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Heart rate variability during pre-competition and competition periods in volleyball players

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Summary

Study aim: Regular exercise training is thought to modify cardiac autonomic control. One of the body's responses to training stimuli is heart rate variability (HRV). The use of HRV in the management of sport training is a common practice. The objective of the present study was to assess the impact of the physical activity level on HRV of 1st league national volleyball players prior to and during the competition period.
Materials and methods: The study involved 11 players whose HRV was evaluated during the two analysed training periods. Selected indicators of spectral analysis (total power, %VLF, % LF, % HF powers, LF n.u, HF n.u, and LF/HF powers) as well as time analysis (HR, RR, RMSSD, NN50) were assessed on the basis of recordings.
Results: The studies conducted in the pre-competition and competition periods showed significant differences in the parameters of spectral VLF% analysis and time NN50 analysis. In the competition period, a significant increase in VLF [%] may be the result of increased psycho-physical arousal, when compared to the pre-competition period.
Conclusions: Resting bradycardia, assessed on the basis of time analysis indicators, may be the result of internal changes in the sinus node, which reflects the impact of long-term training on the cardiac conduction system. A high level of physical activity of volleyball players in the tested periods could have contributed to a reduction in vagal tone and a shift in the balance of the autonomic nervous system in the direction of the sympathetic system, which may be the result of overtraining.

Keywords: Autonomic nervous activity – Team sport – Training

Introduction

Heart Rate Variability (HRV) is a physiological phenomenon which is a measure of beat-to-beat changes in duration of electrocardiographic interpulse (R-R) intervals in the electrocardiogram [31, 50, 56]. Many psycho-physiological models consider HRV as a source of non-invasive information about the balance between sympathetic and parasympathetic/vagal influences on the heart rate (HR) at rest or during exercise [56], and/or an individual's autonomic flexibility and the ability to engage in regulated emotional responding [2, 31, 47, 56]. Being strongly associated with physical activity [11, 37], HR and HRV measurements are often used for assimilation of training loads, prognosis of income, and the design of training loads from certain parameters in assessing sports [13, 45]. Furthermore, HRV is being investigated as a diagnostic marker of overreaching and overtraining [25]. In connection with HRV and its sympatho-vagal modulation, it is expected that the duration of exercise and/or the type of training play a key role in the value of HRV indices [43]. Sports training triggers perpetual physiological changes, giving an overview of the adaptation to exercise [6, 23]. Such adaptation is not always uniform, especially in sports training, depending on the nature of the exercise. Vesterinen et al. [54] state that a higher HRV may reflect a great ability to adapt to harder training. HRV is currently used for non-invasive assessment of autonomic changes associated mainly with short-term and long-term endurance exercise training [25]. It has already been observed that after an aerobic training period subjects showed higher levels of vagally mediated cardiac control as indexed by HRV [22]. An elevated level of parasympathetic tone in endurance athletes was shown in comparison to sedentary people [21, 28]. The study conducted by Berkoff et al. [5] revealed interesting outcomes showing no differences between aerobically and power-based athletes in terms of HRV data. The effect of dynamic high-performance resistance training on autonomic tone is less clear.

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Numerous publications have also shown that the resting heart rate is lower in people who participate in sport than in physically inactive individuals [46, 20]. It is commonly believed that resting bradycardia occurring in athletes is caused by increased vagal tone. Such an observation, as presented by a number of studies, may stem from the fact that heavy (but not extreme) multi-month physical training of athletes preparing for competition leads to more active parasympathetic dominance of their autonomic nervous system (ANS) [12, 24, 26]. The practice of a high-level sport in competition requires a perfect balance between the time of rest, training, and competition, as well as good management of various constraints [36]. Therefore, the analysis of HRV during different competition periods seems to be one of the special issues in the course of a training process.

When examining HRV in subjects who practice different sports or perform different types of exercise, one can conclude that indicators of spectral and time analyses vary for these types of workloads [3]. Therefore, it is assumed that HRV is a result of the influence of various factors. These include voltage oscillation in the ANS, the function of the limbic system and the cerebral cortex (especially the effects of emotional stimuli), the mechanical influences of respiratory movements, circulating hormone levels, the volatility of sensitivity to stimulation of arterial baro – and chemoreceptors, and the stretching of the walls of the heart with blood flowing during diastole, including changes in blood pressure caused by physical labour, emotional states, etc. [38]. Most researchers dealing with the topic of HRV assume that apart from physical activity, breathing movements and emotional arousal also have a great influence on the ANS [15, 38, 29]. Over the past 10 years, over 2,000 articles concerning HRV have been published, showing that changes in heart function can be tested with the use of various techniques [1, 4, 53]. It appears that HRV measurement is one of the simplest tests which can be applicable to both children and adults [16].

The objective of the present study was to assess the impact of athletic performance on HRV in 11 volleyball players at a high-performance level in pre-competition and competition periods.

Materials and methods

Ethics

The study was conducted in accordance with the Helsinki Charter of Human Rights and was approved by the Ethics Committee of the State Higher Vocational School in Raciborz. Each subject expressed their willingness to voluntarily participate in the study, which was confirmed by written consent. The subjects were allowed to withdraw from the study at any stage.

Participants

The tests were conducted with a group of 11 male volleyball players between the ages of 20 and 23 (21.4 ± 1.14) as participants, who were members of a 1st league volleyball club. The study subjects' training experience averaged 7.2 years. Detailed anthropometric characteristics of the study sample are summarised in Table 1. It is also worth noting that the analysed pre-competition (Pre-C) and competition (C) periods constituted the first year of training after the selected group of volleyball players advanced to the 1st league. This means that they had had no previous experience in playing at this level of competition. Three subjects were excluded from the data analysis (3 drop-outs): two subjects due to poor attendance rate (<80% of training units) and 1 due to technical problems with R-R interval collection. At the completion of the competition season, the analysed team took 5th place in the 1st national league and 3rd in the AZS Polish Academic Championships. The sampling was designed in such a way that all the players involved in the Pre-C period constituted the primary core of the team participating in all the league and academic matches during the C period.

Training characteristics

The results of 8 players, participating in the Pre-C (September 2011) and C periods (March 2012), were used for statistical analysis of HRV measurements. Maximum heart rate (HR_{max}) was calculated for all the players according to the following formula: 208 – 0.7 × age [49]. The Pre-C period lasted for 4 weeks: the first phase of the Pre-C period involved training of moderate intensity at 52–65% HR_{max} (HR 100–125 beats · min^{-1}), whereas the second part of the period consisted of high-intensity workouts at 65–78% HR_{max} (HR 125–150 beats·min^{-1}) [52]. During that period the trainings were held twice a day, 6 times a week. Morning training lasted for 2.5 h and the evening one was 2 h long. The C period lasted for a total of 6 months. The trainings during that period were held once a day 5 times a week. In that period, the trainings were characterized by a shorter duration (2 h), but increased intensity. The intensity of training, measured at the selected training units by means of HR (twice per week at Pre-C and C periods), ranged between 83–93% (HR 160–180 beats·min^{-1}). HR was monitored using polar heart rate monitors (Polar S-610; Polar Electro, Kempele, Finland) and supervised by the investigators. Fragments of actual matches were practiced in the main part of the training (Tuesdays and Wednesdays). Tactical training was carried out on Thursdays and Fridays. Matches were played on Saturdays, whereas Sundays were reserved for regeneration training followed by resistance training on Mondays. In the C period, the players played a total of 21 matches, competing on a weekly basis (with a break during the Christmas period).

Procedures

Body height with an accuracy of 0.1 mm and body mass (with accuracy up to 0.1 kg) were measured with calibrated medical scales with a stadiometer – WB-150 (ZPU Tryb-Wag, Poland). HRV recordings were carried out on each of the tested athletes at their homes with use of a Polar S 810 Sport – Tester. The tests were conducted twice: at the end of Pre-C period (7 days before C period commenced) and at the end of C period (1 month prior to the beginning of the transitional period), each test carried out in the morning hours (8:00–10:00). The following criteria for elimination from the studies were established: musculoskeletal problems leading to the exclusion of a player from at least 20% of the training units, smoking, and the use of drugs or substances that inhibit the functions of the ANS. The subjects were instructed to avoid physical activity and maintain their current food intake, excluding alcohol and caffeine, for 24 hours before testing. On the test day, the subjects were on empty stomachs and the HRV measurements were taken in the supine position. The subjects had their eyes closed for the purpose of isolating their sensual perception. The recordings of HR frequency lasted for 15 minutes. The subjects stayed in standard study conditions (temperature 20–22^{o}C; humidity 45% – thermo neutral conditions), in accordance with the basic procedures of sports metrology.

HRV data were analysed according to the published methodology [8]. HR frequency recordings were transferred to a computer and processed with the use of Polar Precision Performance 3. This programme is compatible with HRV Analysis Software (designed by the Department of Applied Physics, University of Kuopio in Finland). With the use of HRV Analysis Software, 60–720 sec. arrangements were selected out of 15-minute recordings, which were subsequently used in further analysis. When connecting the equipment, players are often very excited and sometimes during the recording breaks occur. Therefore, in order to analyse the best record there were selected sections reduced by 60 seconds at the beginning and 120 seconds of disturbed recording. The results were analysed with the use of spectral and time analysis. Power Spectrum Density (PSD), which is a nonparametric method, was applied to measure HRV in the spectral method.

The range of frequency was measured with the use of a traditional and basic method of Fast Fourier Transformation (FFT) [7, 18]. The following frequency ranges were calculated in HRV analysis: Very Low Frequency (VLF – in the range of 0.0033 Hz to 0.05 Hz), LF (Low Frequency – in the range of 0.05 Hz to 0.15 Hz), and HF (High Frequency – in the range of 0.15 Hz to 0.4 Hz) [48, 51].

After processing, the following indicators were chosen for further analysis out of all of the recorded parameters: total power (TP) [ms^2], VLF [%], LF [%], HF [%], LF – normalised units [n.u], HF – normalised units [n.u], and LF/HF ratio. In the case of time analysis, the following were calculated: HR mean (frequency of heart rates, R-R (ms): mean time of R-R intervals between sinus stimuli, RMSSD [ms] – square root of the mean of the sum of the squares of differences between successive R-R intervals), and NN50 – the number of R-R intervals differing from the preceding one by more than 50 milliseconds.

Statistical analysis

The results of HRV analysis were presented in tables and standard statistical calculations were done according to a descriptive statistics module: arithmetic mean, standard deviation, minimal and maximal values, and statistical significance between the groups. Due to the small population of the group (8 subjects) and the existence of some parameters with skewed distribution, a nonparametric U Mann-Whitney test was used to calculate statistically important differences between the groups. The statistical significance level was set as $p < 0.05$. Calculations were done with the use of the Statistica PL v.10 program.

Results

Table 1 presents the somatic characteristics of the tested volleyball players in the Pre-C and C periods.

Table 1. Somatic characteristics of tested volleyball players (n = 8) in the pre-competition (Pre-C) and competition (C) periods.

Parameters	Pre-C period	C period	Statistical significance level p < 0.05
	Mean ± stand dev. (min–max)		
Age [yrs]	21.4 ± 1.14 (20–23)	22 ± 1.14 (20.6–23.6)	0.0431
Training experience [yrs]	7.2 ± 2.28 (5–11)	7.8 ± 2.28 (5.6–11.6)	0.0431
Body mass [kg]	86.35 ± 7.57 (76.9–97.2)	88.5 ± 6.52 (81–100)	0.2076
Body height [cm]	194.6 ± 4.96 (190–201)	194.5 ± 4.92 (190–201)	0.1614
BMI [kg/m^2]	22.80 ± 1.9 (20.6–25.8)	23.37 ± 1.02 (22.2–24.8)	0.2076
Rohrer index [g/cm^3]	1.17 ± 0.11 (1.03–1.36)	1.20 ± 0.06 (1.12–1.30)	0.1614

Based on the results contained in Table 1, statistically significant differences were observed between the Pre-C and C periods in parameters such as age and training experience. The age of the subjects indicated that they were fully biologically mature individuals while training experience signified a high athletic level. Therefore, the impact of the above-mentioned factors on the results was recognised as negligible. No significant changes in the body mass of the subjects, and thus their BMI, were observed. BMI values of the volleyball players indicated that the study subjects fell within the normal range. The Rohrer index in both periods indicated a mesomorphic body build of the volleyball players, which underwent no significant changes either (Table 1).

There were no significant differences between the Pre-C and C periods in most of the parameters of spectral analysis. These included: total power [ms^2], LF [%], HF [%], LF [nu], HF [nu], and LF/HF ratio. The only differences that were found to be significant between the two analysed periods were those in the VLF [%] parameter (an increase in value). A similar phenomenon, which is the lack of significant differences between the analysed periods, was observed in the case of most time analysis parameters, i.e., the R-R [ms], HR [1/min], and RMSSD [ms]. Only the change in the NN50 parameter was statistically significant (a decrease in value) (Table 2).

Discussion

Our study confirmed the significant impact of physical activity on the voltage of the sympathetic and parasympathetic branch of the ANS in the case of two parameters. On the basis of spectral analysis, a significant increase in the VLF value was found in the C period in relation to the Pre-C period. According to classical studies the VLF component reflects the activity of the parasympathetic nervous system and the endocrine system [3, 51]. In comparison to the Pre-C period, it was observed that during the C period there was a slight, not significant increase in sympathetic activity in the tested group of volleyball players expressed in LF n.u., which could be associated with the increase in VLF rate. The significant VLF [%] increase observed in the subjects during the C period can also be the result of high emotional arousal, resulting from the increased mental and physical burden of playing the matches. League volleyball matches (the C period) require a stronger psycho-physical mobilisation of the players than scrimmages (the Pre-C period). A growing number of empirical studies support the assumption that resting HRV is related to self-regulatory strength and emotion regulation [14, 17, 19]. On the basis of time analysis, a significant decline in the value of the NN50 index during the C period was observed, which may signify a decrease in vagal tone as the NN50 marker reflects the tension of the parasympathetic ANS [50].

There were no significant changes in the values of the remaining analysed parameters, although some of them provide interesting information. A slight upward trend in total power from the Pre-C to the C period indicates no significant differences between the two periods in terms of effort. On the whole, the values of total power generated in both periods were low. Consistently low values of total power can be an indicator of the players suffering from chronic fatigue [44]. This opinion is confirmed by Mourot et al. [42], who tested athletes displaying symptoms of overtraining.

Table 2. Selected parameters of spectral and time analysis of a group of volleyball players (n=8) in the pre-competition (Pre-C) and competition (C) periods

Parameters	Pre-C period	C period	Statistical significance level $p < 0.05$
	Mean ± stand. dev. (min–max)		
Total Power [ms^2]	1994.7 ± 1652.24 (548–5316)	2141.0 ± 2126.34 (856–7253)	0.7794
VLF [%]	18.7 ± 7.91 (12.0–33.2)	37.1 ± 18.86 (4.5–69.0)	**0.0499**
LF [%]	46.8 ± 17.89 (19.9–67.5)	38.2 ± 11.34 (23.0–60.1)	0.1235
HF [%]	34.5 ± 18.65 (12.6–67.2)	24.7 ± 20.17 (8.0–66.6)	0.0687
LF [n.u.]	57.9 ± 22.07 (23.1–81.1)	64.2 ± 18.70 (30.2–83.3)	0.2076
HF [n.u.]	42.1 ± 22.07 (18.9–76.9)	35.8 ± 18.70 (16.7–69.8)	0.2076
LF/HF ratio	1.96 ± 1.40 (0.30–4.29)	2.4 ± 1.56 (043–4.98)	0.2626
R-R [ms]	1027.6 ± 168.92 (807–1305)	944.5 ± 103.20 (753–1076)	0.2076
HR [1/min]	60.2 ± 9.66 (47–75)	64.9 ± 7.60 (56–80)	0.2626
RMSSD [ms]	70.6 ± 532.95 (18–18)	61.8 ± 51.73 (30–187)	0.2626
NN50	289.4 ± 160.32 (107–588)	223.4 ± 160.15 (87–560)	**0.0499**

Significant differences ($p < 0.05$) have been marked in bold

In a developed state of overtraining, the return to proper body function may take up to a year [24]. This condition is related to imbalance of the ANS that controls the endocrine system. Recently, a new joint consensus statement of the European College of Sport Science (ECSS) and the American College of Sports Medicine (ACSM) on the Overtraining Syndrome (OTS) was reported [41], in which the authors state that a keyword in the recognition of OTS might be 'prolonged maladaptation' not only of the athlete, but also of several biological, neurochemical, and hormonal regulation mechanisms. In a series of earlier works [24, 32, 33, 42] it was found that the main factor responsible for the development of the state of overtraining is 'exhaustion' of the cortex and adrenal medulla that secrete hormones such as adrenaline, noradrenaline, and cortisol. There are two main forms of overtraining: Basedow type and Addison type. The former develops earlier, the latter occurs in sequence of the former. We believe that in the case of our study it is the Basedow type of overtraining that developed, due to remarkable psychophysical stimulation and accelerated HR at rest observed in the tested volleyball players. Such basic symptoms of overtraining are common in young, inexperienced, or untrained individuals practicing strength and high-speed sports. A short-term (1.5 month of C-period) performance decrement was observed in volleyball players who played much below expectations (1 win out of 6 matches). This observation was supported with test results obtained through laboratory investigation (not published data). Although the players analysed in our study had been playing volleyball competitively for a relatively long time, they had previously played in lower leagues, thus the analysed season was the first to be played at 1st league level.

Buchheit et al. [10] as well as Mourot et al. [42] maintain that the shift in the direction of sympathetic dominance may be one of the indicators of overtraining in endurance sports. When training is optimal, the balance in the ANS should be shifted towards its parasympathetic counterpart. Low values of the LF/HF index indicate such dominance. One should note that Berkoff [5] showed that elite track and field athletes tend to have higher parasympathetic tone (higher HRV) than recreational athletes, although overall fluctuation is still subject to the same external variables. As a result of league games played by our subjects during the C period, there was a further decrease in vagal tone in relation to the Pre-C period, reflecting parasympathetic activity in the neural regulation of the heart. A decrease in the value of the HF index may suggest changes in the ANS of the analysed volleyball players as an effect of prolonged maximum effort during league games.

Based on the results, a negligible increase in the sympathetic part in the C period, expressed by the values of the LF n.u. index, can be concluded. As a significant increase in sympathetic voltage can be an indicator of the increased efficiency of training [26], its insignificant increase may have been due to the reduced volume and lower intensity of workouts during the C period.

Similar data was obtained by Mazon et al. [40] in their studies of the autonomic modulation of HRV before and after a competition period in volleyball players. No statistically significant differences between the values of any of the parameters of spectral analysis were found before and after the 12-week competition period. The researchers related the explanation of this phenomenon to anaerobic efforts and training of too severe intensity, which is dominant during matches in a competition period. Such a hypothesis is consistent with the findings of several other studies that showed no changes in the autonomic control of the heart in athletes engaged in intense anaerobic training [9, 55]. At the same time, it should be noted that the data on these issues are not clear. Low values of total power (ms^2) and HF index along with high values of LF and LF/HF markers in the tested group of volleyball players, which persisted for an extended period, may indicate a lack of balance between efforts of high intensity and the amount of time dedicated to regeneration after training during the rest period. In practice, they may suggest the occurrence of a state of overtraining resulting from gruelling workouts and/or not enough time for rest and biological renewal. In contrast to the above-mentioned studies, which showed a lack of significant impact of intense anaerobic training on modulation in the ANS, the available literature contains data confirming such an impact. It had been revealed that tough and long-lasting workouts cause a voltage reversal phenomenon in the ANS, ranging from the characteristic vagotonia to sympathicotonia [6, 42].

When analysing the parameters of the time analysis, there was a statistically insignificant increase in the value of the RMSSD index in the Pre-C period that correlated with the HF marker in the spectral analysis. In addition, the resting HR was exceptionally high for the body of a trained volleyball player [27]. A low level of physical fitness often manifests itself through proneness to overtraining and weakening of an athlete's body during the C period, due to the slow pace at which an athlete's body recovers. During the C period, there was an insignificant increase in HR and a decrease in the mean R-R interval, a derivative of HR, which may have resulted in similar values of the observed differences. In the Pre-C period, there were statistically insignificant prolonged episodes of R-R intervals in relation to the C period. The difference in the tested group of volleyball players between the tested training periods was found to be about 83 ms. Prolonged episodes of R-R in the Pre-C period could be a response to minor internal changes in the sinus node. Long-term, optimal sports training induces resting bradycardia [3]. Resting bradycardia in the tested periods may be associated with internal changes occurring in the sinus node and changes in the neural control of the heart [39]. These changes reflect the adaptation of the heart to prolonged exercise. Aubert et al. [3] and Stein et al. [48], among others, have partially confirmed this opinion by conducting research using pharmacological agents. Following the application of atropine (blocking the vagus nerve) and propranolol (barring the impact of the sympathetic nervous system) there were changes in the cardiac conduction system, affecting its automaticity associated with specific electrical changes in the conductive tissue cells of the heart. Significant changes in the parameters of spectral and time analysis are more evident when analysing the impact of intense exercise in untrained persons [34], albeit training of variable intensity shows no such changes in the values of those parameters which concern HRV [34, 35].

Conclusions

The studies conducted with a group of volleyball players as participants in the Pre-C and C periods showed statistically significant differences in selected parameters of spectral (VLF %) and time (NN50) analyses. A significant increase of the VLF [%] indicator during the C period may be the result of increased emotional arousal, stemming from the increased mental and physical burden of playing volleyball matches. Low total power in the tested periods may be an indicator of chronic fatigue of the Basedow type, which the analysed volleyball players experienced due to their excessive physical and emotional stimulation apparently resulting in accelerated HRs. Moreover, these kinds of basic symptoms of overtraining are common in young, inexperienced individuals practicing strength and high-speed sports (such as volleyball) [30].

Resting bradycardia, assessed on the basis of time analysis indicators in the volleyball players during the analysed periods, may be the result of internal changes in the sinus node, which reflects the impact of long-term training on the cardiac conduction system. The high level of physical activity of volleyball players in the tested periods could have contributed to a reduction in vagal tone and a shift in balance from the ANS towards its sympathetic counterpart, which may be the result of overtraining. An imbalance in the ANS results in changes in the HRV of the volleyball players subjected to intensive training.

The main limitation of our study is a relatively small number of participants, diminishing the power of statistics. However, one should bear in mind that this is mainly due to the specificity of the discipline, as the number of players who constitute the primary core of the volleyball team and who train under the supervision of one coach and in the same conditions is always limited and rarely exceeds 10 players. Notwithstanding this, the measurement of HRV in different training periods may be very useful in evaluating the effectiveness of volleyball workouts owing to the fact that changes in HRV may be of prognostic value, potentially reducing the risk of overtraining. Therefore, it would be advisable to conduct another series of research involving players at high-performance level of other volleyball teams, which would be carried out according to our original research scheme. This line of research should be continued on the basis of methodological manipulations, which would involve expanding the research observations into other periods of the training macro cycle as well as the control group. To sum up, although more studies are necessary to confirm our results within specific strength-speed events and to further process our understanding of the importance of HRV changes, there is sound evidence that HRV measures what it is supposed to measure.

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