Application of Heart Rate Variability in Monitoring Fatigue of Athletes

心率變異在監控運動員疲勞之應用

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Physiological background of Heart Rate Variability

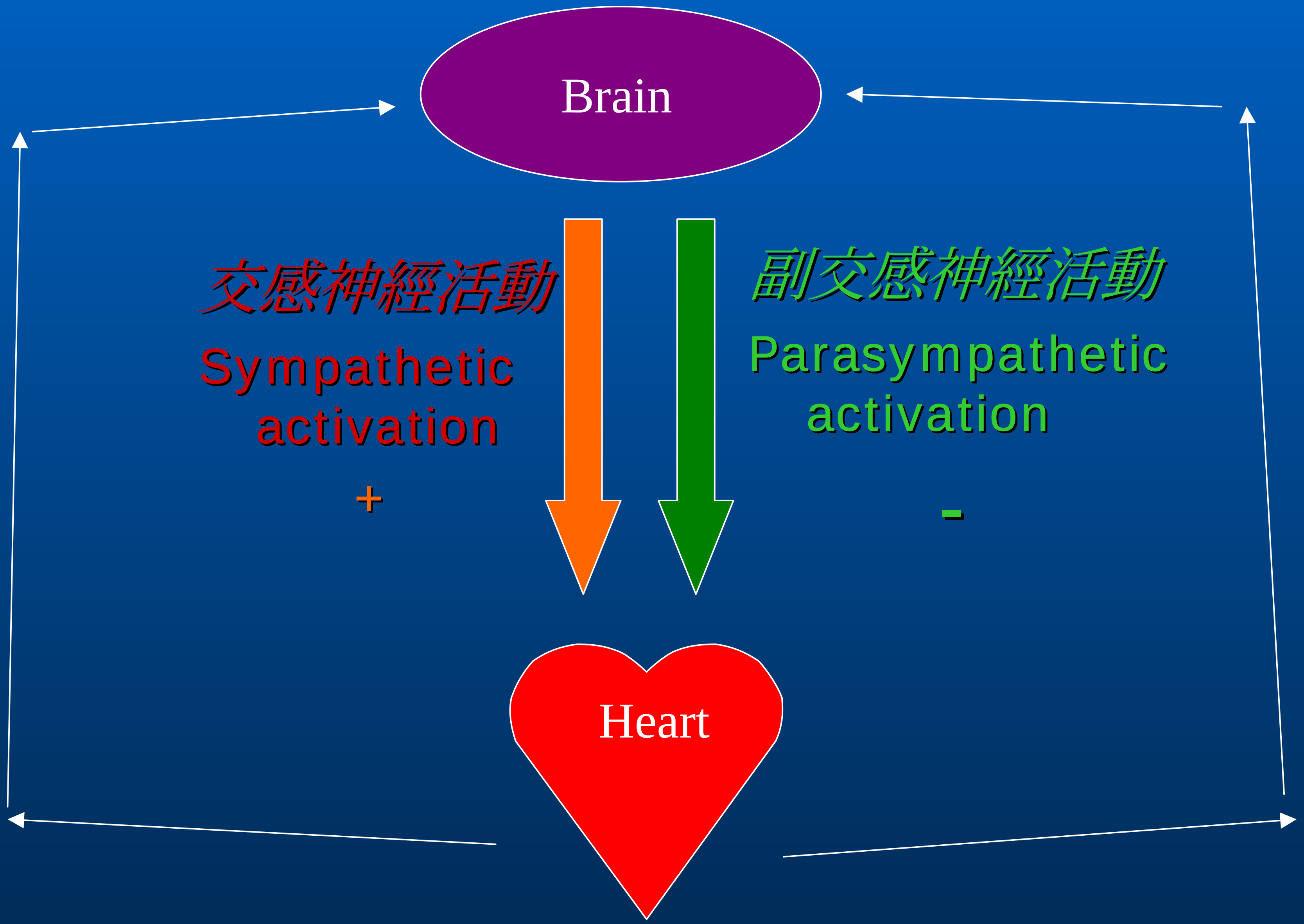
Sympathetic Nervous System

交感神經系統

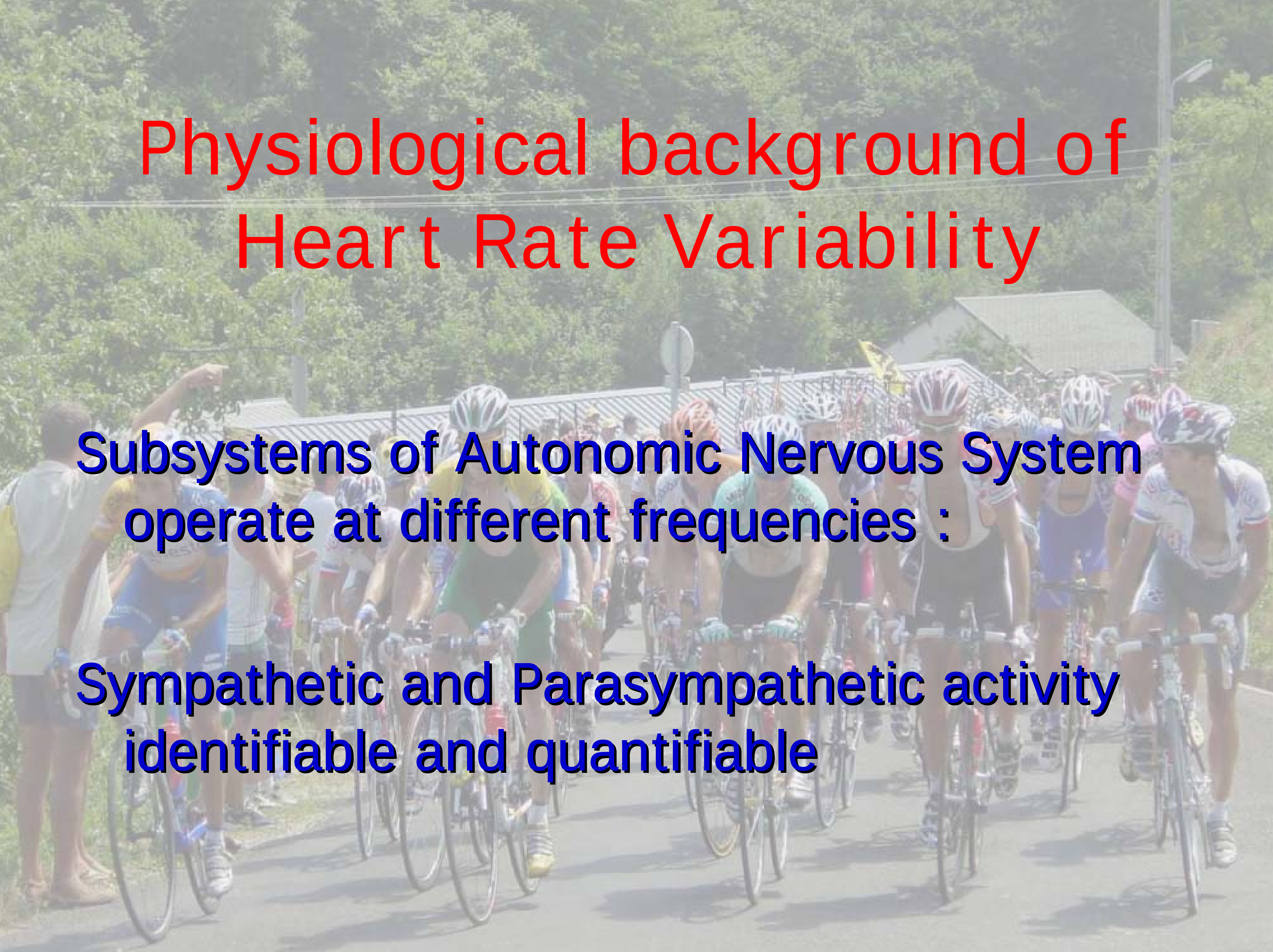
Parasympathetic Nervous System

副交感神經系統

Heart Rate is a net result…


Brain
交感神經活動
Sympathetic activation
+
副交感神經活動
Parasympathetic activation
-
Heart

Physiological background of Heart Rate Variability



Subsystems of Autonomic Nervous System operate at different frequencies :

Sympathetic and Parasympathetic activity identifiable and quantifiable

Measurements of Heart Rate Variability

High Frequency bias (高頻)：

Parasympathetic dominance

副交感神經活動作主導

→ ↑ **HRV** 心率變異

Low Frequency bias (低頻)：

Sympathetic dominance

交感神經活動作主導

What is Heart Rate Variability (HRV) (心率變異)?

- Quantified by analysis of variations of the intervals between consecutive normal heart beats…

- Heart Beat Interval is the time between consecutive R wave peaks.

(Pumprla et al 2002)

Measurements of HRV

時域分析

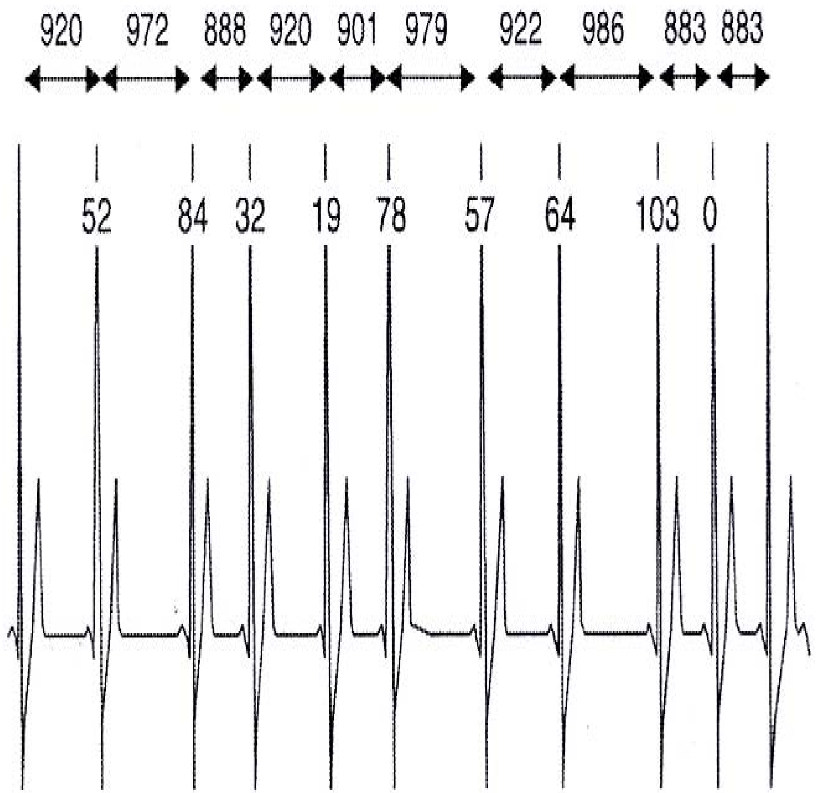
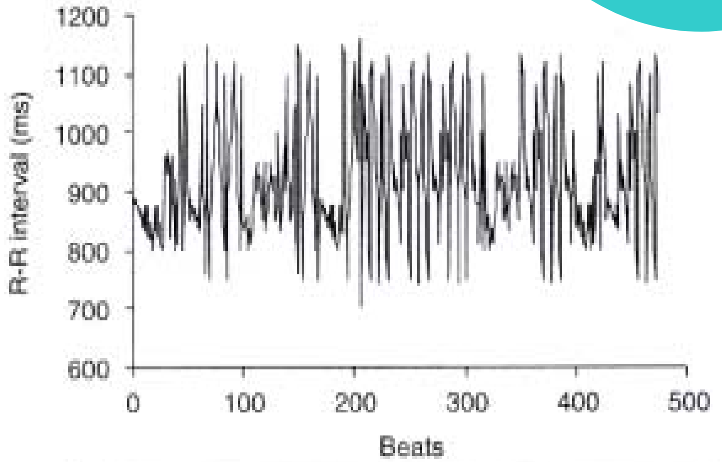


Fig. 2. Example of an ECG output over 11 beats. R-R interval times and difference between adjacent R-R intervals are displayed.

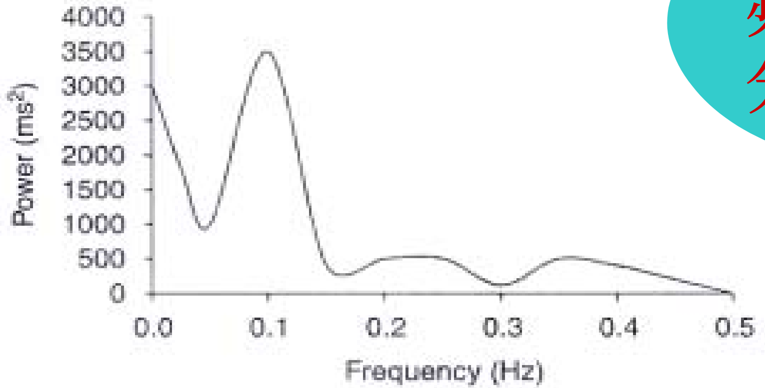


R-R intervals in time-domain	
AverageNN (ms)	Average of all normal R-R intervals
SDNN (ms)	Standard deviation of all normal R-R intervals
r-MSSD (ms)	Root mean square successive difference
pNN-50 index (%)	Percentage of differences between adjacent normal R-R intervals that are >50ms

Fig. 1. Example of R-R interval time between each subsequent beat measured over a 7-minute period at rest (~500 beats) and common ways to express heart rate variability in the time-domain.

Measurements of HRV

頻譜
分析



R-R intervals in frequency-domain	
Total power (ms^2)	The power in the heart rate power spectrum between 0.00066 and 0.34Hz
VLFP (ms^2)	The power in the heart rate power spectrum between 0.0033 and 0.04Hz
LFP (ms^2)	The power in the heart rate power spectrum between 0.04 and 0.15Hz
HFP (ms^2)	The power in the heart rate power spectrum between 0.15 and 0.36Hz
LFP : HFP ratio	

Fig. 3. An example of the power spectrum which shows the magnitude of the variability as a function of frequency. The most commonly found areas in the power spectrum, which represent different influences of sympathetic and parasympathetic nervous system, are displayed in the box. **HFP** = high frequency power; **LFP** = low frequency power; **VLFP** = very low frequency power.

Supine

Vs

Standing

HRV

Good or Bad??

Applications of HRV

- Clinical relevance first noted in 1965
- Predict mortality following an acute myocardial infaraction
- Detect autonomic neuropahty in diabetics
- Cardiac transplanation
- Myocardial dysfunction

Applications of HRV

- "Decreased HRV associated with four-fold increased risk for sudden cardiac death in patients with coronary artery disease and ….significantly associated with all-cause mortality in general populations"

(Cripps et al.,1991; Makikallio et al.,2001)

HRV and Physical Fitness

Rochelle et al. (1997)

- 37 healthy volunteers, 22-44yrs,
- various activity levels :
  - sedentary (no exercise) , intermediate and active (>1hr,3times/week,>6mths)
- VO_2max ranged from 25 to 70 ml/min/kg
- 24-hr ECG recordings

HRV and Physical Fitness

Figure 1

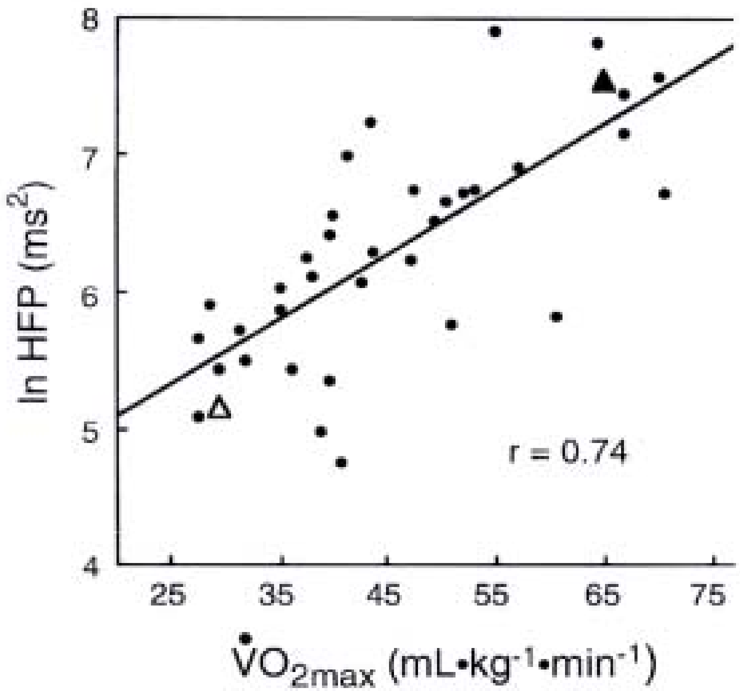
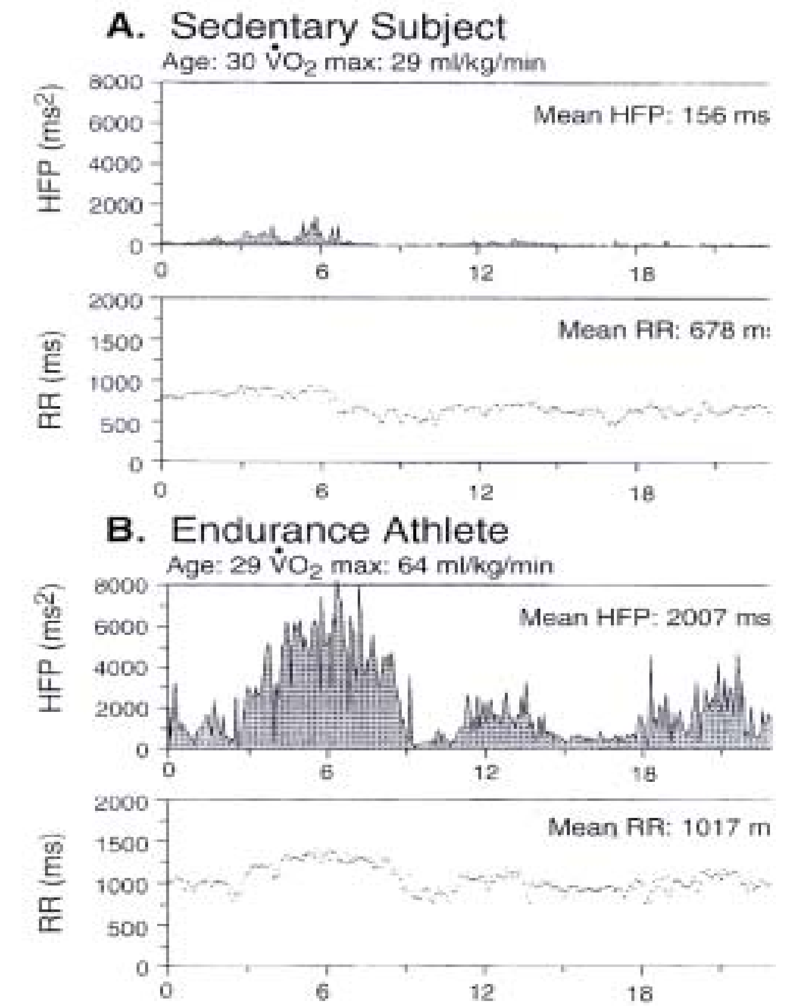


Figure 1-The inverse relationship between the natural logarithm of high frequency power and maximal oxygen consumption. The two subjects depicted by triangles are of similar age and body mass index. The [white up pointing small triangle] respresents a 30-yr-old sedentary man with mean body mass index is 23 kg·m-2 and whose ·VO2max is 29 mL·min-1·kg-1. The [black up pointing small triangle] represents a 29-yr-old triathlete whose mean body mass index is also 23 kg·m-2 and whose ·VO2max is 64 mL·min-1·kg-1. The R-R intervals and high frequency power of these two subjects are shown in Fig. 2. HFP, high frequency power; ln, natural logarithm; ·VO2max, maximal oxygen consumption.

From: GOLDSMITH: Med Sci Sports Exerc, Volume 29(6).June 1997.812-817



Rochelle et al. (1997)

HRV, Physical Fitness & Age

Figure 4

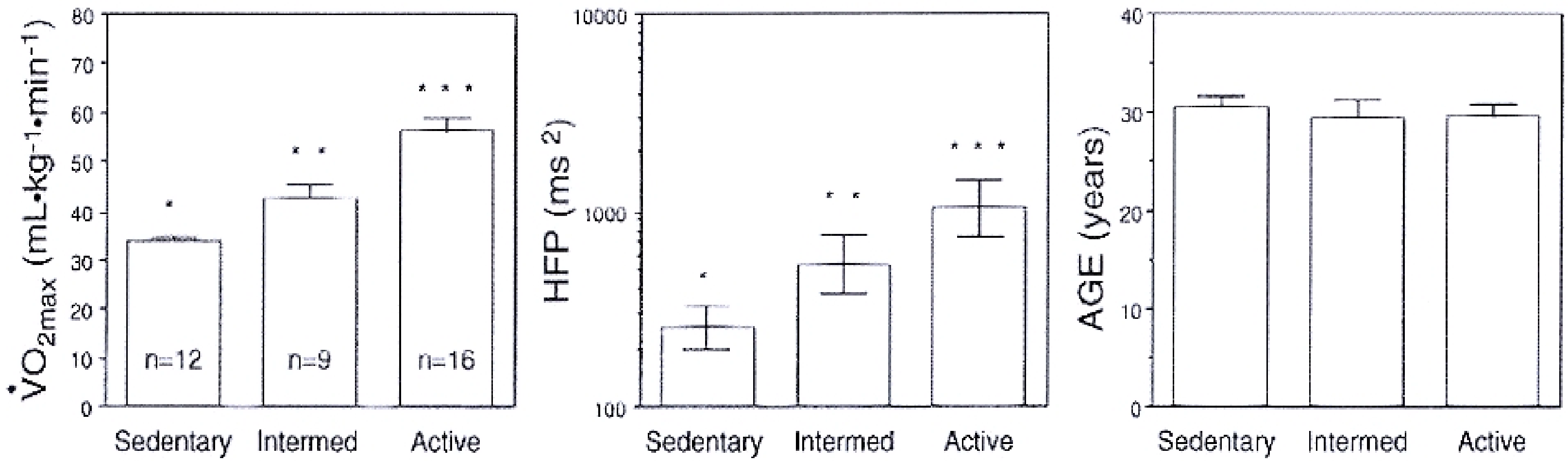


Figure 4-Graphs showing the relationship between activity level and·VO2max (left), HF power (middle) and age (right). Sedentary, intermediate, and active are defined in the text. Shown are the arithmetic means and SE for ·VO2max and age. The geometric means and their 95% confidence intervals for HF power are displayed on a logarithmic scale so that equal differences would represent equal ratios. Age was similar in the three groups, while ·VO2max and HF power varied directly with reported activity level. HFP, high frequency power; ·VO2max, maximal oxygen consumption; intermed, intermediate. * sedentary vs intermediate(P <0.05); **intermediate vs active(P < 0.05); * sedentary vs active(P < 0.05). These *post hoc* comparisons**

Rochelle et al. (1997)

HRV and Physical Fitness

Kouidi et al. 2002

- HRV in 60 track & field athletes of different VO2max
- Highest HRV in long-distance runners
- HRV (r) VO2max in long-distance runners
- Higher HRV in athletes than the untrained

→ Training improving aerobic capacity modulates parasympathetic activity

HRV and Physical Training

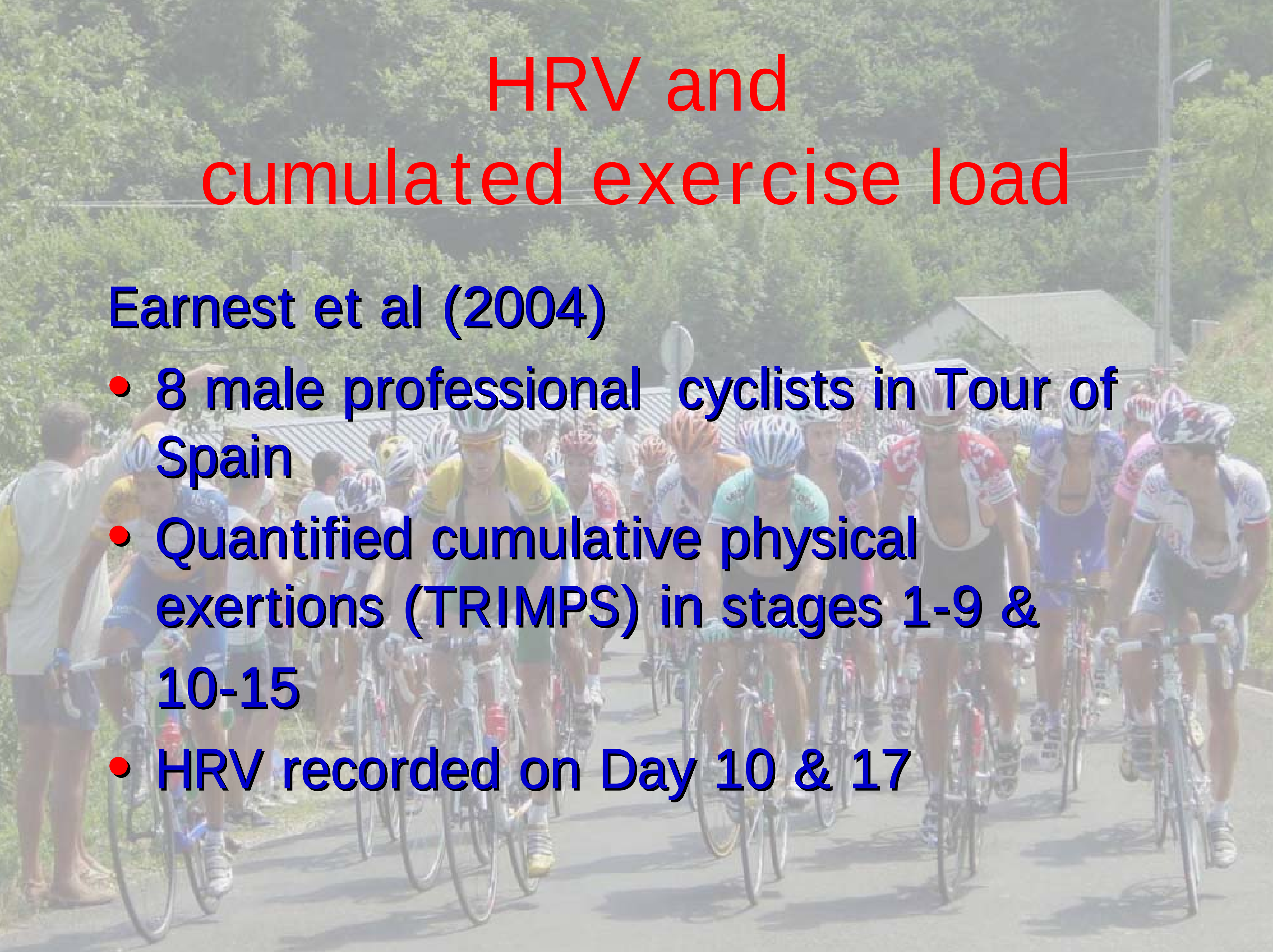
Table 3. Cross-sectional: athletes versus sedentary population

Author	N	Age	Spectral analysis	Remarks
		(years)		
Tonkins[142]	39	21.2±3	No change	24 h Holter
	39			time domain
Aubert[211]	10	18-34	HF (increase)	FFT
	10	19-31		
Verlinde[30]	10	18-34	HF (increase)	Wavelet
	10	19-31		
Dixon[146]	10	22-33	HF (increase)	AR
	14	23-33		
Goldsmith[147]	8	24-38	HF (increase)	24 h Holter, FFT
	8	24-38		sleeping and awake
Furlan[151]	21	16±0.6	LF (increase)	trained
	15	16±0.5	HF (increase)	detrained
	29	16±0.4		
Jansen[152]	18	19-32	LF (decrease)	supine
	11	23-33		

N: number of subjects, LF: low frequency power, HF: high frequency power, FFT: fast Fourier transform, AR: autoregressive method.
Last row for each author: sedentary comparison group

- *Shift of sympathovagal balance towards parasympathetic dominance!*

HRV and cumulated exercise load



Earnest et al (2004)

- 8 male professional cyclists in Tour of Spain
- Quantified cumulative physical exertions (TRIMPS) in stages 1-9 & 10-15
- HRV recorded on Day 10 & 17

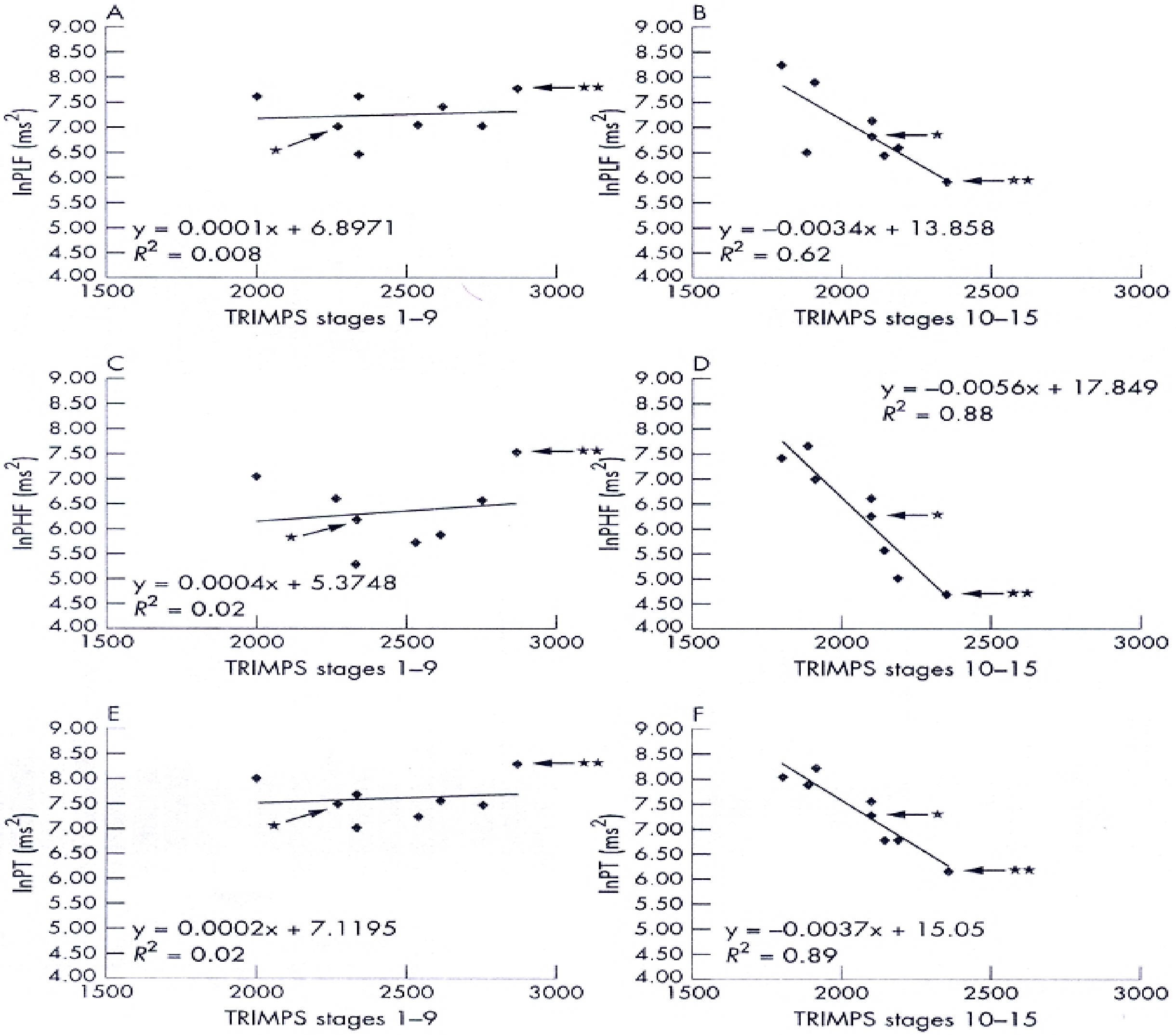


Figure 2 Frequency domain analysis of eight professional cyclists participating in the 2001 Vuelta a España. The power spectra were quantified by measuring the area in three frequency bands and are low frequency power (P_{LF}; 0.04–0.15 Hz; A, B), high frequency power (P_{HF}; 0.15–0.40 Hz; C, D), and total frequency power (P_T; 0.04–0.40 Hz; E, F). (A, C ,E) TRIMPS accumulated for stages 1–9. (B, D E) TRIMPS accumulated for stages 10–15. The heart rate variability response of a multistage winner/team leader (*) and a domestique (**) are indicated. These are the individual cyclists analysed in fig 3.

Earnest et al (2004)

Supine HR and HRV characteristics of eight professional cyclists during the 2001 Tour of Spain

	Baseline	Day 10	Day 17
Heart Rate (bpm)	53.23 (1.8)	48.99 (2.8)	48.02 (2.6)
Time domain measures			
SDNN (ms)	59.10 (6.52)	70.44 (5.08)	60.67 (6.65)
RMSSD (ms)	44.89 (5.21)	51.98 (5.52)	49.54 (7.43)
Frequency domain measures			
LnPLF (ms)	6.83 (0.25)	7.22 (0.15)	6.95 (0.28)
LnPHF (ms)	6.28 (0.25)	6.34 (0.26)	6.26 (0.39)
LnPT (ms)	7.35 (0.20)	7.61 (0.15)	7.44 (0.30)

Earnest et al (2004)

HRV and overtraining

Pichot et al (MSSE, 2000)

- 3 weeks heavy training + 1 easy week on 7 middle distance runners; 24-hr ECG recording x 2nites
- Progressive ↓ parasympathetic indices of 41% during the 3-week
- Sympathetic activity ↑ by 31%
- LF/HF significant ↑ by 75%
- Cardiac autonomic balance shifted to sympathetic over parasympathetic drive
- – good tool to estimate cumulated physical fatigue

HRV and overtraining

Hedelin et al (2000)

- 9 international-class canoeists
- 50% increase in training load in 6 days
- Decrease in RunT, VO2max, Max-La, HR at all workload, PV ↑
- No diff. In HRV parameters

HRV and overtraining

Hedelin et al (2000)

- Case study on a junior cross-country skier
- 20hrs training/week
- 2 months recovery

HRV and overtraining

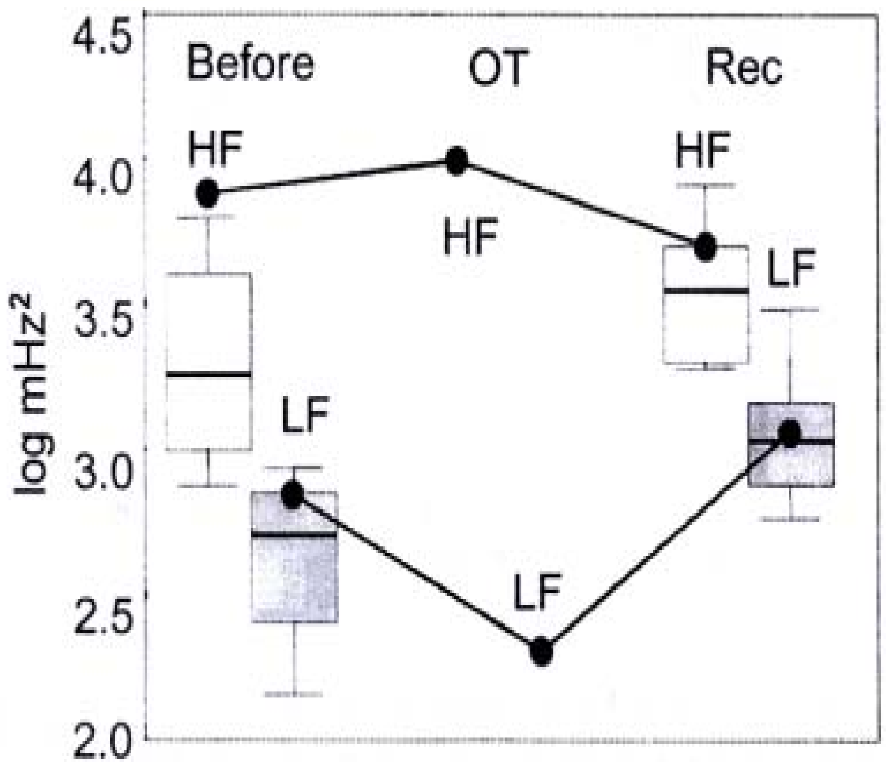


Figure 1—High (HF) and low (LF) frequency heart rate variability at rest during controlled breathing in one athlete (●) before, when overtrained, and after recovery. *Boxes* (median, quartiles, and range) represent seven normally trained athletes examined at the same time points as "Before" and "Recovered."

HRV and overtraining

	Control (N = 7)		Case		
	Before	After	Before	OT	Recovery
HR (bpm)	59 ± 3	59 ± 6	62	59	62
Log total power (mHz^2)	3.51 ± 0.37	3.69 ± 0.31	3.92	4.03	3.86
Log HF (mHz^2)	3.31 ± 0.36	3.39 ± 0.55	3.88	4.00	3.69
HF (nu)	76 ± 12	71 ± 12	91	98	81

Hedelin et al (2000)

- *Relative parasympathetic dominance*

HRV and overtraining

Portier et al (2001)

- 8 elite long distance runners
- 3 wks rest & 12 wks intense endurance training

HRV and overtraining

	Relative Rest Period		Intensive Training Period		
	Supine	Standing	Supine	Standing	P
LF (nu) ⬇	1.7 ± 0.5	7.3 ± 3.6	1.3 ± 1.1	4.5 ± 2.3	<0.01
HF (nu) ⬆	1.1 ± 0.9	0.85 ± 0.8	1.6 ± 0.8	2.1 ± 1.6	<0.05
LF/HF ⬇	1.5 ± 1.7	8.6 ± 5.4	0.8 ± 0.4	2.1 ± 1.2	<0.01

Portier et al (2001)

- *HRV could be used for detecting fatigue that could result in overtraining*

HRV and overtraining

Uusitalo et al (2000)

- Heavy Training group (n=9) (+80%) vs Normal Training group (n=6) in 6-9 weeks
- 4 were overtrained : diff responses
- Sign. ↑ LF during supine in Heavy Training group; ↓ in HF
- Individual physiological response to overtraining
- Corresponds to two over-training types.

HRV and overtraining

- Early stage of over-training syndrome, sympathetic system was continuously modulated.
- During advanced stage, activity of sympathetic system was inhibited, resulting in marked dominance of the parasympathetic system.

Kuipers, H.(1998)

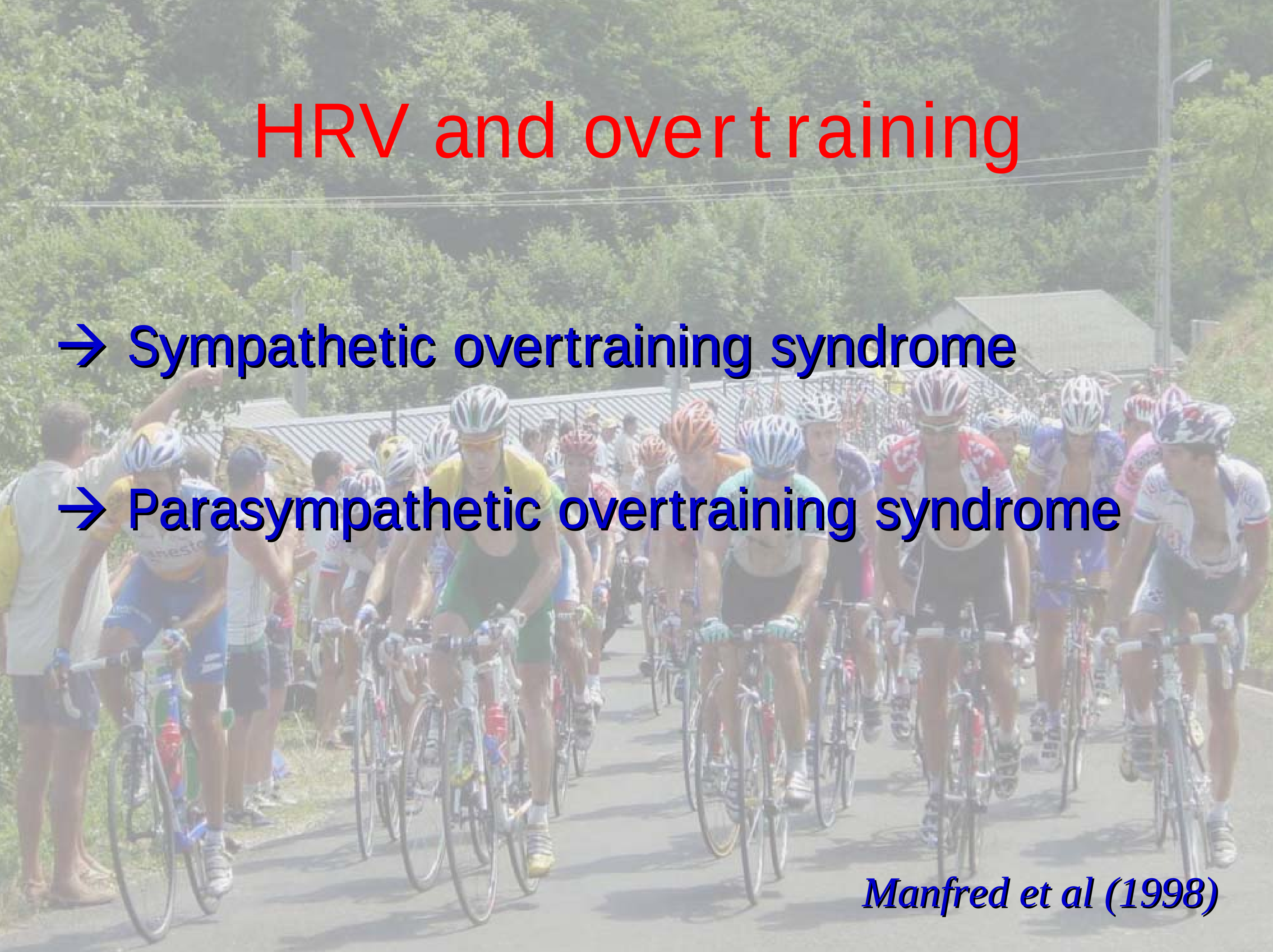
HRV and overtraining

- High training intensity is associated with dominance in sympathetic activities.

- High training volume is related to the dominance parasympathetic modulation.

Kuipers, H.(1998)

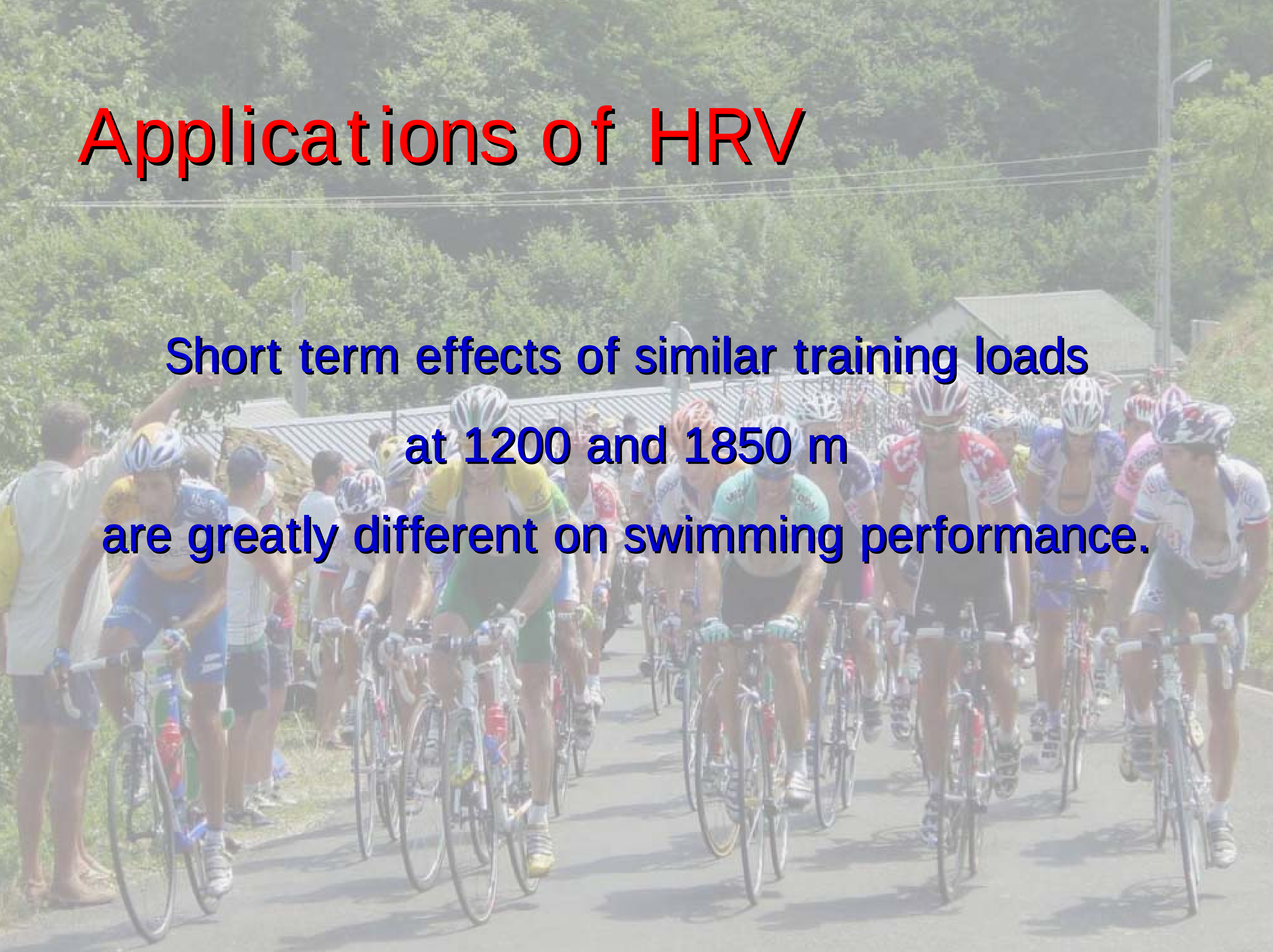
HRV and overtraining



→ Sympathetic overtraining syndrome

→ Parasympathetic overtraining syndrome

Manfred et al (1998)



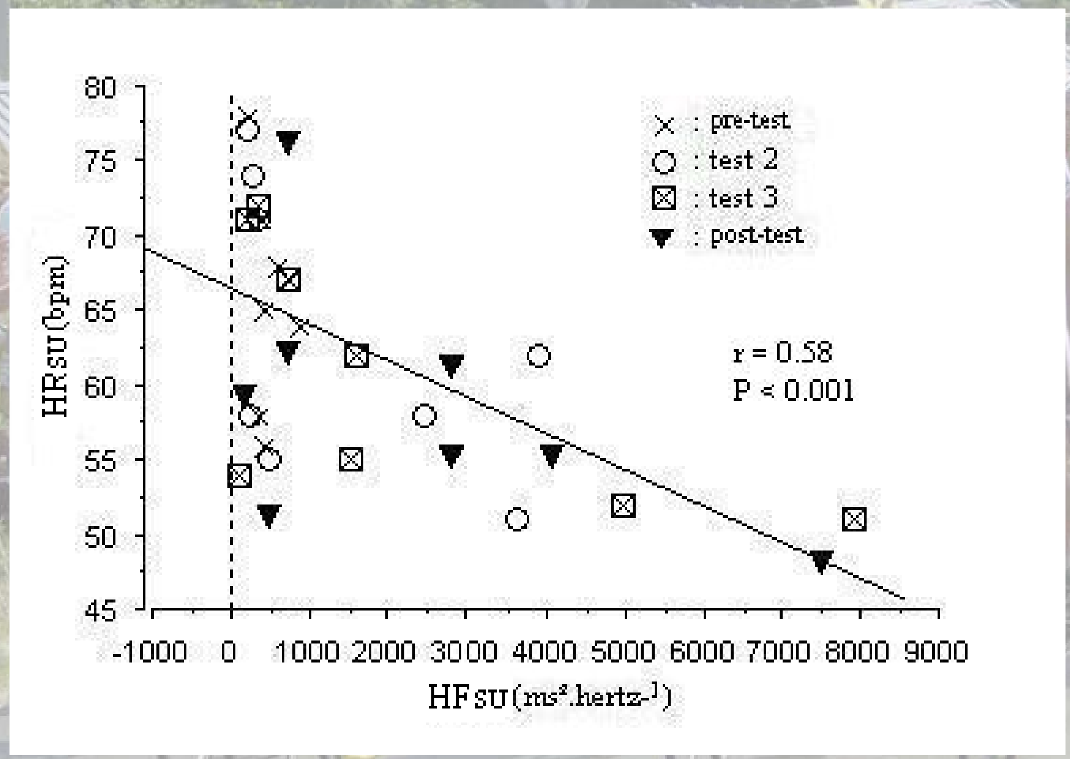
Applications of HRV

Short term effects of similar training loads

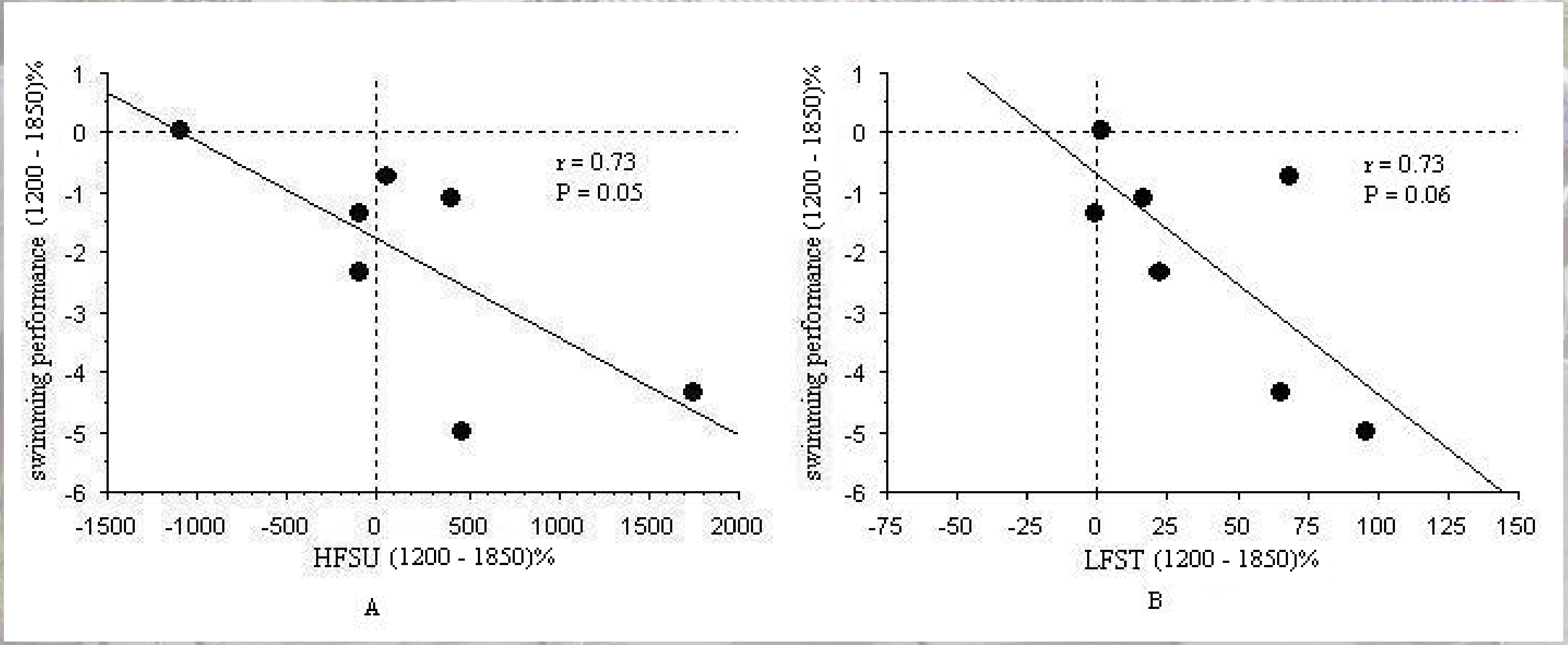
at 1200 and 1850 m

are greatly different on swimming performance.

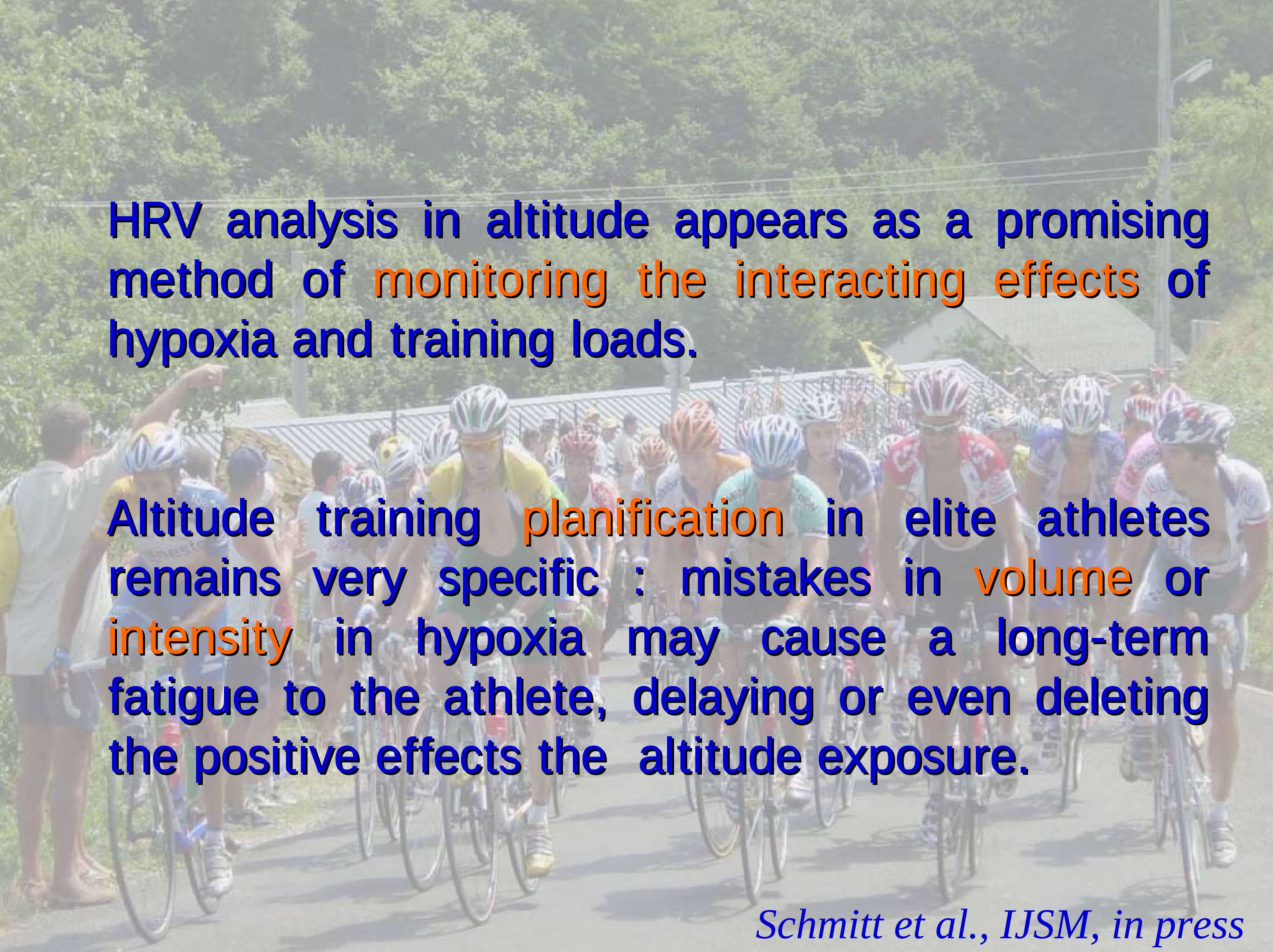
HF_{SU} was significantly correlated with HR_{SU} during T1200 but not during T1850.



Change in performance was correlated with the increase in HF_{SU} (r = 0.73 ; P<0.05) and had a tendency to be correlated with the increase in LF_{ST} (r = 0.73 ; P = 0.06).



+ Moderate aerobic training and hypoxic stress may have opposite effects since the aerobic training stimulates the total spectral power and HF modulation.



HRV analysis in altitude appears as a promising method of monitoring the interacting effects of hypoxia and training loads.

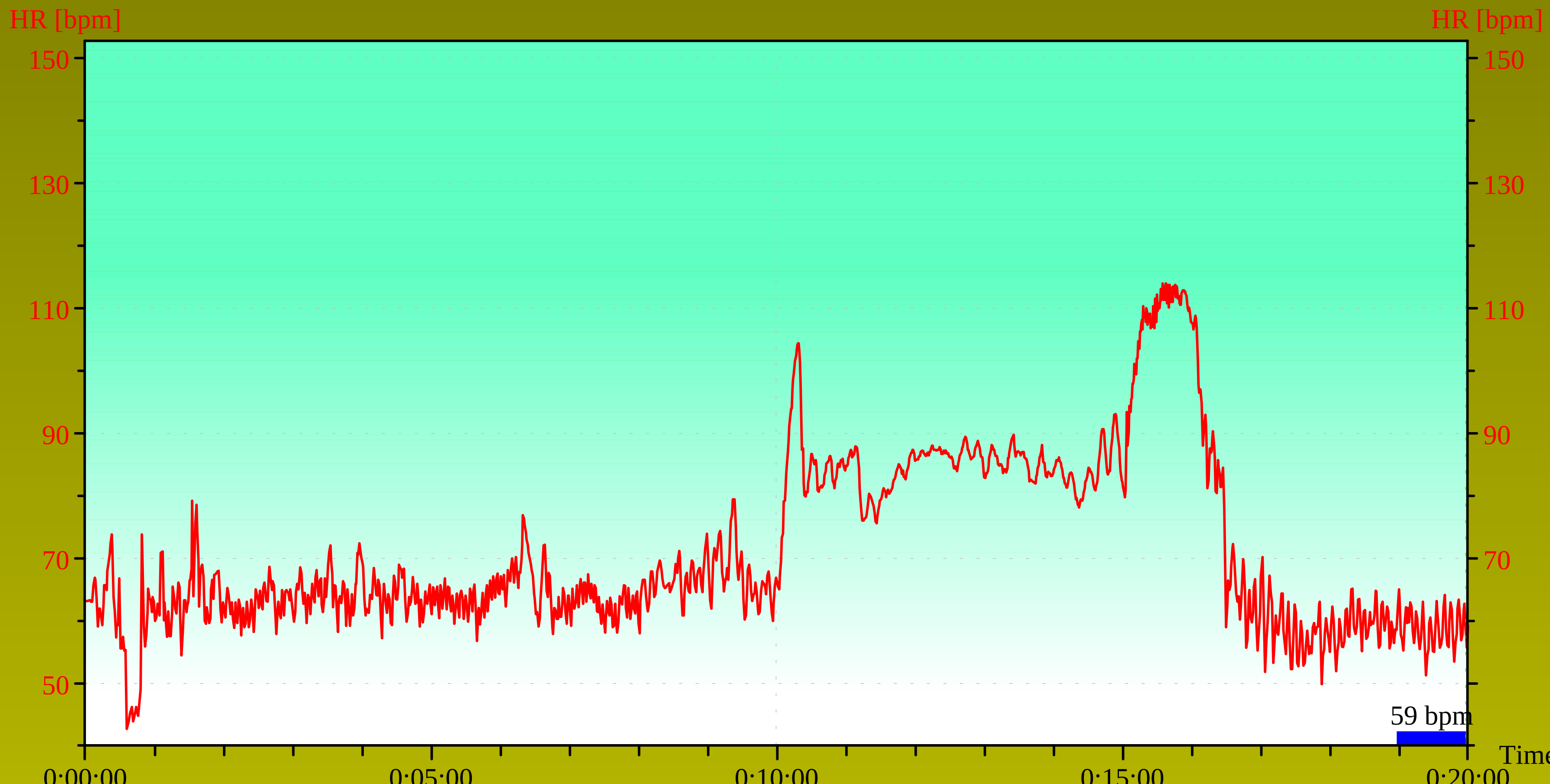
Altitude training planification in elite athletes remains very specific : mistakes in volume or intensity in hypoxia may cause a long-term fatigue to the athlete, delaying or even deleting the positive effects the altitude exposure.

Schmitt et al., IJSM, in press

Applications on our Athletes

Conducting HRV test

- Comparable timings to avoid circadian variations
- Supine and standing positions
- Durations
- HR/ECG recorder
- Avoid caffeine,alcohol
- Avoid exercise prior to test



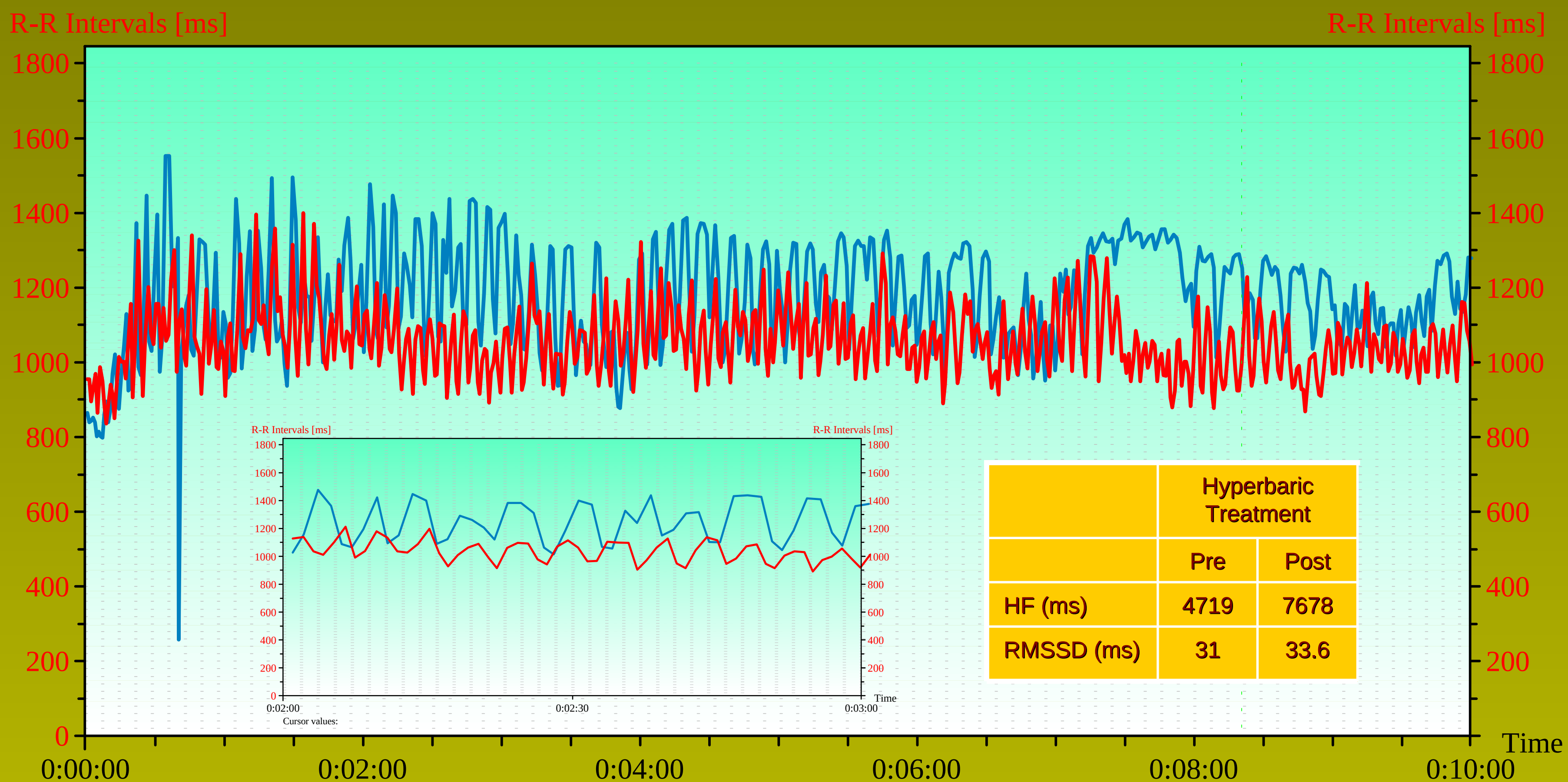
Time: 0:19:58.5

HR: 59 bpm

Person		Date	4/2/2005	Heart rate averag	59 bpm		
Exercise	05040202	Time	8:40:42 PM	Heart rate max	65 bpm		
Sport	MultiSport	Duration	0:20:02.5				
Note				Selection	0:19:00 - 0:19:59 (0:01:00.2)		

Data	Value	Unit
Duration	0:01:00	
Sampling Rate	R-R Intervals	
Number of Heart Beats	**59**	**beats**
Minimum R-R Interval	924	ms (65 bpm)
Average R-R Interval	1021	ms (59 bpm)
Maximum R-R Interval	1172	ms (51 bpm)
RLX baseline	38	ms
Standard Deviation	53.4	ms
Max/min ratio	1.27	
Weighted RR Average	1024	ms
SD1	38.2	ms
SD2	64.5	ms
RMSSD	53.8	ms
pNN50	**22.0**	**%**
Total power (0.00 - 0.40 Hz)	**3401.07**	**ms^2**
VLF (0.00 - 0.04 Hz)	897.60	ms^2 (26 %)
LF (0.04 - 0.15 Hz)	422.88	ms^2 (12 %)
HF (0.15 - 0.40 Hz)	**2080.59**	**ms^2 (61 %)**
LF/HF ratio	**20.4**	**%**

R-R Summary report by Polar software (Polar Electro Oy, Finland)



Cursor values:
Time: 0:08:21.0
HR: 997 ms (60 bpm)

No	Exercise	Date	Cursor HR	Heart rate	Duration	Note
1.	Pre-hyperbaric O2 therapy	2005/4/3	997	50 / 65	0:20:02.9	At 1,300m Altitude
2.	Post-hyperbairic O2 therapy	2005/4/3	1106		0:20:03.3	At 1,300m Altitude
3.						
4.						
5.						

Pros and Cons of HRV

Pros	Cons
• easy to conduct • non-invasive • assess cumulative training effects • assess training stress on nervous system	• affecting factors • Highly individualized • Analysis method

Summary of HRV

- *Assesses cumulative central fatigue state*
- *Highly individualized*
- *Long-term monitoring*
- *Assists in monitoring training stress and provides hints for training adjustment*

Future explorations of HRV

- *Standard protocols*
- *Magnitude of training intensity and volume adjustment*
- *HRV @ different altitudes*
- *Relationship with other fatigue-monitoring parameters*
- *Monitoring recovery with different recovering modality*
- *Trainability vs heredity*