Decrease in heart rate variability with overtraining: assessment by the Poincaré plot analysis

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Accepted for publication
Received 4 July 2003;
accepted 29 September 2003

Key words
autonomic nervous system; endurance training; fatigue; head-up tilt test; overtraining syndrome; spectral analysis

Summary

Numerous symptoms have been associated with the overtraining syndrome (OT), including changes in autonomic function. Heart rate variability (HRV) provides non-invasive data about the autonomic regulation of heart rate in real-life conditions. The aims of the study were to: (i) characterize the HRV profile of seven athletes (OA) diagnosed as suffering of OT, compared with eight healthy sedentary (C) and eight trained (T) subjects during supine rest and 60° upright, and (ii) compare the traditional time- and frequency-domain analysis assessment of HRV with the non-linear Poincaré plot analysis. In the latter each R-R interval is plotted as a function of the previous one, and the standard deviations of the instantaneous (SD1) and long-term R-R interval variability are calculated. Total power was higher in T than in C and OA both in supine (1158 ± 1137, 6092 ± 3554 and 2970 ± 2947 ms^2 for C, T and OA, respectively) and in upright (640 ± 499, 1814 ± 806 and 1092 ± 712 ms^2 for C, T and OA, respectively; $P<0{\cdot}05$) positions. In supine position, indicators of parasympathetic activity to the sinus node were higher in T compared with C and OA (high-frequency power: 419·1 ± 381·2, 1105·3 ± 781·4 and 463·7 ± 715·8 ms^2 for C, T and OA, respectively; $P<0{\cdot}05$; SD1: 29·5 ± 18·5, 75·2 ± 17·2 and 37·6 ± 27·5 for C, T and OA, respectively; $P<0{\cdot}05$). OA had a marked predominance of sympathetic activity regardless of the position (LF/HF were 0·47 ± 0·35, 0·47 ± 0·50 and 3·96 ± 5·71 in supine position for C, T and OA, respectively, and 2·09 ± 2·17, 7·22 ± 6·82 and 12·04 ± 10·36 in upright position for C, T and OA, respectively). The changes in HRV indexes induced by the upright posture were greater in T than in OA. The shape of the Poincaré plots allowed the distinction between the three groups, with wide and narrow shapes in T and OA, respectively, compared with C. As Poincaré plot parameters are easy to compute and associated with the 'width' of the scatter gram, they corroborate the traditional time- and frequency-domain analysis. We suggest that they could be used to indicate fatigue and/or prevent OT.

Introduction

An overtraining state (OT), originating in a 'training/competition/recovery imbalance' may happen quite often in high-level performance sports (McKenzie, 1999). Moreover, training as well as non-training stressors are thought to make this OT state worse with large individual variations. In the given literature a variety of symptoms of OT, which may also serve as diagnostic parameters, are presented (for reviews see Kuipers & Keizer, 1988; Lehmann *et al.*, 1993; Kuipers, 1996, 1998; Hartmann & Mester, 2000). To date, symptoms are numerous and the lack of uniform features makes diagnosis difficult.

Heart rate variability (HRV) reflects the continuous oscillation of the R-R intervals around its mean value, providing non-invasive data about the autonomic regulation of heart rate in real-life conditions (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). HRV, reflecting cardiovascular control exerted by both parasympathetic and sympathetic nervous system, has been used to evaluate modifications of autonomic functions due to acute exercise or training. It is admitted that a sufficient long or intense endurance training leads to an increased HRV (Seals & Chase, 1989; Dixon et al., 1992; Goldsmith et al., 1992; De Meersman, 1993; Janssen et al., 1993; Shi et al., 1995; al-Ani et al., 1996; Macor et al., 1996; Melanson & Freedson, 2001; Verlinde et al., 2001; Yamamoto et al., 2001). In competitive sports, improved performance is often effected by alternating prolonged periods of intensive training and shorter periods with relative rest. The intense training phase, also called overreaching (Kuipers, 1998), has been associated with a decrease in HRV. But interpretation of this results is complex. Despite a decrease in overall HRV, both a shift towards sympathetic activity (Iellamo et al., 2002) or towards parasympathetic activity predominance (Pichot et al., 2000; Portier et al., 2001) have been reported. Regarding OT, altered HRV has been found in a young cross-country skier with an autonomic balance shift to higher parasympathetic modulation, compared with before this OT state and after sufficient recovery (Hedelin et al., 2000a). However, this was a one-subject case study that needs to be confirmed in a greater number of subjects as no change (Hedelin et al., 2000b) or a decrease (Uusitalo et al., 2000) in HRV with OT has also been reported.

Information about HRV has been commonly obtained by using linear methods such as power spectral analysis (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). However, a number of studies dealing about HRV have shown that R-R intervals fluctuate in a very complex manner exhibiting patterns suggestive of non-linear processes (Braun et al., 1998). Because of these non-linear components, the R-R interval time series signal cannot be properly assessed using linear techniques such as spectral analysis (Braun et al., 1998). A Poincaré plot of HRV, where each R-R interval is plotted as a function of the previous interval, is a non-linear method that allows calculation of changes in heart dynamics with trends. In addition of a visual measure of autonomic nervous system activity (Woo et al., 1994; Kamen et al., 1996), this method permits immediate recognition of ectopic beats or artefact which may otherwise go unobserved (Myers et al., 1992).

Thus, the aims of the present study were to: (i) characterize, with traditional time and frequency analysis, the HRV profile of athletes suffering of OT, against the ones of control and trained subjects during supine rest and 60° upright positions, and (ii) evaluate the effectiveness of the non-linear Poincaré plot method in the assessment of the changes in HRV induced by OT.

Methods

Subjects

Seven athletes (five women and two men; two endurance runners, four cross-country skiers, one motorcyclist) diagnosed as suffering from OT syndrome (OA; see below criteria) were compared with endurance trained eight subjects (four women and four men) performing regular physical training since at least 3 years (T) and eight (four women and four men) sedentary control subjects (C). The group's characteristics are presented in Table 1. Their medical history and a medical examination were used to discard subjects with cardiovascular, pulmonary, or metabolic diseases. The subjects were normotensive and none was taking any medication. The study protocol complies with the Helsinki declaration for human experimentation. Possible risks and benefits were explained and written informed consent was obtained from each subject prior to all testing.

Table 1 Characteristics of the subjects.

	C	T	OA
Age (years)	22·8 ± 3·2	17·8 ± 1·8	23·0 ± 8·1
Height (cm)	165·0 ± 6·1	168·1 ± 7·9	169·0 ± 6·3
Weight (kg)	59·9 ± 6·1	60·2 ± 7·5	60·6 ± 9·8
SBP (mmHg)	117·0 ± 8·8	123·8 ± 6·3	126·9 ± 6·5
DBP (mmHg)	67·0 ± 7·1	66·3 ± 6·2	69·1 ± 5·3

C, control subjects; T, trained subjects; OA, subjects diagnosed as suffering from the overtraining syndrome; SBP, systolic blood pressure; DBP, diastolic blood pressure.

Diagnostic criteria

Overtraining is a condition of chronic fatigue syndrome (Budgett, 1998; Shephard, 2001) and OT syndrome was diagnosed following indications of Holmes et al. (1988). Briefly, the subjects reported debilitating fatigue, lack of energy and extreme tiredness as universal symptoms. All patients also stated that they were performing below an acceptable level in their sport and were having difficulty maintaining their training programme. All subjects were still exercising at the time of their inclusion in the study, albeit at a severely reduced level. In all cases, the symptoms were not relieved by a period of either rest or bedrest depending on the severity of the condition. All the subjects had previously been undertaking an exercise training programme and competing in their respective sport in either amateur or professional competition, some up to international level. They reported the onset of their condition to have occurred over a period of 1–6 weeks. In some cases, the OT syndrome occurred following a period of increase volume or intensity of training. The most commonly reported non-fatigue symptoms included muscle pain, sleep disturbance, depression, irritability, lapses in memory or concentration, lack of co-ordination, and an increased susceptibility to infections, particularly cold and stomach complaints. Testing for infections (Epstein–Barr virus), pulmonary function and exercise ECG (myocarditis) were all negative/normal. No illness, injury or other explanatory factor could explain the performance decrement (Israel, 1976; Lehmann et al., 1993). Haemoglobin ($13{\cdot}8 \pm 1{\cdot}4$ g dl^{-1}), red blood cells ($4{\cdot}6 \pm 0{\cdot}9 \times 10^{12}$ l^{-1}), white blood cells ($5{\cdot}9 \pm 0{\cdot}7 \times 10^{9}$ l^{-1}), ferritin ($54{\cdot}5 \pm 38{\cdot}4$ ng ml^{-1}), urea ($4{\cdot}8 \pm 0{\cdot}9$ mmol l^{-1}) were in the normal range but cortisol was above normal values ($847{\cdot}5 \pm$

226·8 nmol l^{-1}, range 600–1040 nmol l^{-1}; normal range 140–550 nmol l^{-1}; Guyton & Hall, 1996).

Study protocol

The subjects came to the laboratory between 9.00 and 12.00 AM. They were instructed to fast for at least 2 h before testing. They were also asked to refrain from ingesting beverages containing caffeine and alcohol and not to exercise during the 24 h preceding the test sessions (Furlan *et al.*, 1993). A tilting table was used with a board as foot support. After an adaptation period of 20 min in the supine position, data acquisition was initiated and the subjects remained supine 10 min before being tilted at 60° for 10 min. The ambient temperature was kept at 22–24°C.

Measurement of HRV

Electrocardiographic (ECG) data were collected at 500 Hz and converted from analog to digital with a 16-bit resolution. R-wave peaks were detected using an R-wave detection algorithm (BSL pro v.3.6.5., Biopac System, Santa Barbara, CA, USA). The program calculated instantaneously the R-R intervals as the difference between successive R-wave peaks. Time- and frequency-domain analyses of HRV and Poincaré plot were performed on a series of five consecutive minutes manually selected. At least 256 cycles were used for each analysis. All the R-R intervals were edited by visual inspection to exclude all the undesirable beats [i.e. to ensure that each analysis for the segment was free of: (i) movement artefact, (ii) sharp transient in the signal due to premature beats], which accounted for <1% in every subjects.

Spectral and time-domain analysis

Three time-domain measures were used as quantification of total variation in HR during the respiratory cycle: the standard deviation of the R-R intervals (SDNN), the root mean square of successive differences of successive R-R intervals (rMSSD), and the proportion of the number of interval differences of successive R-R intervals >50 ms (pNN50). Spectral analysis was performed with the coarse graining spectral analysis (CGSA) method (Yamamoto & Hughson, 1991) to quantify the total harmonic power of HRV (TP) and the power of spectral components in the low (LF: 0·04–0·15 Hz) and high frequencies (HF: 0·15–0·50 Hz). The very low frequencies (0–0·04 Hz) were not addressed in the present study. HF power is almost entirely mediated by the parasympathetic activity to the sinus node directly associated with respiratory activity (Pomeranz *et al.*, 1985), whereas LF power reflects the mixed modulation of parasympathetic and sympathetic activities (Bernardi *et al.*, 1994). Changes in the ratio LF/HF were taken as an indication of changes in sympathetic activity (Yamamoto & Hughson, 1991), although the ratio may be an index of sympathovagal balance (Pagani *et al.*, 1986). Parasympathetic and sympathetic nervous system activity were also evaluated by HF/TP and LF/TP ratios, respectively (Yamamoto *et al.*, 1991; Nakamura *et al.*, 1993; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

Poincaré plot analysis of HRV

The Poincaré plot is a diagram (scatter gram) in which each R-R interval of a tachogram is plotted as a function of the previous one. The Poincaré plot gives useful visual contact to the R-R data by representing qualitatively with graphical mean the kind of R-R variations included in the recording. A quantitative analysis of the Poincaré plots was performed and the following parameters were calculated from each individual scatter gram as described by Tulppo *et al.* (1996): standard deviation of the instantaneous beat-to-beat variability data (SD1), and standard deviation of the continuous long-term variability (SD2). SD1 and SD2 were calculated as absolute values and in normalized units (SD1n and SD2n, respectively), obtained by dividing the absolute value by the average R-R interval and then by multiplying by 1000. The instantaneous beat-to-beat variability of R-R intervals (SD1) reflects parasympathetic efferent activity on the sinus node (Tulppo *et al.*, 1996, 1998). The physiological meaning of SD2 is less well defined, although, at least in part, it is thought to reflect the continuous long-term variability of the R-R intervals (Tulppo *et al.*, 1996). SD2 is altered by atropine (Tulppo *et al.*, 1996) and moxonidine (De Vito *et al.*, 2002) and thus reflected both the parasympathetic and sympathetic modulations to the sinus node.

Statistical methods

Standard statistical methods were used for the calculation of mean and standard deviation. Normal Gaussian distribution of the data was verified by the Kolmogorov–Smirnov test. The data distribution for all measures was markedly skewed; for this reason the natural logarithm was used in order to deskew the distributions. The new data were used for posterior statistical analysis. Position and group effects on HRV measures were estimated by a two-way repeated measures ANOVA. Paired tests within groups were made using a paired t-test. When testing for differences in HRV response between groups, the Bonferroni correction was used. A P-value <0·05 was considered significant. Statistical analyses were performed using SigmaStat® software (SPSS Inc., Chicago, IL, USA).

Results

HRV profiles

During supine

The HRV analysis values for the three groups are presented in Tables 2–4. Statistical tests showed that R-R interval, SDNN, rMSSD, pNN50, TP, HF, SD1 and SD1n were significantly higher in T than in OA and C. HF/TP was higher in C than in T and OA

Table 2 HRV analysis indexes in control (C) and trained (T) subjects and in athletes diagnosed as suffering from the overtraining syndrome (OA) during supine rest.

Supine	C	T	OA
R-R interval (ms)	878·5 ± 105·1	1034·9 ± 81·2[a]	920·4 ± 125·8[b]
SDNN	44·4 ± 15·3	104·7 ± 30·9[a]	65·3 ± 37·7[b]
rMSSD	38·7 ± 17·2	122·4 ± 35·0[a]	54·6 ± 41·5[b]
pNN50	16·3 ± 18·3	64·6 ± 10·4[a]	27·0 ± 29·0
TP (ms^2)	1158 ± 1137	6092 ± 3554[a]	2970 ± 2947[b]
LF (ms^2)	170·3 ± 202·5	511·0 ± 602·6	1153·5 ± 1487·1
HF (ms^2)	419·1 ± 381·2	1105·3 ± 781·4[a]	463·7 ± 715·8[b]
HF/TP	0·40 ± 0·15	0·20 ± 0·12[a]	0·14 ± 0·12[a]
LF/TP	0·16 ± 0·10	0·07 ± 0·05[a]	0·25 ± 0·17[b]
LF/HF	0·47 ± 0·35	0·47 ± 0·50	3·96 ± 5·71[ab]
SD1	29·5 ± 18·5	75·2 ± 17·2[a]	37·6 ± 27·5[b]
SD2	60·8 ± 26·7	113·5 ± 33·3[a]	82·4 ± 47·7
SD1n	32·1 ± 15·0	73·6 ± 19·5[a]	40·6 ± 27·0[b]
SD2n	68·0 ± 22·0	109·8 ± 29·7[a]	92·0 ± 53·4

Values are presented as mean ± SD. R-R interval, time between two successive peak R waves; SDNN, standard deviation of the R-R intervals; rMSSD, root mean square of successive differences; pNN50, percentage of difference between adjacent R-R intervals that are >50 ms; TP, total frequency power of heart rate variability; LF, low frequency power of heart rate variability; HF, high frequency power of heart rate variability; SD1, standard deviation of instantaneous beat-to-beat interval variability; SD2, standard deviation of continuous beat-to-beat interval variability; n, normalized unit; $P<0{\cdot}05$.
[a]Significantly different from C.
[b]Significantly different from T.

Table 3 HRV analysis indexes in control (C) and trained (T) subjects and in athletes diagnosed as suffering from the overtraining syndrome (OA) during the 60° upright position.

60° upright position	C	T	OA
R-R interval (ms)	720·5 ± 124·7[a]	754·9 ± 69·8[a]	691·6 ± 111·5[a]
SDNN	41·3 ± 16·8	66·3 ± 16·1[ab]	53·3 ± 21·2
rMSSD	25·0 ± 6·1[a]	36·2 ± 13·7[ab]	27·7 ± 11·8
pNN50	2·7 ± 2·5[a]	10·9 ± 9·5[ab]	8·7 ± 6·8[b]
TP (ms^2)	640 ± 499	1814·0 ± 805·7[ab]	1092·4 ± 712·0
LF (ms^2)	236·1 ± 423·6	687·4 ± 427·0[b]	353·0 ± 252·2
HF (ms^2)	274·7 ± 554·2[a]	115·1 ± 121·1[a]	47. 8 ± 41·9
HF/TP	0·19 ± 0·14[a]	0·06 ± 0·06[a]	0·04 ± 0·02[ab]
LF/TP	0·21 ± 0·10	0·36 ± 0·11[ab]	0·38 ± 0·20[b]
LF/HF	2·1 ± 2·2[a]	7·2 ± 6·8[ab]	12·0 ± 10·4[ab]
SD1	15·0 ± 4·2[a]	24·6 ± 8·1[ab]	19·2 ± 7·8
SD2	49·9 ± 11·0	89·5 ± 20·7[ab]	73·2 ± 29·4
SD1n	21·3 ± 5·7[a]	32·5 ± 10·2[ab]	27·0 ± 9·7
SD2n	71·3 ± 16·8	119·3 ± 29·4[b]	104·4 ± 40·0

Values are presented as mean ± SD. R-R interval, time between two successive peak R waves; SDNN, standard deviation of the R-R intervals; rMSSD, root mean square of successive differences; pNN50, percentage of difference between adjacent R-R intervals that are >50 ms. TP, total frequency power of heart rate variability; LF, low frequency power of heart rate variability; HF, high frequency power of heart rate variability; SD1, standard deviation of instantaneous beat-to-beat interval variability; SD2, standard deviation of continuous beat-to-beat interval variability; n, normalized unit; $P<0{\cdot}05$.
[a]Significantly different from supine.
[b]Significantly different from C.

($P<0{\cdot}05$). Moreover, T exhibited the lowest LF/TP values ($P<0{\cdot}05$) and the highest SD2 and SD2n values ($P<0{\cdot}05$) whereas LF/HF was higher in OA than C and T ($P<0{\cdot}05$).

Tilt test

In the three groups, the 60° upright position significantly decreased the length of mean R-R interval. An important decrease in SDNN and TP was observed during standing in T ($P<0{\cdot}05$) compared with OA (NS) and C (NS). rMSSD, pNN50, HF, SD1 and SD1n decreased significantly ($P<0{\cdot}05$) during 60° upright position in C and T but not in OA. LF increased in C and T but decreased in OA (NS). HF/TP decreased significantly in the three groups whereas LF/TP increased significantly only in T. LF/HF increased significantly ($P<0{\cdot}05$) in the three groups. Thus, in the 60° upright position, a decrease in HRV and parasympathetic activity was observed with the three methods of HRV analysis. The decrease was more important in T than in C and OA subjects, as indicated by the relative changes (Table 4). Nevertheless, T exhibited higher SDNN, TP, LF, SD1, SD1n, SD2 and SD2n than the other two groups in the 60° upright position (Table 3).

Poincaré plot analysis

Tachograms, power spectrums and Poincaré scatter grams during supine (Fig. 1) and 60° upright position (Fig. 2) in one representative subject of C and T groups are presented together with profiles of two OA subjects. OA2 was considered as severely overtrained compared with the other OA athletes. The scales on *x*- and *y*-axis are preserved. During supine rest, T presented an increased scatter compared with the other subjects. The scatter gram of OA1 was similar to that of C whereas OA2 had a very narrow shape. Finally, during standing, scatter grams were similar regardless of the trained status.

Discussion

The first objective of this study was to characterize the HRV profiles of athletes in OT state, compared with healthy sedentary and trained subjects. Our results showed that during supine rest and 60° upright positions, HRV of OA was similar to that of C with a predominance of sympathetic activity whereas T had a higher HRV with a marked predominance of parasympathetic activity. Moreover, the orthostatic changes in indexes of HRV to the tilt test appeared blunted in OA, compared with T. Secondly, these results were observed not only with time- and frequency-domain analysis of HRV but also with the non-linear Poincaré plot analysis.

The reported symptoms of physical inability in view of the training history support the diagnosis of an OT syndrome in

Table 4 Posture-induced relative changes in HRV analysis indexes in control (C) and trained (T) subjects and in athletes diagnosed as suffering from the overtraining syndrome (OA).

Changes (%) from supine to 60° upright position	C	T	OA
R-R interval (ms)	−17·8 ± 10·6	−26·9 ± 6·7	−25·1 ± 10·6
SDNN	−1·3 ± 38·8	−32·7 ± 22·6	−18·5 ± 29·3
rMSSD	−23·5 ± 38·5	−68·6 ± 13·0[a]	−49·4 ± 24·8
pNN50	21·7 ± 259·7	−83·0 ± 14·4	−67·9 ± 19·0
TP (ms^2)	−22·0 ± 67·7	−64·7 ± 19·2	−63·6 ± 16.4
LF (ms^2)	182·5 ± 466·2	312·0 ± 559·5	−70·5 ± 26.3[b]
HF (ms^2)	−40·2 ± 65·3	−91·0 ± 9·4	−92·3 ± 6·5
HF/TP	−54·2 ± 28·8	−71·7 ± 26·1	−68·5 ± 47·8
LF/TP	169·8 ± 341·4	893·6 ± 901·0	53·7 ± 85·9[b]
LF/HF	679·8 ± 976·9	2208·7 ± 3492·6[a]	204·2 ± 101.2[b]
SD1	−35·7 ± 33·0	−65·6 ± 13·0	−49·8 ± 22·0
SD2	−5·1 ± 43·2	−17·3 ± 23·6	−11·0 ± 30·7
SD1n	−22·7 ± 38·6	−52·9 ± 17·6	−33·5 ± 24·0
SD2n	16·8 ± 54·1	14·3 ± 35·5	−13·3 ± 34·4

Values are presented as mean ± SD. R-R interval, time between two successive peak R waves; SDNN, standard deviation of the R-R intervals; rMSSD, root mean square of successive differences; pNN50, percentage of difference between adjacent R-R intervals that are >50 ms; TP, total frequency power of heart rate variability; LF, low frequency power of heart rate variability; HF, high frequency power of heart rate variability; SD1, standard deviation of instantaneous beat-to-beat interval variability; SD2, standard deviation of continuous beat-to-beat interval variability; n, normalized unit; $P<0{\cdot}05$.
[a]Significantly different from C.
[b]Significantly different from T.

these athletes (Kuipers & Keizer, 1988; Lehmann et al., 1992a). In the search for responsible mechanisms of OT-related symptoms, one area of interest has been changes in autonomic function. Altered catecholamine release (reduced adrenaline, less reduced noradrenaline and dopamine excretion) has been shown in overtrained athletes indicating an adaptation of the sympathetic nervous system (Lehmann et al., 1992b,c). A reduced intrinsic sympathetic activity (Lehmann et al., 1992b,c) or an increase in parasympathetic relative to sympathetic activity has also been reported (Israel, 1976; Hedelin et al., 2000a), although short-term OT does not alter HRV (Hedelin et al., 2000b).

Studies based on pharmacological and non-pharmacological methods (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996) have demonstrated that spectral indices such as HF or HF/TP and temporal ones such as pNN50 and rMSSD are only parasympathetically mediated. Based on the results of the present study (Tables 2 and 3), T subjects had clearly higher parasympathetic modulation during supine rest compared with C subjects. Note that T also exhibited the greater mean R-R interval, which indicated a sympathovagal balance shift to parasympathetic predominance (Goldberger, 1999). Moreover, LF/TP values were lower in T compared with C, also suggesting a lower sympathetic modulation (Ekblom et al., 1973). Our results are consistent with the literature since an increased resting HRV and parasympathetic tone have been found in highly trained compared with sedentary subjects (Dixon et al., 1992; Goldsmith et al., 1992; De Meersman, 1993; Janssen et al., 1993; Macor et al., 1996; Verlinde et al., 2001) and in previously sedentary people after endurance training (Seals & Chase, 1989; Shi et al., 1995; al-Ani et al., 1996; Melanson & Freedson, 2001; Yamamoto et al., 2001).

Contrary to T, OA had lower values of HRV and parasympathetic indicators suggesting that training effects on HRV were blunted. Their HRV profile was comparable with that of C. Moreover, indicators of sympathetic activity (LF, LF/TP) were all higher in OA than in T. It suggests a shift towards a sympathetic predominance in the supine position during heavy training (Iellamo et al., 2002) or OT (Uusitalo et al., 2000) and underlines the increased LF/HF ratio in OA.

The same general pattern of adaptation to upright position was observed in the three groups. The standing position was accompanied by a decrease in parasympathetic indicators (i.e. rMSSD, pNN50, TP, HF, HF/TP) that occurred together with increased sympathetic indicators (LF/TP, LF/HF), indicating a shift in sympathovagal balance towards sympathetic predominance (Bahjaoui-Bouhaddi et al., 2000). However, the magnitude of these changes was higher in T suggesting a higher reactivity of the cardiovascular regulatory system to postural changes. Nevertheless, during standing, T always had higher HRV than C and OA. A lower HRV during standing in the OT state has been observed after 6–9 weeks of intensive training (Uusitalo et al., 2000; Portier et al., 2001). Altogether, our results demonstrated that in the OT state, HRV was lower during supine rest and also during 60° upright positions and that the response to tilt test is blunted.

Together with changes in HRV due to acute manoeuvres (Carrasco et al., 2001), Poincaré plot could discriminate altered HRV due to physical fitness (Tulppo et al., 1998), endurance training (Mourot et al., 2003) or acute fatigue following prolonged strenuous exercise (Hautala et al., 2001). The results of the present study demonstrate that cardiovascular autonomic changes induced by OT could also be recognized with this method. An association between sympathetic activity and the shape of the Poincaré plot has been established, where the narrower the pattern observed, the larger the sympathetic activity occurred (Woo et al., 1994; Carrasco et al., 2001; Mourot et al., 2003). The visual pattern found in the present study agrees with that association (Figs 1 and 2). In the supine position and the training state, when the parasympathetic activity was predominant, Poincaré scatter gram had an elliptic form. In standing position and in the OT state, as the parasympathetic activity decreased and sympathetic activity increased, Poincaré scatter gram became narrower. An OT athlete (AO2 in Figs 1 and 2) was diagnosed as severely overtrained and it could be observed that together with a very low HRV, the Poincaré scatter gram was very narrow. Because the Poincaré scatter gram gives visually distinguishable patterns for each manoeuvre and is able to differentiate training status,

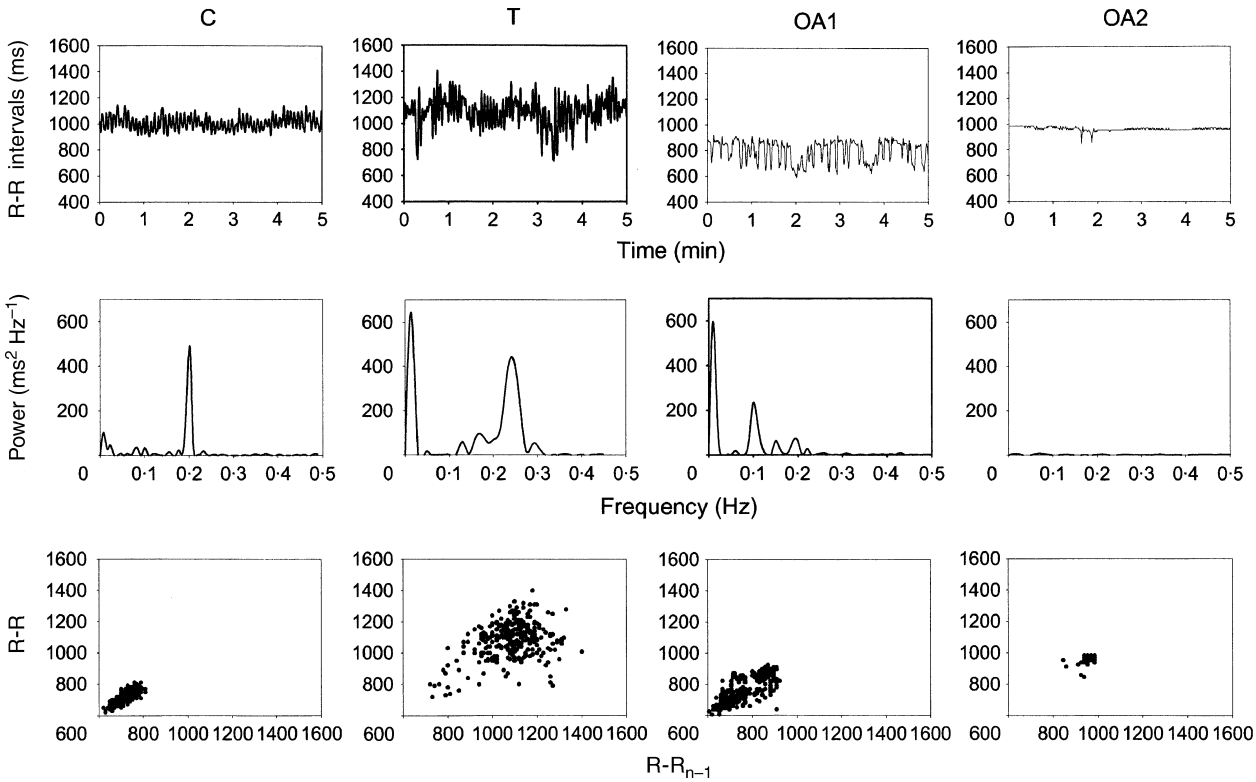

Figure 1 Tachograms, power spectrums and Poincaré scattergrams during supine rest in one representative control (C) and trained (T) subjects presented together with profiles of two subjects suffering from the overtraining syndrome (OA). OA2 was considered as severely overtrained compared with the other OA athletes.

it may be considered as a useful tool to describe the autonomic activity effect over the R-R interval dynamics. Moreover, changes in SD1 and SD1n paralleled changes observed in rMSSD, pNN50, TP, HF, HF/TP. All these indicators reflects parasympathetic activity (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996; Tulppo *et al.*, 1996). Thus, SD1 and SD1n could be considered as surrogates of traditional time- and frequency-domain indicators of parasympathetic activity.

Limitations

The distinction between overreaching and overtraining (also called short-term and long-term overtraining, respectively; Kuipers, 1998) has not been clearly established. Based on the criteria of the present study, and mainly on the prolonged decrease in athletes' performance, the subjects were reported as suffering from the OT syndrome. The shift in the autonomic balance towards sympathetic predominance as observed in the present study is not always associated with a decrease in performance. Indeed, Iellamo *et al.* (2002) followed the Italian junior national team of rowing during the year preceding the Rowing World Championship. The authors observed that the progressive increase in the training load 6 months after the beginning of the study led to an increase in HRV and a shift towards parasympathetic predominance. However, the final increase in training load leads to a decrease in HRV and a shift towards sympathetic predominance. This latest shift occurred 20 days before the start of the World Championship where three of the seven athletes won a medal. In this case, an intentional increase in the training load, planned in the training program, seems associated with a shift towards sympathetic activity without a decreased performance.

It is of importance to note that in women, the menstrual cycle can be a confounding factor as parasympathetic and sympathetic nervous activities are higher in the follicular and luteal phases, respectively (Sato *et al.*, 1995; Saeki *et al.*, 1997). This specific alteration was not controlled in the present study. However, the effect of menstrual cycle could be considered as minimal because women were included in each group (half in C, half in T, and five over seven in OA) and it is doubtful that in one group all the women were at the same time of their cycle. Female endurance athletes can experience amenorrhoea or disturbance in the menstrual cycle profile (Keizer & Rogol, 1990), which could alter HRV analysis. However, the women of the present study had no menstrual irregularities.

Conclusion/perspective

Overtraining is a long-term form of overloading with prolonged imbalance between training load and recovery

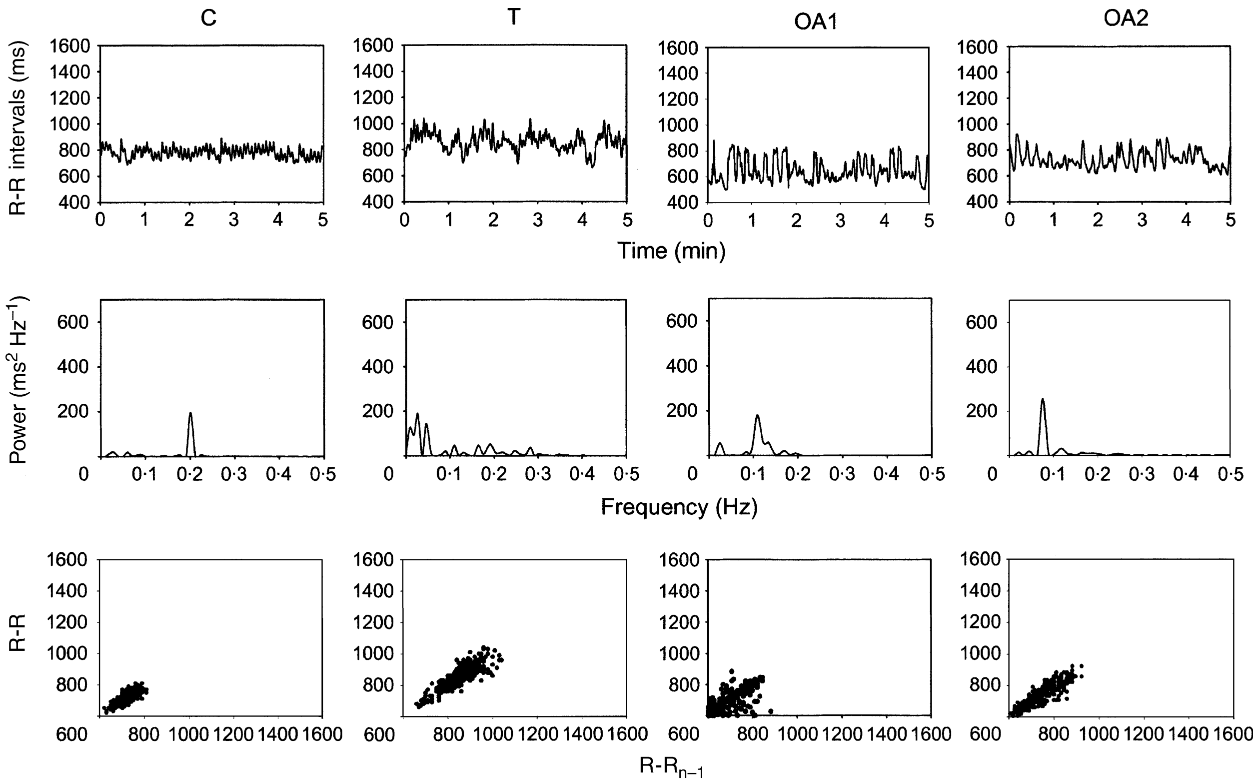

Figure 2 Tachograms, power spectrums and Poincaré scattergrams during 60° upright position in one representative control (C) and trained (T) subjects presented together with profiles of two subjects suffering from the overtraining syndrome (OA). OA2 was considered as severely overtrained compared with the other OA athletes.

(Lehmann *et al.*, 1993). Symptoms varied from one person to another and the diagnosis is primarily based on medicine history and typical physical and psychological symptoms (Kuipers & Keizer, 1988). Systemic OT usually requires one to several weeks or months for recovery and to date specific drugs or treatments to bring down OT are still unknown. Therefore, special attention must be paid to the prevention or early detection of OT. However, no specific, sensitive and simple diagnostic test is available and only reviewing monitored physical characteristics may be helpful to complete diagnosis (Kuipers & Keizer, 1988). However, most often medical tests are invasive (i.e. need blood samples) and are therefore hesitantly performed by the athletes. Moreover, technical and ethical aspects hampered the routine performance of these tests. The present results demonstrate that differences in HRV profile could be highlighted from non-invasive short-term tilt test (10 min in both supine and 60° upright position positions were used). Endurance training leads to an enhanced HRV with a marked parasympathetic predominance contrary to athletes diagnosed as overtrained, which has a marked predominance of sympathetic modulation. Moreover, responsiveness to standing position was higher in T than in OA. These profiles were observed with both linear and non-linear methods and suggest that both could be used. However, spectral analysis of HRV required specific software and standardized conditions (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). The major drawback is that a stationary signal is required and the HRV signal cannot be properly assessed using linear techniques (Braun *et al.*, 1998), especially during short-term recording. Poincaré plot method is a non-linear technique and the single shape of the plot can be used to classify the signal into various classes of disease (Schechtman *et al.*, 1993; Woo *et al.*, 1994) or to indicate fatigue after prolonged exercise (Hautala *et al.*, 2001). The results of the present study indicate that the scatter gram could also be used to distinguish between T and OA. There is, however, no doubt that generalization of our current interpretation requires further expansion of the present results.

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