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VAGAL RESPONSE TO 15-WEEKS OF HIGH-INTENSITY FUNCTIONAL TRAINING: A PILOT STUDY

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ABSTRACT

The purpose of this investigation was to examine the training effects of a 15-week High-Intensity Functional Training (HIFT) on Autonomic Nervous System (ANS). Eleven apparently healthy college students participated in this study. Participants were enrolled in a 15-week CrossFit® training based academic course, two days a week. On the first and last scheduled day of class participants performed a HIFT trial and ANS activity was measured through Heart Rate Variability (HRV) for 10 minutes prior to and following each bout using the log-transformed square root of the successive R-R differences (lnRMSSD) and high frequency power (lnHF). A significant decreased was observed for the lnRMSSD after the HIFT trial before (Pre: 3.86 ± 0.39 vs. Post: 2.58 ± 1.12; $P < 0.001$) and after (Pre: 4.00 ± 0.46 vs. 1.96 ± 0.84; $P < 0.001$) the intervention. Similarly, the lnHF was significantly reduced before (Pre: 3.66 ± 0.36 vs. Post: 2.88 ± 0.86; $P < 0.05$) and after (Pre: 3.73 ± 0.41 vs. 2.69 ± 0.65; $P < 0.001$) 15-weeks of this intervention. The exercise modality known as HIFT was effective in improving repetitions completed during the HIFT trial, when comparing pre and post trials. The findings of this study suggest that resting HRV and post exercise vagal reactivation is not influenced by 15-weeks of a HIFT intervention.

Keywords: Heart Rate Variability, CrossFit ®, Exercise

INTRODUCTION

According to the American College of Sports Medicine (ACSM) current trends in fitness have shifted towards programs that promote body weight circuits, high-intensity interval training (HIIT), and strength training [1]. Coincidently, these are key components of a relatively new mixed-modal exercise-training program best referred to as high-intensity functional training (HIFT). Recently, HIFT programs (e.g. P90x™, CrossFit®, EXOS™) have garnered a strong following within the general population due to its focus towards achieving general preparedness, along with an emphasis on high-intensity and short duration bouts [2]. Although popularity has increased [2], little empirical data exists regarding physiological adaptations to HIFT programming. These adaptations are believed to occur through various mechanisms that lead to improved control of homeostatic function (e.g., cardiovascular activity, blood pressure, and thermoregulation), which results in less physiological disruptions and decreases time to recovery.

Control over the homeostatic functions of the body, occurs through the autonomic nervous system (ANS) [3]. The most practical system to measure and evaluate homeostatic function is the cardiovascular system, which through alterations of cardiac parasympathetic activity provides a reliable means to determine deviations in homeostasis [4,5]. A rapid and noninvasive measure of cardiac parasympathetic activity can be achieved through the analysis of Heart Rate Variability (HRV), which quantifies the oscillations between consecutive beat-to-beat intervals derived from an electrocardiogram [6].

The evaluation of resting HRV prior to exercise is important to examine due its relationship to homeostatic control and parasympathetic dominance, in that it pertains to recovery and readiness to perform [5]. Improvements in resting vagal activity are associated with increases in peak oxygen consumption and performance, however these responses are highly individualized [7,8]. Additionally, HRV has been used to gauge deviations of cardiac autonomic control (e.g. dyshomeostasis) following acute bouts of exercise in order to assess physiological stress and recovery [9]. The initial reactivation of vagal activity following exercise is not fully understood, but may serve as an indirect measure of cardiovascular demand needed for the restoration of homeostasis [5]. It is well established that various traditional aerobic training programs improve resting HRV in sedentary and physically fit populations [10,11]. To date, little research has examined this parameter of cardiac autonomic control following acute bouts of HIFT, or even long-term HIFT programing. We believe a thorough understanding of the autonomic response and adaption to HIFT training would lead to effective prescription of this modality. Thus, the purpose of this investigation was to examine the training effect of a 15-week HIFT program on resting markers of HRV in healthy college age participants. Additionally, this study set out to gauge alterations in vagal reactivation following an acute trial of HIFT. We hypothesize that 15-weeks of HIFT training would elicit an increased resting HRV as well as lead to improved vagal reactivation of HRV markers.

MATERIALS AND METHODS

PARTICIPANTS

The University Institutional Review Board approved the procedures and protocols of this study. In order to accomplish the aims of this study, we recruited students from a university located in the southwestern United States who participated in a 15-week CrossFit® training course. CrossFit® training is defined as "constantly varied functional movements performed at relatively high intensity" [12] and incorporates various aspects of Olympic lifting, gymnastics, and callisthenic movements combined with bouts of cardiovascular training [12].

Eleven apparently healthy male and female college students participated in this study. All participants were determined to be at low risk for cardiovascular, pulmonary, and/or metabolic disease following the American College of Sport Medicine (ACSM) risk stratification criteria [13]. Prior to each testing session, participants were instructed to avoid caffeine and exercise for a minimum of 12-hours.

MEASURES

Anthropomorphic Measurements

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Prior to and following the 15-week course, participant's height (m) and weight (kg) were measured using a traditional standing physicians scale with height rod. BMI was calculated following the standard formula (kg/m^2).

Chronotropic Measurements

The Zephyr Bioharness system (Zephyr Technology, Annapolis, MD) was used to collect Resting Heart Rate (RHR), Average heart rate (HRave), and the Percent Heart Rate Max during HIFT trials (%HRmax). The %HRmax was calculated by dividing the HRave achieved by the age predicted maximal heart rate (220 – age).

Heart Rate Variability Analysis

The markers chosen for HRV were the time domain as the root mean square of the standard deviation of consecutive N-N intervals (RMSSD), and frequency domain as High Frequency (HF) power (0.15-0.40 Hz). The transformation of ECG into time domain and Frequency domain components was done through specialized HRV software (Kubios V 2.2). In order to assess RMSSD, the ECG recordings were converted into a tachogram, which plots the successive R-R intervals (y-axis) against the number of beats within the ECG (x-axis). From the tachogram the 5-minute segments were calculated for RMSSD. Analysis of the frequency domain was performed through a power spectral analysis, which was completed by applying a fast Fourier transformation to the R-R intervals of the sampled ECG. RMSSD and HF are sensitive markers of parasympathetic activity and have been used in several studies [4,9,14,15]. RMSSD is not significantly influenced by breathing frequency and is capable of measuring parasympathetic activity in a short period of time [15], making it a suitable marker for this study. The frequency domain has several components (i.e., VLF, LF, HF, LF:HF); however HF is the only frequency marker that is widely accepted to accurately reflect vagal activity [3,16].

PROCEDURES

Experimental Approach to the Problem

All data were collected at a CrossFit® affiliate, while participants were enrolled in a semester long CrossFit® training elective course (15-week), in which they followed the facility's programming two days a week. Data collection and testing occurred during the first and last scheduled day of class. During the first testing day, participants signed an informed consent and underwent basic demographic (age, gender) and anthropomorphic (height, weight, BMI) measurements. Immediately after, participants were instructed to lie in a supine position for ten-minutes to obtain chronotropic and HRV measurements. After completion of resting values participants performed a general ten-minute warm-up and then performed a HIFT trial followed a post evaluation of HRV. Upon the completion of the 15-week semester each student was re-evaluated and the HIFT trial was repeated.

The investigation was conducted as a blinded study, where the investigators did not have any input on the type and/or intensity of each class and the instructor did not have access to the participant's information. Study participants were asked to adhere to all class instructions throughout the semester course. A certified CrossFit® coach delivered the course and each participant was monitored throughout each session. The certified coach determined if modifications to any workout were needed by any of the participants in order to maintain their safety during any of the workouts throughout the 15-weeks of the program. Failure to participate in the study, or provide pre- or post measurements had no influence in whether a participant obtained a passing or failing grade in the course.

HIFT Trial

The testing protocol chosen for this study was a modified version of the body-weight-circuit “Cindy.” The modified circuit was comprised of as many rounds as possible of 5 pull-ups, 10 push-ups, and 15 air-squats in 10-minutes. Completion of all the prescribed repetitions for each movement was required before moving onto the next round. Work performed was quantified by total number of repetitions at the end of the 10-minutes.

Chronotropic and HRV Collection protocol

Before and immediately after the HIFT trial, participants were instructed to lie on the matted gym floor while the room was dimly lit and silent. The Zephyr Bioharness system includes a chest and shoulder strap to secure the reading device (called a puck) to the left side of the ribcage in line with the zyphoid process.

Data was collected and transferred from the Zephyr collection puck, uploaded to the Zephyr software and the ECG recordings were converted into an excel file using the Zephyr Bioharness system (Zephyr Technology, Annapolis, MD) following manufacturer recommendations. The files were further converted by using the Zephyr to Kubios RR File Format Converter in order to be analyzed through the online Kubios Heart Rate Variability Analysis Software (Kubios HRV, version 2.2). All files were examined for ectopic/non-sinus beats, which were replaced by the adjacent R-R interval when observed [17]. Any segments containing three or more ectopic beats were excluded from the analysis [17,18]. Two separate 10-minute recordings (pre and post-test) were obtained during the testing day. The 10-minute ECG recordings obtained were divided into two 5-minute segments. The first 5-minutes were considered an adjustment period and discarded. The second 5-minutes were then analyzed into the following time points: Pre-Intervention-Pre-HIFT, Pre-Intervention-Post-HIFT, Post-Intervention-Pre-HIFT, Post-Intervention-Post-HIFT.

STATISTICAL ANALYSIS

Participants’ data was entered into Excel 2003 (Microsoft Co., Redmond, WA), and all statistical analyses were conducted with SPSS, version 19 for Mac (SPSS, Inc., Chicago, IL). A Shapiro-Wilk test was performed to determine the normality of the HRV distribution within the population. The data set violated normality; therefore, a logarithmic transformation was applied to RMSSD and HF data prior to further analysis (lnRMSSD and lnHF). A Paired Samples t-test was used to assess differences between pre and post-trial variables, as well as to compare pre and post-intervention points following the 15-weeks. Significance was set to alpha less than 0.05. Data is presented as means ± standard deviations.

RESULTS

All 11 participants completed the pre and post intervention HIFT trials. Overall, our sample was a relatively older group of college students with females being older (21.7 ± 2.8 yrs.) than males (20.8 ± 1.6 yrs.). As expected, males were taller (1.8 ± 0.08 m vs. 1.6 ± 0.02 m) and heavier than females at the beginning (78.6 ± 5.2 kg vs. 61.8 ± 5.5 kg) and at the end of the study (80.6 ± 6.7 kg vs. 62.9 ± 4.6 kg). Even though there were differences between the genders, body weight did not change statistically after the 15-weeks of training ($p = 0.057$).

We were interested in examining changes in HRV markers prior to and after the testing HIFT trial and after the 15-week intervention. Overall, lnRMSSD and lnHF values were significantly different before and after the HIFT trial, but not after the 15-week intervention (Table 1). No significant chronotropic adaptations were seen in this group of participants, as RHR, HRave and %HRmax did not differ after 15-weeks of training (Table 2). Lastly, even though we did not observe any chronotropic adaptations, all participants did significantly improve their overall performance after the 15-week intervention as seen in the total number of repetitions completed at the end of the HIFT trial after the intervention compared to the prior the intervention (Pre: 236.2 ± 13.6 repetitions vs. Post: 275.9 ± 68.5 repetitions; $p < 0.001$).

DISCUSSION

The purpose of this investigation was to examine alterations in cardiac autonomic control following participation in a 15-week HIFT course. Cardiac autonomic control was assessed through the alterations of HRV following a HIFT trial, which was performed prior to, and following the 15-week intervention. As expected, acute alterations of vagal tone markers (lnRMSSD and lnHF) occurred immediately following both pre and post trials. However, the hypothesis that a 15-week HIFT intervention would improve resting HRV as well as improve vagal reactivation following a HIFT trial was rejected due to a lack of significant difference between pre and post testing values. Despite this, an improvement in performance was observed following the intervention when comparing the total repetitions completed between HIFT trials.

HRV Response to Exercise

The HIFT trials resulted in significant reductions of vagal markers both pre and post-intervention (Table 1). This was an expected response as previous investigators have established that the onset of exercise results in the acute depression of HRV [9,14,18]. The magnitude and duration of HRV depression is not consistent amongst all exercise, but rather, dependent on factors such as exercise intensity and modality [9,18]. In general, exercise bouts of higher intensity results in greater autonomic disruption [9,18,19]. For instance, Parekh & Lee examined HRV following an acute bout of low (50% VO_2R) vs. high (80% VO_2R) intensity cycling; each intensity bout resulted in significant depression of lnHF [18]. However, the high-intensity bout (80% VO_2R) demonstrated a greater depression of HRV when compared to the low-intensity bout (50% VO_2R), suggesting that exercise intensity was the key factor in the magnitude of HRV depression.

Table 1: Heart rate variability variables (M ± SD)

	Pre-Intervention		Post-Intervention	
	Pre-HIFT Trial	Post-HIFT Trial	Pre-HIFT Trial	Post-HIFT Trial
lnRMSSD (ms)	3.86 ± 0.39	2.58 ± 1.12**	4.00 ± 0.46	1.96 ± 0.84**
lnHF (ms^2)	3.66 ± 0.36	2.88 ± 0.86*	3.73 ± 0.41	2.69 ± 0.65**

	Pre-HIFT Trial		Post-HIFT Trial	
	Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention
lnRMSSD (ms)	3.86 ± 0.39	4.00 ± 0.46	2.58 ± 1.12	1.96 ± 0.84
lnHF (ms^2)	3.66 ± 0.36	3.73 ± 0.41	2.88 ± 0.86	2.69 ± 0.65

** Significantly higher than females ($P \leq 0.05$)*

*** Significantly higher than females ($P \leq 0.001$)*

The additional influencing factor related to magnitude and duration of the vagal disruption is mode of exercise. Chief amongst these modalities are resistance-based exercises, which create greater vagal withdrawal and duration of depression when compared to other modalities [9,19,20]. A comparative study performed by Heffernan et al. showed that a resistance exercise trial (i.e. three sets of 10-repetitions of eight different exercises) resulted in a lnHF depression five-times greater to that of 30-minutes aerobic cycling at 65% VO_{2peak} [19]. Furthermore, a recent study examining the high-intensity bodyweight circuit “Cindy” compared to a intensity matched treadmill bout of exercise revealed the circuit to be more taxing on the ANS despite similar intensities [9]. In other words, exercise bouts that are resistance based tend to elicit greater challenges to vagal control.

Alterations in HRV with training (resting and response)

Exercise training has been shown to be a pragmatic intervention for the improvement of resting autonomic control (e.g. HRV) [5,17,21]. For instance, Melanson and Freedson demonstrated that a 16-week moderate-to-vigorous exercise training program in sedentary participants significantly improved RMSSD and HF within the first 12-weeks of the intervention [21]. Significant improvement in vagal activity following exercise interventions is an expected outcome within a sedentary population; however, improvements amongst trained athletes can also be observed. Kiviniemi et al. examined two different approaches to aerobic training (i.e. traditional aerobic vs. HRV guided programming) that lasted four-weeks in recreational male runners; both groups experienced significant increases in resting lnHF regardless of the training intervention [17]. Conversely, findings of the current study did not show significant improvements of resting vagal tone markers lnRMSSD ($p = 0.260$) or lnHF ($p = 0.478$) after 15-weeks of training. Although this was an unexpected observation, it is not the only occurrence in which high-intensity training has not elicited alterations in resting vagal tone. In a study examining 10-weeks of exercise in a low-intensity group (30% HRR) and high-intensity group (66%HRR), researchers observed no significant changes in resting HRV following the interventions, despite improvement in aerobic performance [22]. Additionally, Catai et al. examined healthy young (~21 yr.) and older (~53 yr.) males participating in an aerobic training program over a three-month period and showed no improvements in vagal markers, though improvements in resting heart rate were observed [23].

A proposed mechanism for the lack of significant improvement in resting vagal activity within this study may be due to an occurrence referred to as “pre-competitive arousal.” This takes place when an individual is anticipating a difficult task or has concerns about performance leading to anxiety, which can lead to depressions in vagal tone [24]. Thus, a pre-competitive arousal prior to the HIFT trial may have resulted in an acute depression of vagal tone, consequently masking any potential positive alterations. Future studies should account for pre-competitive arousal when examining post intervention HRV.

HRV Depression Following Exercise Training

Parasympathetic rebound is a key component to general recovery following exercise [5]. Rapid rebound (i.e. 5-10 minutes) is an indication of enhanced cardiac autonomic control influencing rate of recovery [14,25]. Control of resting autonomic function has been observed to improve following exercise training interventions [17]. However, to the best of our knowledge this is the first study to attempt to bridge the gap between training and its influence on post exercise attenuation of vagal tone or early rebound. In order to examine the influences of HIFT intervention on early vagal rebound, participant HRV was obtained prior to and immediately following a HIFT trial at the beginning and end of the intervention. The influencing factors of vagal rebound are important to consider when examining the bout of HIFT used in this study. The HIFT trial is considered to be a high-intensity bout of exercise based on the mean %HRmax observed during the trials as established by ASCM guidelines [13] (Table 2). Furthermore, the HIFT bout is a form of body weight resistance exercise that has been demonstrated to result in greater depression of HRV [9]. As such, the HIFT trial was optimal for challenging the vagal activity and reactivation. However, our study failed to show significant changes in early vagal reactivation following the 15-week of training, despite an improvement in performance. Although a lack of significant alterations was observed, this study was a novel step towards examining the question of alterations in rapid vagal rebound as it pertains to a15-week HIFT intervention.

HIFT Trial Outcome

Even though we did not find significant changes in HRV after the 15-week intervention, we did see significant improvements in the participant's work capacity. This was indicated by a 16.5% ($p < 0.001$) improvement in the number of repetitions completed in the HIFT trial before and after the 15-week intervention. These findings are in agreement with the literature [26,27] as it suggests that high-intensity exercise improves various markers of performance. To our knowledge, this is one of the few studies to evaluate improvements in performance using repetitions completed in a body weight circuit as an outcome measure. However, other performance markers such as aerobic capacity, anaerobic capacity, and strength have been shown to improve following high-intensity training. For instance, six-weeks of high-intensity intermittent training (20-sec exercise, 10-sec rest at 170% VO_{2max}) improved both aerobic (+ 7 $ml/kg/min^{-1}$) and anaerobic (+ 28% ml/kg^{-1}) capacities among healthy and active college age males [26]. Similarly in strength resistance measures, maximal voluntary contractions improved an approximate 39% following a 35-day (three days per week) high-intensity resistance-training program [27]. Our findings, along with those in the literature demonstrate that high-intensity style training is an effective means to improve work capacity.

Table 2: Chronotropic variables (M ± SD)

	Pre-Intervention	Post-Intervention	P value
RHR (bpm)	75.8 ± 8.8	75.31 ± 9.3	P = 0.858
Ave HR (bpm)	174.5 ± 13.6	171.6 ± 9.5	P = 0.512
%HRmax (%)	87.9 ± 7.0	86.4 ± 4.1	P = 0.498

Chronotropic Responses: Average resting heart rate obtained prior to the exercise trial (RHR). Average heart rate achieved during the HIFT trial (Ave HR). The average percent HR max as determined by Ave HR and age predicted HR max (%HRmax).

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Limitations

Though this study was a novel first step at examining the effects of HIFT on autonomic control, it was not without limitations. First, due to the constraints of class scheduling, only a ten-minute post-exercise period was available, which limited the observation of the rate of recovery. In addition, the timing of the post intervention trails in this study occurred prior to semester final exams, which may have resulted in additional emotional stress. Emotional stress may lead to temporarily depressed levels of HRV and therefore, future studies involving college students should be cognizant of outside emotional stressors such as academic final exams. Lastly, the sample population size of this study is considered a limitation; future research should increase number of participants.

CONCLUSIONS

In summary, the findings of this study suggest that resting vagal tone and post exercise vagal reactivation was not influenced by 15-weeks of a HIFT intervention amongst healthy active participants. However, it seems that the exercise modality known as HIFT, was an effective means to improve overall performance over a period of 15-weeks.

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