Alterations in Cardiac Vagal Modulation-to-Vagal Tone Ratio in response to accumulated exercise stress in intermittent team sport

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Summary

Study aim: This investigation examined the cardiac vagal modulation-to-vagal tone ratio and its utility to represent the dose response to accumulated exercise stress in intermittent team sport.

Material and methods: Fourteen international calibre female field hockey players training as part of a national team were participants over a three-week period. Exercise stress was expressed through cardiovascular strain using heart rate (HR) dynamics and was quantified as a training load (AU) and time spent exercising above anaerobic threshold (min). Cardiac autonomic activity was examined using heart rate variability; R-R intervals (ms) were collected immediately upon awakening throughout each weekend. The square root of the mean squared differences of successive R–R intervals were individually calculated, and log transformed prior to being averaged (Ln rMSSD) along with the corresponding mean R-R interval length. Multiple linear regression analysis examined the association between cardiac autonomic activity and indices of accumulated exercise stress.

Results: Significant inverse associations (95% CI) between the Ln rMSSD:R-R ratio and both training load [$r = -0.48$ (-0.70 : -0.18), $p = 0.012$] and time spent exercising above anaerobic threshold [$r = -0.51$ (-0.72 : -0.22), $p = 0.006$] were observed. The association between mean R-R interval length and Ln rMSSD was not significant [$r = 0.05$, $p = 0.950$].

Conclusion: The current study demonstrated high intensity exercise, as defined through time spent above anaerobic threshold, displayed a stronger association with the Ln rMSSD:R-R ratio compared to a HR-derived training load when examining the dose response to accumulated intermittent exercise.

Keywords: Heart rate variability – Cardiovascular physiology – Exercise physiology

Introduction

Intermittent team sport involves frequent and repeated bouts of low and high intensity exercise that are largely reliant upon cardiorespiratory performance. Recent inquiry towards preferences of team sport practitioners for monitoring the dose-response to exercise has revealed significant reliance on the cardiovascular response to exercise during training and competition [25]. Team sports such as field hockey demand a high level of cardiorespiratory function in order to execute technical, tactical and physiological oriented activities throughout the entirety of a match [16]. The reliance on sustained cardiorespiratory performance has shown to elicit large heart rate (HR) derived training loads [19, 21] and prolonged periods of exercising above the anaerobic threshold [22]. This evidence supports the

efficacy for integrative support staff within the sport of field hockey to concentrate on HR dynamics as part of their procedure for examining the dose-response to exercise.

Post exercise cardiac autonomic activity has demonstrated to be a valuable assessment for examining the dose-response to exercise in intermittent team sport [9, 10]. Alterations in cardiac autonomic activity can be examined through two distinct possibilities. The first, cardiac vagal tone, expressed through resting HR or the mean in successive R-R (ms) intervals, is a reflection of the action of the vagus nerve on the sinoatrial node, while the second, heart rate variability (HRV), conveys the magnitude of modulation between successive R-R intervals over a given recording period, and as such, one component may change without the other [13]. However, the analysis of HRV has been questioned when not accounting for vagal tone and its underlying influence on parasympathetic modulation [5, 11].

The examination of each vagal index in relation to each other has been suggested to provide a more compelling assessment in cardiac autonomic activity post endurance training [12]. Plews et al. established the efficacy for monitoring HRV in response to exercise stress in endurance athletes as a function of its corresponding R-R interval, whereby demonstrating the ratio between the two vagal indices may be more descriptive in displaying the dose-response to exercise [24]. However, a polarized training model commonly utilized by endurance athletes fails to represent the intermittent nature of team sport, whereby HR dynamics can fluctuate in relation to both aerobic and anaerobic threshold. This difference between sports may be critical as exercise intensity is largely responsible for determining post-exercise HRV throughout a 48-hr period, where the suppression or supercompensation in vagal activity is dependent upon the exercise intensity experienced in relation to anaerobic threshold [27].

As such, this investigation examined the cardiac vagal modulation-to-vagal tone ratio and its association with accumulated exercise stress quantified through indices of cardiovascular strain; 1) a HR-derived training load and 2) time spent exercising above anaerobic threshold. It was hypothesized that time spent above anaerobic threshold would demonstrate a greater inverse association with the rMSSD:R-R ratio compared to a HR-derived training load.

Material and methods

Participants

Fourteen international calibre female field hockey players training as part of a national team were participants over a three-week period. Participant characteristics are provided in Table 1. All participants provided written informed consent to participate in the daily monitoring activities performed as members of the national team. The current investigation was approved by and followed the recommendations of the Clinical Research Ethics Board at the University of British Columbia and were in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

Study design

This investigation examined the association between accumulated exercise stress in intermittent team sport and

the response in cardiac autonomic activity. Data collection took place during a three-week period where all participants trained together in a centralized location as members of the national team.

Training sessions were scheduled for Monday, Wednesday, and Friday of each week with Saturday and Sunday designated for complete rest. Training sessions were conducted in the morning and session start and finish times were standardized throughout the study. Weekly periodized exercise stress was decided by the national team's coaching staff and based on the objectives set forth towards developing the team's technical, tactical and physiological abilities. Training sessions followed a standardized structure beginning with a 15-min warm-up, followed by technical, tactical, and physiologically oriented field hockey drills, concluding with a 15-min cool down. Data collection and its analysis throughout the investigation was conducted by a standardized examiner.

Heart rate derived training load

Each participant was assigned a Polar® Team² heart rate monitor (Polar, Electro, Oy, Kempele, Finland) programmed to record at 1-sec intervals. HR monitors were provided to each participant prior to beginning the warm-up and were collected after completion of a cool down. Training loads were calculated from the start of the warm-up until the completion of the cool-down automatically by the Polar® Team² system and were developed utilizing the original training impulse method (TRIMP) [3, 4] that was customized with a recovery estimation model [17]. Each participant's maximum heart rate value used in the calculation of a training load was recorded from the graded maximal exercise test prior to entering the study, recent competition or during regular on-field training. The highest heart rate value observed was identified as the maximum heart rate and was utilized in the training load calculation model. Participants who did not complete a training session, or for whom any indices of exercise stress were not recorded over a single session, were excluded from analysis for the given week.

Time spent exercising above anaerobic threshold (>LT2)

Time (min) spent exercising above anaerobic threshold (>LT2) was determined using each participant's HR value recorded at anaerobic threshold and was automatically calculated by the Polar® Team² system. Each

Table 1. Participant characteristics

Age [y]	Height [cm]	Weight [kg]	BMI [kg/m ²]	VO _{2MAX} [mL · kg ⁻¹ · min ⁻¹]
22.3 ±2.0	168.7 ±5.3	64.4 ±5.8	22.6 ±1.4	51.2 ±3.0

Values are represented as a mean (±SD) (n=14).

participant completed a graded maximal exercise test prior to entering the study. Participants were fitted with a mouthpiece consisting of a one-way non-rebreathing valve (Hans Rudolph, Kansas City, MO) for the collection of expired gas concentrations which were analysed using a calibrated metabolic cart (ParvoMedics TrueOne 2400, Salt Lake City, UT). A treadmill grade of 2.0% was held throughout each test with a starting speed of 8.1 km/h. Each stage was 3 min in duration and involved increments of 0.8 km/h until volitional fatigue. Alterations in expired gas concentrations were computed to identify ventilatory threshold / anaerobic threshold and its corresponding HR value.

Cardiac parasympathetic activity

Cardiac autonomic activity was examined through recording R-R intervals (ms) in the morning upon waking in the supine position [27] and were recorded each day over the weekend and were averaged to demonstrate parasympathetic response to accumulated exercise stress [20]. R-R intervals were recorded using a Polar® Team² HR monitor equipped to sample at 1000Hz and were exported to a computer software program, Kubios HRV 2.2 (Biosignal Analysis and Medical Imaging Group at the Department of Applied Physics, University of Kuopio, Kuopio, Finland) for analysis. A one-minute stabilization period [8] was utilized before using visual inspection for selecting a five minute artefact-free segment. [28]. Correction for ectopic beats or artefact that varied greater than 0.25 sec when compared to the mean was automatically adjusted for with the use of a cubic spline interpolation method utilizing a third-degree polynomial pre-programmed into Kubios HRV 2.2 [1]. If one of two R-R recordings over the weekend was not collected or was invalid, that participant was not included in the weekly data set.

The square root of the mean squared differences of successive R-R intervals (rMSSD) was chosen for examining parasympathetic activity based on its efficacy

to represent cardiac vagal modulation [28], its resilience against respiratory sinus arrhythmia during spontaneous breathing [18], and when not accounting for menstrual cycle phase [23]. Each rMSSD value was log-transformed (Ln rMSSD) using the natural logarithm to help reduce bias through possible non-uniformity in error. The relationship between vagal modulation and vagal tone was demonstrated as a ratio and was calculated using Ln rMSSD and its corresponding R-R (ms) interval (Ln rMSSD:R-R). Resting heart rate was determined from the same five-minute R-R recording period and was calculated in conjunction with HRV analysis using Kubios HRV 2.2.

Statistical analysis

All data in text, figures, and tables are displayed as a mean ($\pm$ SD) unless otherwise stated. A repeated measures design was utilized to examine variation in each index of exercise stress and parasympathetic activity using a one-way, repeated measures ANOVA with a Bonferroni correction procedure for post-hoc comparisons. Significance was declared using a probability of $p < 0.05$. A Shapiro-Wilk's test of normality ($p > 0.05$) was conducted and revealed a range in Kurtosis of ($-0.57 : 0.28$) and a range in Skewness of ($-0.03 : 0.46$).

Multiple linear regression analysis (R^2) was employed using VO_{2MAX} as a covariate for its influence on post-exercise cardiac autonomic activity [6] to examine the association between the Ln rMSSD:R-R ratio and: 1) a HR derived training load and, 2) time spent exercising above anaerobic threshold. Additionally, a Pearson Correlation coefficient (r) and its corresponding 95% confidence interval was conducted separately to examine individual associations between each index of exercise stress and each index of cardiac autonomic activity. The following principles were applied for identifying the strength of correlation; 0.10–0.29 small, 0.30–0.49 moderate, >0.50 large [7].

Table 2. Multiple linear regression analysis examining parasympathetic activity and accumulated exercise stress

Models	Standard error	<i>t</i>	<i>F</i>	<i>r</i> (95% CI)	R^2	<i>p</i> -value
Ln rMSSD : R-R (ms)	0.000		5.99	−0.51 (−0.72 : −0.22)	0.26	0.006
Time (min) Above Threshold	0.000	2.03				0.050
VO_{2MAX}	0.000	−1.44				0.158
Ln rMSSD : R-R (ms)	0.000		5.09	−0.48 (−0.70 : −0.18)	0.23	0.012
Training Load (AU)	0.000	1.62				0.114
VO_{2MAX}	0.000	−2.53				0.016
Ln rMSSD (ms)	0.469		0.05	0.05 (−0.28 : 0.37)	0.003	0.953
R-R (ms)	0.001	0.31				0.761
VO_{2MAX}	0.026	0.06				0.954

Table 3. Within participant parasympathetic response to indices of accumulated exercise stress

n	Week#1					Week#2					Week#3				
	TL	>LT2	Ln rMSSD	RHR	Ln rMSSD:R-R	TL	>LT2	Ln rMSSD	RHR	Ln rMSSD:R-R	TL	>LT2	Ln rMSSD	RHR	Ln rMSSD:R-R
	[AU]	[min]	[ms]	[bpm]	[ms]	[AU]	[min]	[ms]	[bpm]	[ms]	[AU]	[min]	[ms]	[bpm]	[ms]
1	488	24.5	4.576	57	0.0043	417	13.6	4.620	55	0.0043	587	24.5	4.595	46	0.0035
2	552	46.3	4.468	51	0.0038	742	61.5	4.287	57	0.0041	631	46.3	4.339	51	0.0037
3	554	59.5	3.936	53	0.0035	789	97.43	4.055	53	0.0036	609	59.5	4.066	59	0.0040
4	687	78.2	4.563	56	0.0042	788	67.5	3.784	57	0.0036	691	78.2	3.973	57	0.0038
5	652	40.4	3.246	73	0.0039	751	52.6	3.793	64	0.0041	649	40.4	3.920	63	0.0041
6	N/A	N/A	N/A	N/A	N/A	801	91.1	4.776	61	0.0049	682	47.4	4.088	68	0.0047
7	607	55.4	4.468	56	0.0043	775	59.1	4.287	51	0.0039	616	55.4	4.339	63	0.0044
8	469	30.3	4.307	62	0.0044	878	72.4	4.170	59	0.0041	775	30.3	3.908	63	0.0041
9	N/A	N/A	N/A	N/A	N/A	397	9.5	4.691	45	0.0035	452	9.4	4.384	48	0.0035
10	737	78.1	5.033	59	0.0050	1004	113.0	4.428	65	0.0048	793	78.1	5.189	54	0.0046
11	452	37.5	4.886	48	0.0039	642	59.2	5.097	47	0.0040	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	722	63.0	3.969	65	0.0043	577	54.3	3.819	68	0.0043
13	N/A	N/A	N/A	N/A	N/A	715	73.3	4.366	58	0.0042	624	62.0	4.722	48	0.0038
14	682	50.6	3.661	60	0.0037	853	55.3	3.498	61	0.0036	803	50.6	3.593	62	0.0037
Mean	588	50.1	4.314	57	0.0041	733.9	63	4.273	57	0.0041	653	49.0	4.226	58	0.0040
STDV	100	18	0.551	7	0.0004	163	28	0.437	6	0.0004	98	20	0.431	8	0.0004

Indices of cardiac parasympathetic response in relation to cardiovascular strain expressed as a training load (TL) [19] and the estimated time (min) exercising above the anaerobic threshold (>LT2).
N/A = Values not available due to injury, non-participation, or equipment error.

Results

A total of 37 data sets out of a possible 42 were analysed. Missing data sets were the result of HR monitors failing to record either R-R intervals or a HR-derived training load value in one of three exercise sessions within the week. Significant inverse associations between the Ln rMSSD:R-R ratio and both HR-derived training loads [$r = -0.48$ (-0.70 : -0.18), $p = 0.012$] and time spent above anaerobic threshold [$r = -0.51$ (-0.72 : -0.22), $p = 0.006$] were observed (Table 2). Within participant variation in indices of cardiovascular strain and parasympathetic activity remained unremarkable over the three-week investigation (Table 3). The association between mean R-R interval length and Ln rMSSD was not significant [$R^2 = 0.003$, $p = 0.950$]. Individual associations between indices of exercise stress and indices of cardiac autonomic activity are presented in Figure 1.

Discussion

This investigation examined indices of accumulated intermittent exercise stress when quantified through cardiovascular strain and their association with the Ln rMSSD:R-R ratio over a three week period. The main findings of this study were as follows; 1) each index of

exercise stress demonstrated significant and inverse associations with the HRV to vagal tone ratio, and 2) change in the ratio was the result of alterations in both vagal tone and vagal modulation.

The comparable strength of association observed between the Ln rMSSD:RR ratio and each index of exercise stress may be the consequence of cardiac autonomic response after performing different levels of exercise intensity. HR-derived training loads typically quantify exercise HR dynamics in relation to both aerobic and anaerobic threshold. When exercising above the anaerobic threshold, an immediate 24-hr suppression in HRV is observed, that eventually supercompensates above baseline values at 48-hr post-exercise [27]. This undulating response is in contrast to the immediate 24-hr elevation in HRV when exercising at the aerobic threshold, which eventually diminishes below baseline levels at 48-hr post exercise [27]. The current study examined cardiac autonomic activity over a 48-hr period and may have allowed for alternating dynamics in HRV to produce comparable associations between each index of exercise stress and the Ln rMSSD:RR ratio. These findings are in support of previous literature whereby demonstrating a similar strength of association between day-to-day variation in Ln rMSSD (ie. Ln rMSSD_{CV}) over a 48-hr period and both a HR-derived training load and time spent exercising above anaerobic [20]. Collectively, these results support the utility of global and high intensity indices of

Fig. 1. Association between each index of exercise stress and indices of cardiac parasympathetic activity

cardiovascular strain when examining the dose response to exercise using cardiac autonomic activity in team sport athletes.

Post exercise, vagal indices of HRV have shown to be a valuable tool in assessing an athlete's physiological response to exercise [2]. However, the sole reliance on examining HRV may not be sufficient for interpreting an athlete's response to exercise. Similar HRV values have been observed in elite endurance athletes during periods of both normal training and non-functional overreaching, a result that can be displayed through a bell-shaped curve in HRV in relation to R-R interval length [24]. Differences in cardiac autonomic response between intermittent team sport and endurance sport may be largely determined through their distinct training methods. Endurance athletes typically utilize a polarized training model that focuses on performing the majority of exercise with an intensity at the aerobic threshold, with the remainder of training performed above anaerobic threshold [26]. Constant and prolonged exercise at aerobic threshold has shown to develop the saturation of acetylcholine receptors at the sinoatrial node, whereby eliciting heightened vagal tone and sustained parasympathetic dominance, with concomitant reductions in respiratory heart sinus arrhythmia HRV [15]. The current study demonstrated change in the Ln rMSSD:R-R ratio as a result of alterations in both vagal modulation and vagal tone. Although the respective association between each index of exercise stress and both HRV and vagal tone was not significant, our results identified unique tendencies in vagal activity in response to accumulated exercise stress (Fig. 1). HR-derived training loads demonstrated an inverse association with both Ln rMSSD ($r = -0.23$, $p = 0.230$) and R-R interval length ($r = -0.25$, $p = 0.132$). In contrast, the association between time spent above anaerobic threshold and Ln rMSSD demonstrated an almost non-existent relationship ($r = 0.05$, $p = 0.778$) while vagal tone demonstrated an inverse association ($r = -0.22$, $p = 0.190$). This difference elicited a larger ratio and a stronger relationship between time spent above threshold and the Ln rMSSD:R-R ratio (Table 2).

The current investigation is limited to examining exercise stress in the form of on-field training. It remains undetermined where the strength of associations may have been altered with the inclusion of resistance training. As such, we must acknowledge the influence of resistance training on daily parasympathetic HRV indices [14] and its potential impact on altering the strength of association between total weekly accumulated exercise stress and the HRV to vagal tone ratio. We encourage future studies to include concurrent training styles in intermittent team sport to expand on our findings.

Conclusion

In summary, cardiovascular strain when expressed as a HR-derived training load or time spent exercising above anaerobic threshold displayed a significant inverse association with the Ln rMSSD to R-R ratio. Alterations in the ratio were the result of variation in both vagal tone and parasympathetic modulation. Although time spent above threshold demonstrated a marginally stronger association, our results suggest practitioners may concentrate on either index of cardiovascular strain when examining the dose response to intermittent exercise using the Ln rMSSD:R-R ratio. Preference may be given towards indices that are analysed in a time efficient method, allowing rapid evidence-based decision making between coach and practitioner.

Conflict of interest: Authors state no conflict of interest.

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