

## Differences in heart rate variability between endurance and resistance trained athletes

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- Introduction** : *The use of heart rate variability (HRV) to assess the cardiac autonomic regulation has been proved to be benefit research and clinical applications. It has also been known that endurance exercise training can affect the autonomic balance of the cardiovascular system.*
- Objective** : *The purpose of the study is to compare the heart rate variability among endurance athletes, resistance athletes, and sedentary controls.*
- Design** : *Cross-sectional, experimental study.*
- Subjects** : *A total of 40 Thai male athletes (aged 20 - 25 yr) were recruited and equally assigned into 2 groups based on their athletic categories: endurance or resistance trained group. The endurance athletes (EA) were long - distance runners and the resistance athletes (RA) were weightlifters. Another 20 age- matched non-athletic men (NA) volunteered as controls.*
- Methods** : *Electrocardiographic (ECG) signals were continuously recorded for 5 minutes on each subject at rest and during cycling at 50 % of maximal aerobic capacity. Spectral analyses of HRV obtained from the ECG recordings were studied and compared among the 3 physical activity groups.*

**Results** : The EA group demonstrated a significantly lower resting heart rate ( $56 \pm 8$  bpm) than the RA group ( $65 \pm 7$  bpm) and the NA group ( $68 \pm 9$  bpm). Spectral analyses of the HRV at rest showed a significantly greater ( $P < 0.001$ ) HF power component (indicative of parasympathetic control) in EA group ( $421 \pm 121$  ms<sup>2</sup>) than in the other 2 groups ( $241 \pm 72$  ms<sup>2</sup> and  $200 \pm 55$  ms<sup>2</sup> for RA and NA groups, respectively). Although the difference in the LF component (indicative of a balance between sympathetic and parasympathetic controls) of the HRV determined at rest between the EA and RA groups ( $302 \pm 82$  ms<sup>2</sup> vs.  $268 \pm 75$  ms<sup>2</sup> for EA and RA, respectively) was not statistically significant, the LF component of the EA group was significantly greater than that of the NA group ( $231 \pm 70$  ms<sup>2</sup>). During dynamic exercise, both HF and LF powers were largely decreased in all subject groups. No difference in any of the HRV components was found among the 3 groups during exercise at 50% VO<sub>2</sub>max.

**Conclusion** : These results support that endurance training is related to increased cardiac parasympathetic control. On the contrary, resistance training does not influence cardiac autonomic regulation

**Keywords** : Heart rate variability, Autonomic function, Endurance training, Resistance training.

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- ความนำ** : การประเมินความผันแปรของอัตราการเต้นของหัวใจสามารถนำมาใช้อย่างกว้างขวางในงานวิจัยรวมทั้งการประยุกต์ใช้ทางคลินิก เป็นที่ทราบกันโดยทั่วไปว่าการฝึกออกกำลังกายแบบทนทานมีผลต่อความสมดุลของประสาทอัตโนมัติของระบบหัวใจและหลอดเลือด
- วัตถุประสงค์** : เพื่อเปรียบเทียบความผันแปรในการเดินของหัวใจในนักกีฬาที่ฝึกแบบทนทาน นักกีฬาที่ฝึกแบบใช้แรงต้าน และผู้ที่ไม่ใช่ นักกีฬา
- รูปแบบการวิจัย** : การศึกษาแบบภาคตัดขวาง และเป็นการวิจัยเชิงทดลอง
- อาสาสมัคร** : นักกีฬาชายไทย 40 คน (อายุ 20-25 ปี) แบ่งตามลักษณะการฝึกได้เป็น 2 กลุ่ม ๆ ละ 20 คน ได้แก่ การฝึกแบบทนทาน และฝึกแบบใช้แรงต้าน นักกีฬาฝึกแบบทนทานทั้งหมดเป็นนักวิ่งระยะไกล และนักกีฬาที่ฝึกแบบใช้แรงต้านเป็นนักกีฬายกน้ำหนัก อาสาสมัครชายอีก 20 คน ที่อยู่ในช่วงอายุเดียวกันและไม่ได้ฝึกออกกำลังกายแบบใดเลย จัดอยู่ในกลุ่มควบคุม
- วิธีการศึกษา** : ทำการศึกษาโดยการตรวจสอบสัญญาณคลื่นไฟฟ้าหัวใจที่บ้านที่กวดตลอดเวลา 5 นาที ในอาสาสมัครแต่ละคนในท่านอนพักและระหว่างปั่นจักรยานที่ความหนัก 50% ของความสามารถในการใช้ออกซิเจนสูงสุด ทำการศึกษาสเปกตรัล อะนาลิซิสของความผันแปรของอัตราการเต้นของหัวใจที่ได้มาจากการบันทึกคลื่นไฟฟ้าหัวใจ และเปรียบเทียบระหว่าง 3 กลุ่มของอาสาสมัคร
- ผลการศึกษา** : กลุ่มนักกีฬาที่ฝึกแบบทนทานมีอัตราการเต้นของหัวใจขณะพัก ( $56 \pm 8$  ครั้งต่อนาที) ต่ำกว่ากลุ่มนักกีฬาที่ฝึกแบบใช้แรงต้าน ( $65 \pm 7$  ครั้งต่อนาที) และกลุ่มควบคุม ( $68 \pm 9$  ครั้งต่อนาที) ในขณะที่พบว่าค่าคลื่นความถี่สูง (บ่งถึงการควบคุมจากพาราซิมพาเธติก) ของกลุ่มนักวิ่ง ( $421 \pm 121$  มิลลิวินาที) มีค่ามากกว่า ( $P < 0.001$ ) ของกลุ่มนักยกน้ำหนัก ( $241 \pm 72$  มิลลิวินาที) และกลุ่มควบคุม ( $200 \pm 55$  มิลลิวินาที) ส่วนค่าคลื่นความถี่ต่ำ (บ่งถึงความสมดุลในการควบคุมทั้งของซิมพาเธติกและพาราซิมพาเธติก) ไม่พบมีความแตกต่างในระหว่างกลุ่มนักกีฬาทั้งสองประเภท ( $302 \pm 82$  และ  $268 \pm 75$  มิลลิวินาที) สำหรับนักวิ่งและนักยกน้ำหนัก ตามลำดับ) แต่นักวิ่งมีค่าคลื่นความถี่ต่ำ มากกว่ากลุ่มควบคุม ( $231 \pm 70$  มิลลิวินาที) อย่างมีนัยสำคัญทางสถิติ ไม่พบความแตกต่างระหว่างกลุ่มใด ๆ ในค่าคลื่นความถี่ต่าง ๆ ที่วิเคราะห์ในขณะที่ทำการออกกำลังกายคงที่ที่ระดับความหนัก 50 % ของความสามารถในการใช้ออกซิเจนสูงสุด

โดยมีวัตถุประสงค์เพื่อศึกษาความสัมพันธ์ระหว่างการมีภาวะเครียดกับการมีพฤติกรรมการดูแลสุขภาพแบบชนบทที่มีภาวะเครียดสูงและภาวะเครียดต่ำ

การวิจัยครั้งนี้เป็นการวิจัยเชิงพรรณนาแบบตัดขวาง โดยเก็บข้อมูลจากกลุ่มตัวอย่างที่เป็นบุคลากรในหน่วยงานราชการในเขตชนบทที่มีภาวะเครียดสูงและภาวะเครียดต่ำ

การวิจัยครั้งนี้แสดงให้เห็นว่าบุคลากรในหน่วยงานราชการในเขตชนบทที่มีภาวะเครียดสูงมีพฤติกรรมการดูแลสุขภาพแบบชนบทที่มีภาวะเครียดสูง

**สรุป :** ผลการทดลองสนับสนุนว่านักกีฬาที่มีการฝึกออกกำลังกายแบบทนทานมีการควบคุมของพาราซิมพาเทติกที่หัวใจมากขึ้น ในทางตรงกันข้ามการออกกำลังกายแบบใช้แรงต้านไม่มีอิทธิพลต่อการควบคุมโดยประสาทอัตโนมัติในการทำงานของหัวใจ

สถาบันวิทยบริการ  
จุฬาลงกรณ์มหาวิทยาลัย

Despite the presence of cardiac automaticity, critical functions of the heart are profoundly regulated by the autonomic nervous system (ANS). Innervation of sympathetic and parasympathetic nerves ensures rapidity and appropriate responses of the heart to homeostatic changes of the body. Sympathetic stimulation results in activating cardiac pumping action to increase heart rate and contractility by the interaction of norepinephrine released from nerve terminals and the specific beta receptors on the cardiac site. Parasympathetic fibers traveling via the vagus nerve release acetylcholine to interact with myocardial muscarinic receptors. Increased firing rate of parasympathetic impulses results in a decline of heart rate and overall pumping action of the heart. An increase in parasympathetic nerve activity is usually accompanied by a decrease in sympathetic nerve activity. <sup>(1)</sup>

It has been widely demonstrated that the beat-to-beat variability of heart rate is well determined by the autonomic control mechanism. <sup>(2)</sup> The use of power spectral analyses has been introduced as a non-invasive technique to study the spontaneous oscillatory fluctuation in the R-R interval of each heartbeat. <sup>(3)</sup> The amplitude of the frequency specific oscillations of the heartbeats reflects neural regulation, particularly the balance between the sympathetic and parasympathetic nervous systems.

The power spectral of oscillations in the R-R interval has 3 well-defined peaks, including a very-low frequency (VLF) peak (0.003 - 0.04 Hz), a low frequency (LF) peak (0.04 - 0.15 Hz), and a high frequency (HF) peak (0.15-0.40 Hz). <sup>(3)</sup> The VLF peak reflects the influence of circulating neurohormones, thermoregulatory, vasomotor tone, and other slow

variations in autonomic nerve activity. <sup>(3)</sup> The LF fluctuations are jointly mediated by the parasympathetic and sympathetic activities, when the HF fluctuations are solely modulated by the parasympathetic activity. <sup>(4)</sup>

Overall reduction of HRV has been established as an independent marker of an increased risk of cardiac mortality, arrhythmia in particular, after acute MI. <sup>(5-7)</sup> Shin *et al.* <sup>(8)</sup> reported that there was a significant difference in the vagal tone to the heart between endurance-trained athletes and non-athletes. This finding indicates that the parasympathetic tone enhanced with endurance exercise training may play a role in resting bradycardia in endurance-trained athletes. Although reduced resting heart rate appears not to be induced by resistance training, it is not known whether autonomic influence of heart function regardless of the pumping rate is altered with resistance training. Thus, the main purpose of the study is to compare the autonomic controls of heart rate, determined by auto-spectral analysis of R-R interval variability, between the endurance- and resistance-trained athletes.

### Materials and Methods

**Subjects:** A total of 60 healthy Thai men (aged 20 - 25) volunteered for the study. They were classified into 3 groups (n=20 / group) to serve the purpose of the study. One third of the total subjects were long-distance runners (endurance athletes; EA) recruited from the Amateur Athletic Association of Thailand and from Ramkhumheang University. They ran 6 days a week with a distance of 15-30 kilometers per day. Another 20 subjects were resistance trained athletes (RA) who were weightlifters from the Amateur

Weightlifter Association of Thailand; they were trained 6 days per week with a duration of 2-4 hours per day. All athletes in both groups had been trained for at least 3 years and participated in national field competitions. The rest 20 subjects, who served as controls, were students of Chulalongkorn University. The non-athlete control group (NA) was recruited based on personal history of sedentary lifestyle, without participating in regular long-term physical training for at least 3 years prior to the present study. Subjects were excluded from the study if they were active smokers, habitually consumed caffeine and alcohol, chronically used of medication for any illness, or had any conditions that may interfere with exercise and autonomic nerve function tests, or interpretations of the tests. The subjects provided written informed consent at their entry. The study protocol has been approved by the Ethic Committee the Faculty of Medicine, Chulalongkorn University.

#### **Physical characteristic and body composition measurements:**

The subjects weighed themselves on a balance weighing scale. Body weight and height of the subjects were measured to the nearest one decimal point. Skinfold thickness was measured at biceps, triceps, subscapular, and suprailiac regions using a Lange skinfold caliper. The thickness measurement was repeated three times per site and the average value was used. Body density and percent body fat were calculated according to the formulas of Durnin & Rhamana and Siri:

$$\text{Body density} = 1.1631 - 0.0632 \log S$$

Where S is the sum of four skinfold readings (in mm).

$$\text{Body fat (\%)} = (4.95 / D - 4.5) \times 100$$

Where D is body density.

**Physical fitness testing:** To screen for occult cardiovascular disease as well as to evaluate the maximal cardiorespiratory fitness, the subjects underwent a maximal cycle of ergometer test. Throughout the test, a 12-lead ECG, heart rate, and blood pressure were closely monitored. Oxygen consumption ( $\text{VO}_2$ ), carbon dioxide production ( $\text{VCO}_2$ ), and minute ventilation (VE) were continuously measured breath-by-breath by a computerized system (Quinton Metabolic Cart, Quinton Inc, Washington, USA). Gas exchange data were expressed in a standard condition of temperature, humidity, and barometric pressure.

The subjects performed an incremental exercise test on a calibrated cycle ergometer (Corival 400, Lode B.V., Groningen, The Netherlands) to determine their maximal oxygen consumption ( $\text{VO}_{2\text{max}}$ ). The pedaling speed was maintained at 60 revolutions per minute throughout the test. The first 3 minutes of the test, the subjects pedaled without a load. Thereafter, an incremental load of 25 watts was added each minute until volitional fatigue or the pedaling speed was not maintained. Data on cardiorespiratory fitness were used to obtain an intensity of 50 %  $\text{VO}_{2\text{max}}$  for a cardiac autonomic control test during steady state exercise.

**Cardiac autonomic control testing:** The cardiac autonomic control test was performed at least 2 days after the incremental exercise test. The tests were sequentially performed on each subject during sitting rest and followed by exercising at 50 %  $\text{VO}_{2\text{max}}$ . The subjects reported to the laboratory in the morning no later than 9:30 am. Breakfast was allowed but not

2 hours prior to the test. All subjects were instructed not to perform vigorous exercise nor consume caffeine in the morning of the test day. Upon arrival, the subjects were asked to rest comfortably in a chair for 30 minutes. The room was quiet, in semi-darkness, and maintained at a constant temperature of 23-24°C.

Two 5 - minute continuous ECG recordings were obtained from each subject at sitting rest and during exercise at 50 %  $VO_2$  max on a mechanically braked cycle ergometer (Cateye ergociser EC-1000, Cateye Co. Ltd., Osaka, Japan). The exercise intensity was estimated by the physical fitness test information. The ECG signal for power spectrum analysis was recorded during steady state exercise at which the heart rate varied less than five beats per minute. The total length of time for the steady state exercise was roughly 10 minutes. During sitting rest, subjects were asked to remain awake and relaxed through the 5-minute recordings. However, there was no attempt made to influence the pattern, depth, or rate of respiration during the ECG recordings. Care was being taken to ensure adequate R wave signals for data processing as well as to avoid DC interference and minimize motion artifacts. Additional care was being taken to avoid repetitive external auditory or visual stimuli at the frequencies below 1 Hz. All subjects underwent resting prior to exercising with ECG monitoring for HRV analyses.

#### **Signal processing and power spectral analysis:**

A16-bit analogue to digital convert at 1 kHz was utilized to digitize the ECG signals. A peak detection algorithm for locating the R wave implemented in the software as follows: if the amplitudes of the R

wave on ECG exceeded a preset threshold, the presence of the peak was indicated. The amplitudes of the successive ECG samples were then serially compared to precisely locate the time of a maximum voltage in the QRS complex, indicating the R wave peak. The threshold was set at the level exceeding the noise and the peak amplitudes of the P, S, and T wave in the ECG waveform. An R-R interval series was then constructed from the continuous samples of the ECG data. A parabolic interpolation was also incorporated in the software program to improve the accuracy of R peak identification.

As heart rate variability is a point event series, a power spectral analysis of R-R interval variability requires as follows: a beat-to-beat heart rate series was computed from the successive R-R intervals and the resulting heart rate was re-sampled using linear interpolation to obtain an equally sampling time series. Computations were performed on 512 sample points, each separated by 0.5 s, thus yielding individual records of 5-minute duration. These records were selected for power spectrum analysis. The power spectrum of R-R interval variability was obtained using an algorithm, fast Fourier transform. The powers in the frequency band of 0.04 - 0.15 Hz (LF power), representing sympathetic and parasympathetic activity, and of 0.15 - 0.4 Hz (HF power), a measure of parasympathetic modulation of sinus node depolarization were thereafter derived. Normalized frequency powers (LF and HF norms) were derived from a fraction of the corresponding absolute power of LF and HF, respectively, divided by the total power. The time domain variables including the average normal-to-normal (N-N) interval (intervals between adjacent ORS complexes resulting from sinus node

depolarization) and the standard deviation of the N-N interval were derived from calculations.

**Statistical analysis:** The data were presented as means and standard deviation (SD). Physical characteristics, body composition, and cardiac autonomic control data were compared between the subject groups using ANOVA. An LSD post hoc test was performed as an ANOVA follow-up test. All values were considered significant at  $P < 0.05$ . Statistical analyses were performed on SPSS software program 10.0 version (SPSS Inc., Illinois, USA).

## Results

### Physical characteristics of the subjects (Table 1)

The groups of endurance trained athletes (EA), resistance trained athletes (RA), and non-athletes (NA) had a comparable mean age (EA=22 ± 1.91, RA=21 ± 1.64, and NA=22 ± 1.95 yr). However, body

weight in the EA (56.7 ± 5.5 kg) and NA (61.8 ± 6.7 kg) groups was significantly lower than that of the RA group (66.3 ± 14.4 kg). Percent body fat was significantly lower in the EA group compared with the RA and the NA groups. In addition, the EA subjects also had a lower resting heart rate and systolic and diastolic blood pressure than the other two groups. No difference was found between the RA and NA groups on percent body fat, resting heart rate, or systolic and diastolic blood pressure. In contrast, the NA individuals were on average taller than the other two groups of athletes, while there were no height differences between the EA and RA groups.

As expected, the highest  $VO_{2max}$  was found in the endurance trained athletes (63.0 ± 9 mL/kg/min), while the resistance trained athletes and the non-athlete controls had similar  $VO_{2max}$  (40.5 ± 5 and 36.4 ± 5 mL/kg/min for resistance trained athletes and non-athletes, respectively).

**Table 1.** Physical characteristics of endurance trained athletes (EA), resistance trained athletes (RA), and non-athletes (NA).

| Physical characteristics | EA (n=20)  | RA (n=20)    | NA (n=20)            |
|--------------------------|------------|--------------|----------------------|
| Age, yr                  | 22 ± 1.91  | 21 ± 1.64    | 22 ± 1.95            |
| Body weight, kg          | 56.7 ± 5.5 | 66.3 ± 14.4* | 61.8 ± 6.7*          |
| Height, cm               | 166 ± 7    | 165 ± 5      | 172 ± 5 <sup>#</sup> |
| Heart rate, bpm          | 56 ± 8     | 65 ± 7*      | 68 ± 9*              |
| Systolic BP, mmHg        | 107 ± 8    | 112 ± 8*     | 117 ± 5*             |
| Diastolic BP, mmHg       | 69 ± 8     | 75 ± 6*      | 73 ± 4*              |
| Body fat, %              | 14 ± 2     | 18 ± 4*      | 18 ± 3*              |
| $VO_{2max}$ , mL/kg/min  | 63.0 ± 9   | 40.5 ± 5*    | 36.4 ± 5*            |

Values are mean ± SD

\* significantly different from EA at  $P < 0.05$

<sup>#</sup> significant different from RA at  $P < 0.05$



**Selected physical characteristics during exercise at 50 % VO<sub>2max</sub>** (Table 2)

The 50 % VO<sub>2max</sub> workload performed by the EA group was significantly greater than that by the RA and NA groups. In addition, the RA group performed at a higher workload than the NA group at the same relative intensity of 50 % VO<sub>2max</sub>. However,

the average heart rate during the steady state exercise at 50 % VO<sub>2max</sub> were not statistically different among the 3 groups. In contrast, the EA group demonstrated a greater VO<sub>2</sub> compared to the other two groups, while no difference in VO<sub>2</sub> was found between the RA and NA groups during moderate exercise.

**Table 2.** Physical characteristics during exercise at 50 % VO<sub>2max</sub> of endurance trained athletes (EA), resistance trained athletes (RA), and non-athletes (NA).

| Physical characteristics    | EA (n=20)  | RA (n=20)               | NA (n=20)               |
|-----------------------------|------------|-------------------------|-------------------------|
| Workload, watts             | 147 ± 18   | 122 ± 15*               | 99 ± 15 <sup>#</sup>    |
| Heart rate, bpm             | 130 ± 6    | 132 ± 3                 | 133 ± 4                 |
| VO <sub>2</sub> , mL/kg/min | 31.7 ± 4.7 | 19.1 ± 2.5 <sup>#</sup> | 17.9 ± 2.4 <sup>#</sup> |

Values are mean ± SD

\* significantly different from EA at P <0.05

<sup>#</sup> significant different from RA at P <0.05

**Table 3.** Frequency domain measures of R-R interval variability in endurance trained athletes (EA), resistance trained athletes (RA), and non-athletes (NA) at sitting rest.

| R-R variability measures     | EA (n=20)  | RA (n=20)  | NA (n=20)  |
|------------------------------|------------|------------|------------|
| Time domain                  |            |            |            |
| Average NN interval, ms      | 1087 ± 140 | 924 ± 89*  | 886 ± 94*  |
| SDNN, ms                     | 77 ± 21    | 58 ± 13*   | 51 ± 10*   |
| Frequency domain             |            |            |            |
| Total power, ms <sup>2</sup> | 1079 ± 170 | 714 ± 199* | 591 ± 137* |
| LF power, ms <sup>2</sup>    | 302 ± 82   | 268 ± 75   | 231 ± 70*  |
| HF power, ms <sup>2</sup>    | 421 ± 121  | 241 ± 72*  | 200 ± 55*  |
| LF norm, %                   | 42 ± 5     | 53 ± 7*    | 53 ± 7*    |
| HF norm, %                   | 58 ± 5     | 48 ± 7*    | 47 ± 7*    |
| LF/HF ratio                  | 0.7 ± 0.2  | 1.1 ± 0.3* | 1.2 ± 0.4* |

Values are mean ± SD

NN= normal-to-normal intervals, SDNN= standard deviation of N-N intervals,

LF = low frequency, HF = high frequency,

LF norm = normalized low frequency, and HF norm = normalized high frequency

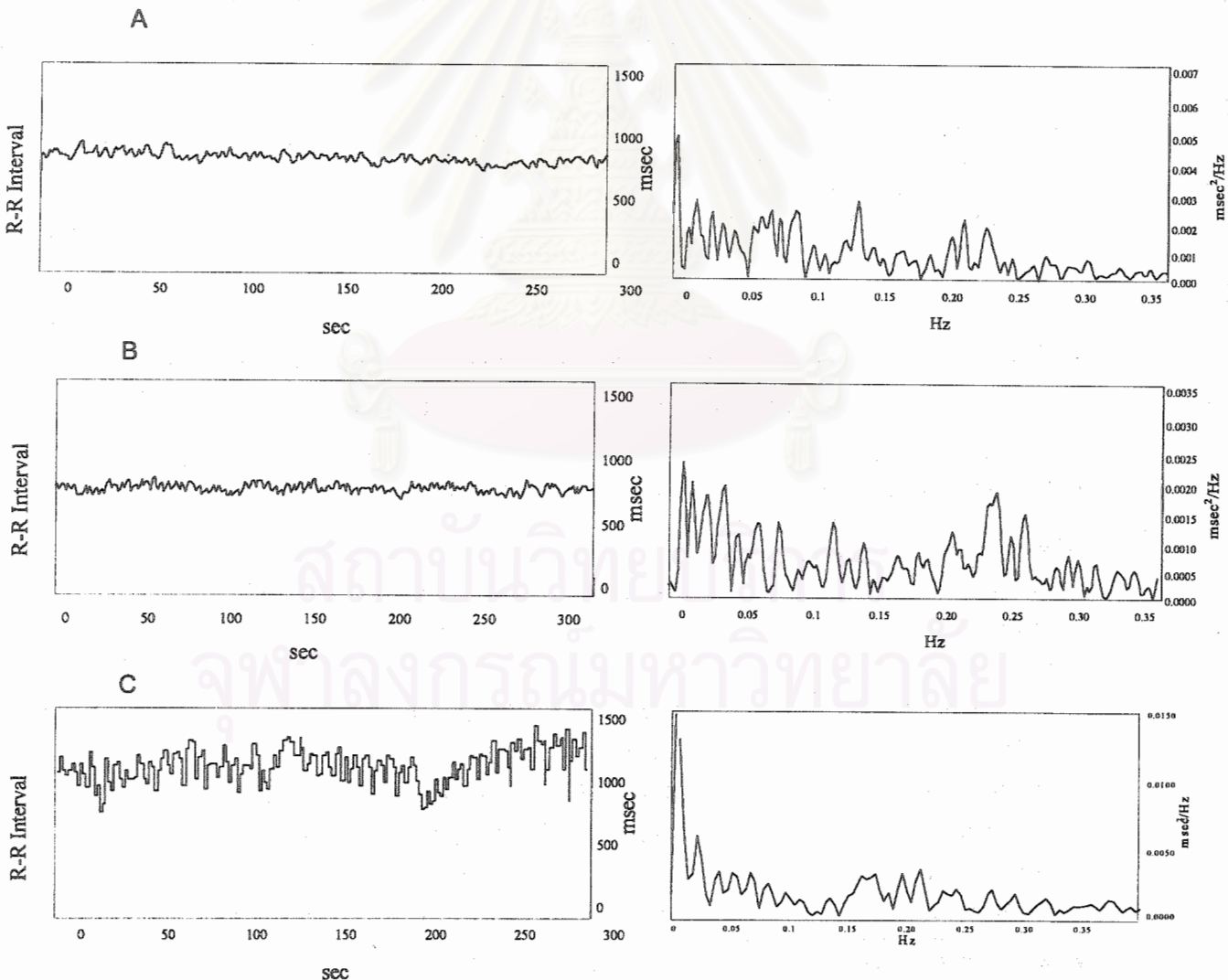
\* significantly different from EA at P <0.05

### Time and frequency domain analysis of HRV at sitting rest (Table 3)

The time domain analyses of heart rate variation at rest showed that the average NN interval and SDNN was significantly greater in the EA compared to the RA and NA groups. There was no difference on both time domain measures between the RA and NA groups.

Examples of recording of R-R interval and frequency power in sedentary subjects, resistance trained athletes, and endurance trained athletes at

rest are presented in Figure 1. At rest, the total and VLF power, LF norm, and LF/HF ratio were significantly higher in the EA than in the RA and NA groups, while no differences on these measures were demonstrated between the RA and NA groups. Significant lower HF power and HF norm were found in the RA and NA groups compared with the EA group. In addition, the RA and NA groups showed similar HF power and HF norm during sitting rest. The lowest in LF power was demonstrated in the NA group, whereas there were no differences on LF power between the two groups of athletes.



**Figure 1.** Examples of recording of R-R interval and frequency power in sedentary subjects (A), resistance trained athletes (B), and endurance trained athletes (C) at rest.

**Table 4.** Frequency domain measures of R-R interval variability in endurance trained athletes (EA), resistance trained athletes (RA), and non-athletes (NA) during exercise.

| R-R variability measures     | EA (n=20) | RA (n=20) | NA (n=20) |
|------------------------------|-----------|-----------|-----------|
| Time domain                  |           |           |           |
| Average NN interval, ms      | 595 ± 55  | 572 ± 48  | 562 ± 60  |
| SDNN, ms                     | 19 ± 6    | 20 ± 8    | 21 ± 5    |
| Frequency domain             |           |           |           |
| Total power, ms <sup>2</sup> | 234 ± 120 | 240 ± 162 | 181 ± 89  |
| LF power, ms <sup>2</sup>    | 72 ± 33   | 80 ± 54   | 77 ± 37   |
| HF power, ms <sup>2</sup>    | 73 ± 39   | 72 ± 51   | 58 ± 35   |
| LF norm, %                   | 51 ± 10   | 55 ± 9    | 55 ± 5    |
| HF norm, %                   | 49 ± 10   | 45 ± 9    | 45 ± 4    |
| LF/HF ratio                  | 1.1 ± 0.5 | 1.4 ± 0.5 | 1.5 ± 0.5 |

Values are mean ± SD

NN= normal-to-normal intervals, SDNN= standard deviation of N-N intervals,

LF = low frequency, HF = high frequency,

LF norm = normalized low frequency, and HF norm = normalized high frequency

#### Time and frequency domain analysis of HRV during exercise (Table 4)

During exercise at 50 %  $VO_{2max}$ , no significant group differences were found on the time domain measures, NN and SDNN.

Similar to the results of the time domain analyses of the heart rate variability during exercise, the frequency domain measures showed no significant difference among the two groups of athletes and one group of sedentary controls.

#### Discussion

The aerobic capacity was greater in the runners compared to the weightlifters and the sedentary counterparts. Additionally, the resting heart rate in the endurance athletes was lower than that of the rest of the subjects. These results were

in line with previous reports of high  $VO_{2max}$  as well as resting bradycardia in endurance athletes. <sup>(9,10)</sup> It has been suggested that resting bradycardia in athletes may have been due to an attenuated intrinsic heart rate. <sup>(11)</sup> However, a body of evidence indicated that alterations within the autonomic nervous system is likely to be responsible for the cardiac adaptation in response to exercise training. <sup>(11)</sup> The present study also demonstrates that  $VO_{2max}$  and resting heart rate of the weightlifters and sedentary controls were similar. These particular findings supports results from other studies that neither aerobic capacity improvement nor bradycardia at rest occurred with resistance training. <sup>(12)</sup>

We monitored the activities of the autonomic nervous system at rest and during exercise at 50 %  $VO_{2max}$  using a non- invasive tool of spectral analysis

of cardiac period variability signals in individuals with different types of athletic activities. The HRV assessment on the frequency domain components revealed a greater resting HF power and the other HF related measures including a lower LF/HF ratio in the runners compared to the weightlifters and non-athletes. However, there was no difference in any of the HF variables between the weightlifters and the non-athlete controls. These results indicate an enhanced vagal tone in endurance athletes while there was no alteration in the vagal activity in resistance trained athletes. Therefore, resting bradycardia found in the group of runners may be, at least in part, explained by augmented vagal function in response to endurance training. In addition, the results also suggest that no change in resting heart rate following resistance training may be due to a lack of changes in the cardiac vagal tone.

Moreover, there were no differences in any markers among the three subject groups during a steady state exercise at 50 %  $\text{VO}_{2\text{max}}$ . These were not the unexpected findings due to the following reasons. Firstly, heart rate during exercise was increased in all individuals resulting in a smaller beat-to-beat variation. Thus, there was a decline in probability to reach a statistical significance in variability differences of the heart beat among the groups. Secondly, all subjects cycled at the same relative workload as the ergometer resistance was set to meet the 50 % of maximal aerobic exercise capacity of individual. Hence, it may be modestly assumed that the autonomic activity of the heart was equally activated. Lastly, there are various factors contributing to cardiac controls and spectral analysis itself has a limitation in terms of sensitivity in detecting

autonomic signals to regulate the heart. Thus, despite of careful monitoring of the heartbeats, a non-significant outcome may be expected in the presence of a real difference in the autonomic function across the groups.

In the study, we found the lowest LF power in non-athlete controls, while the two groups of endurance and resistance trained athletes showed no significant difference in the LF power. However, significant difference in the other measure of LF power component was demonstrated in our study. When the LF power was expressed in normalized unit (LF norm, %), a significant lower LF norm was found in both weightlifters and non-athletic controls compared to the runners. Furthermore, the differences in LF norm across the groups disappeared during moderate exercise as an increase in LF norm was evident with exercise with more apparent in the weightlifters and non-athletes. The absolute LF power was markedly reduced during the steady state exercise which has been previously reported.<sup>(13)</sup> Discrepancy among the studies has impeded the interpretation of the LF component of the spectral analysis.<sup>(3,13-15)</sup> Some considered the LF component as a parameter of sympathetic modulation, particularly when expressed in normalization units.<sup>(13,14)</sup> However, others regarded it as a marker influenced by both sympathetic and parasympathetic modulation.<sup>(3,15)</sup> Although we could not provide evidence of what LF component really represents, our findings paralleled with the results of the HF power components and the interpretation as discussed above.

Neurohormonal factors are considered important in governing the cardiovascular responses and adaptations to exercise. However, the exact

mechanisms of their actions are still largely unexplored or interpreted on the basis of indirect findings. The slow heart rate observed at rest after long-term exercise training<sup>(10)</sup> is considered to reflect a combination of a decrease in intrinsic heart rate<sup>(16)</sup> and an increase in the vagal tone.<sup>(17)</sup> The interpretation of enhanced vagal drive was derived from the findings of elevated acetylcholine levels in myocardium of exercise-trained rats as well as a greater gain of baroreceptive mechanisms in physically conditioned men and animals.<sup>(17)</sup>

It has been proposed that the measures of heart rate variability can be used to assess relative change in autonomic tone, or the balance between sympathetic and parasympathetic activity. One of the methods of assessing sympathovagal balance has been a use of the LF/HF power ratio, with increasing values indicating a shift toward sympathetic predominance.<sup>(18,19)</sup> Thus, a finding of lower LF/HF ratio at rest in the group of endurance athletes compared to the other groups suggested a lower sympathetic influence on cardiac function in the runners. In addition, there is evidence that SA node showed a reduction in the density level of adrenergic receptors possibly due to the down regulation of receptors with exercise training.<sup>(20)</sup>

In conclusion, regulation of cardiovascular system provides physiological basis for HRV and variation of other cardiac variables. Not only that there are multiple control factors, various parts of cardiovascular system is regulated through many complex feedback loops. The study shows that both the reduction in sympathetic tone and augment in the vagal activity, though not all, play a significant role in cardiac adaptation in endurance athletes.

We also provided evidence that resistance type of training does not induce resting bradycardia nor alter autonomic contribution to the heart.

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