 32], and leptin [33] are inversely associated with HRV. Another explanation for these results involve the volume and intensity of physical activities performed by adolescents. Gutin et al. [34] demonstrated an improvement in parasympathetic modulation to the heart after a 4-month vigorous aerobic exercise in obese children, which was also observed in other study [35]. On the other hand, six-month of low intensity aerobic training did not change heart rate variability. In this study, we observed association between leisure-time physical activity, that are most of times vigorous exercise (e.g., exercise, sports, dance, or martial arts), with HRV in obese adolescents. These results reinforce the idea that obese adolescents benefit more from vigorous activities, which is in line with a previous study [35] that showed enhancement in the parasympathetic autonomic modulation of the heart in obese adolescents submitted to training with higher intensities.

Reduced HRV is an independent predictor of risk for cardiovascular diseases and mortality in different subgroups [4]. Furthermore, autonomic modulation has been shown to be impaired in obese adolescents [5], and strategies for counteracting these negative effects are needed. From a practical viewpoint, these results reinforce the idea that greater total commuting and leisure-time physical activities should improve cardiovascular function in normal weight adolescents and that leisure-time physical activity improves the HRV in adolescents with abdominal obesity.

A strength of our study is clearly the large sample size. Furthermore, we tried to control for various potential confounders in the study, and a single researcher in a blinded fashion analyzed HRV. However, current study presents some limitations. First, we evaluated only boys, thus, if the same response would occur in girls is not clear. Second, the cross-sectional design and the correlative nature of the data preclude us from establishing a causal relationship between HRV parameters and risk factors. Finally, although the participants' age was tightly controlled, we could not determine the Tanner stage of the participants.

In conclusion, higher leisure-time physical activity, but not total and commuting physical activity levels were associated with better HRV in adolescents with abdominal obesity. Therefore, engaging in sports practice should be encouraged to improve cardiac autonomic function in obese adolescent boys.

Authors' Contributions BQF conceptualized and designed the study, collected data, carried out the analyses, and drafted the initial manuscript. AA-L contributed to the interpretation of the data, carried out the analyses, and reviewed the manuscript. AHGS collected data, contributed to the interpretation of the data, and reviewed the manuscript. DGDC conceptualized and designed the study, carried out the analyses, and reviewed the manuscript. MVGB designed the data collection instruments, coordinated and supervised data collection, and reviewed the manuscript. WLP contributed to the interpretation of the data and reviewed the manuscript. RMR-D designed the data collection instruments, coordinated and supervised data

collection, conceptualized and designed the study, and reviewed the manuscript.

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Compliance with Ethical Standards

Conflict of interest The authors declare that there are no conflicts of interest.

Ethical Approval The study has been approved by Ethics Committee of the University of Pernambuco in compliance with the Brazilian National Research Ethics System Guidelines.

Informed Consent Legal tutors signed informed consent for all underage subjects participating in this study. All adolescents aged ≥ 18 years who enrolled in the study also signed the informed consent.

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