AUTONOMIC NERVOUS SYSTEM ACTIVITY DURING ACCLIMATIZATION AFTER RAPID AIR TRAVEL ACROSS TIME ZONES: A CASE STUDY

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The rapid transition across time zones also known as jet lag syndrome leads to desynchronization of our endogenous "biological" clock and causes a transient decrease in the adaptation capacity of an athlete. The aim of this study was to verify the use of the spectral analysis of heart rate variability (SA HRV) method as a tool for classification of the answer of the body to both the rapid transition across time zones and the training intensity level during the following acclimatization.

Changes in autonomic activity were assessed by SA HRV during acclimatization after eastward (+6 hours) and westward (–7 hours) flights in two elite athletes.

The results revealed that the athlete, who undertook a flight from Prague to Beijing (China), was able to start with intensive training during the fourth day of his acclimatization. No acute decrease in training ability (adaptability) was found in the athlete after the flight from Prague to Bogota (Columbia). Significant modifications in her training load level were made only on the third day in Columbia. The study confirmed that the reaction of the body to the rapid transition across time zones is highly individual.

Therefore, in the future, the SA HRV method could become a promising tool for solving questions of both the acclimatization strategy and the optimizing of sport performance in elite athletes.

Keywords: Spectral analysis of heart rate variability, jet lag syndrome, adaptation, training load, sport performance.

INTRODUCTION

Travelling across the world is a common component of each elite athlete's career. The rapid transition across several time zones means a shift in the action of light and dark causing a disturbance of the body's circadian rhythm known as "jet lag" (Waterhouse et al., 2002). According to Nagano et al. (2003), the principle of that syndrome is a disturbance of the 24 hour rhythm typical for the hypothalamic suprachiasmatic nucleus, which is considered to be the supervisory centre of the circadian rhythm.

According to several studies, the time needed for regeneration of endogenous biological rhythms is dependent on the flight direction. In 1990, Suvanto, Partinen, Härmä and Ilmarinen described the faster restoration and resynchronization of the endogenous "biological clock" when flying from East to West compared to eastward flights. Aschoff, Hoffmann, Pohl and Wever (1975) estimated that a transition of 92 minutes westward and a transition of 57 minutes eastward correspond approximately to one day of acclimatization. Presently, with more or less positive effect, different strategies are being utilized to achieve acclimatization faster. This includes the administration of melatonin, phototherapy or the regulation of the time when food is served and the structure of a diet (Atkinson & Reilly, 1996; Manfredini, R., Manfredini, F., Fersini, & Conconi, 1998). For now, study results show that, as a consequence of the high inter individual variability of an athlete's adaptability, none of these methods are considered to be reliable. Winget et al. (1992) presented us with the information that about 30% of passengers traveling by plane are resistant to jet lag syndrome, conversely, 30% are not able to adapt to the acute adjustments needed for desynchronization.

The changes in circadian rhythm were also observed in heart rate variability (HRV), which is considered to be a sensitive marker of autonomic cardiac activity (Akselrod et al., 1985; Task Force, 1996). In ordinary terms, vagal activity is dominant during the midnight to early morning hours, and during the daytime sympathovagal balance shift toward sympathetic activity in healthy subjects (Bilan, Witczak, Palusinski, Myslinski, & Hanzlík, 2005; Massin, Maeyns, Withofs, Ravet, & Gepard, 2000; Nakagawa et al., 1998). In the year 2000, Tateishi et al. published a study in which they investigated the time course of HRV parameters due to eastward flight over seven time zones. They found that the recovery rate of autonomic nervous system (ANS) activity varied according to the time of day – ANS activity measured within a morning returned to baseline on the fifth day. However, the recovery of autonomic regulation during sleep was indentified two days later.

Stejskal, Jakubec, Přikryl and Salinger (2004) investigated, in their case study, the diagnostic potential of the spectral analysis of heart rate variability (SA HRV) method as a tool for the assessment of the time course of the acclimatization of the athlete after his rapid crossing over several time zones. It was concluded that the athlete was fully adapted from the eastward flight over eight time zones between the eighth and ninth day of his sojourn. However, authors discussed the possibility of the insertion of the higher training intensity sessions already on the fifth or the six day after arrival. This manipulation may yield the enhancement of blunted sympathetic activity which could lead to the acceleration of the acclimatization.

The goal of this study was to verify the possibility of using the SA HRV method for assessment of both the body's reaction to the rapid crossing of over several time zones and the optimal prescription of training load level during acclimatization.

METHODS

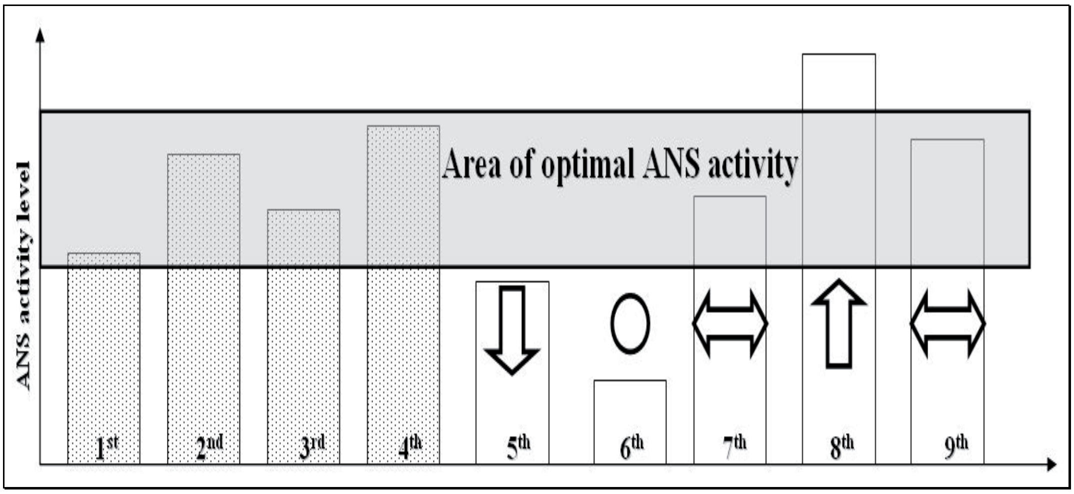
Two elite athletes (1 man, 1 woman) participated in this study. The first monitored subject was a 33 year old athlete (athlete A), who specialized in the decathlon. His ANS activity was assessed during one week of training preparation before the flight, and then nine days during acclimatization after his eastward flight over six time zones. The specialization of the second subject was finswimming (athlete B). She was an 18 year old. Athlete B was monitored during her ten days training preparation before her flight, and then during eight days of her sojourn after the westward flight over seven time zones.

The training load level of both athletes was established mostly upon their ANS activity level via the diagnostic system VarCor PF 7 (Salinger & Gwozdziewicz, 2008). Athlete A was measured during the whole acclimatization and also on the day of his competition. He knew all the results. Based upon the request of the coach, athlete B did not undergo measurements on competition days.

Both athletes tried to keep the time of their measurement, conducted under the new environmental conditions, almost equal to the time before the flight. All measurements of ANS activity were taken between 8 and 9 a.m. in athlete A, and between 2 and 3 p.m. in athlete B.

The ANS activity was assessed by both athletes themselves. The assessment was explained to them in detail. ANS activity was monitored during the standard orthoclinostatics maneuver (supine–standing–supine) via the VarCor PF 7 diagnostics system. ANS activity was expressed by the following complex indexes of SA HRV (Stejskal et al., 2002): the complex index of the va-

Fig. 1
Graphic illustration of optimizing principle of the training load level via VarCor PF 7 diagnostics system before every single training session



Legend:
measurement 1st to 4th – set up of ANS activity level
measurement 5th to 9th – optimizing process of the training load
recommendation ↔ – optimal
↓ – decrease
↑ – increase
○ – temporally interrupt the training process until next measurement of the ANS activity

gal activity (VA), the complex index of the sympathovagal balance (SVB) and the complex index of the total score (TS). The reference values of SA HRV indexes range from –5.0 to +5.0 points. The physiological values have been established for both VA and SVB in a range from –2.0 to +2.0 points and for TS from –1.5 to +1.5 points (Stejskal, Jakubec, Přikryl, & Salinger, 2004).

The optimizing of the training load level of both athletes was managed via the VarCor PF7 diagnostics system. This system generated training recommendations for the athletes based on their actual, current autonomic activity level, which matches their training capacity (Fig. 1). This detailed information about optimizing was supported by previous research (Stejskal, 2008).The analysis of the results of ANS activity was based on the dynamics of both assessed parameters of SA HRV as well as training recommendations.

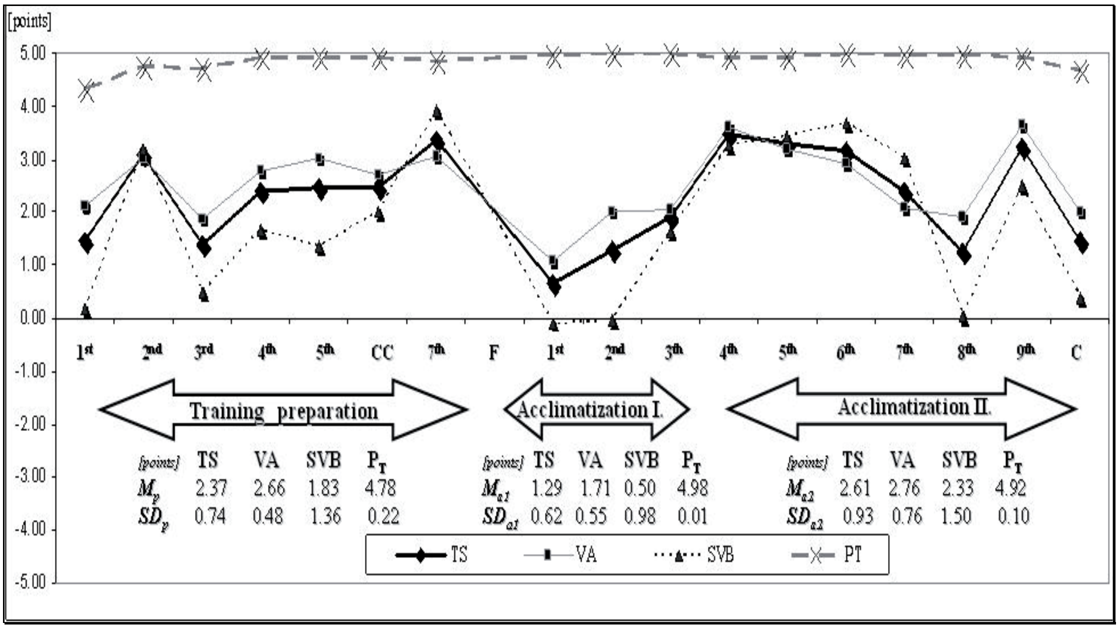
RESULTS

All the assessed SA HRV parameters ranged within the physiological level or above in athlete A. It was investigated that the upper border of physiological values was exceeded by the complex index of the TS elevenfold (65%). Thirteen values (76%) of the complex index of the VA and eight values (47%) of the complex index of SVB were above the normal range. The values of the P_T were over the level of the normal range during the whole assessed period (100%) (TABLE 1).

During the monitored period, athlete A received a recommendation five times to increase (30%) and six times to decrease (35%) his training load level. On the other hand, in the case of six measurements, it was recommended to make small or no changes of the training intensity level.

TABLE 1 show that the highest values of assessed SA HRV parameters were on the day before the flight. On the contrary, the SA HRV parameters reached their lowest values during the first two days after the athlete's arrival in China. Presently, the complex SVB index was found in negative values, conversely, the values of the P_T reached their maximum (TABLE 1, Fig. 2). Subsequently, the value of all assessed complex indexes of SA HRV increased until the fifth day of the acclimatization when athlete A was receiving recommendations in two subsequent days to increase his training intensity. In the following days of acclimatization, a slow decrease in the values of the complex indexes of SA HRV was observed. Only one day before the day of the competition, an increase in training intensity was recommended to athlete A.

Fig. 2
Dynamics of the SA HRV parameters during training preparation and acclimatization period in athlete A



Legend:
M – mean value
SD – standard deviation
p index – training preparation
a_1 and a_2 index – the first and the second part of acclimatization
TS – complex index of the total score
VA – complex index of the vagal activity
SVB – complex index of the sympathovagal balance
P_T – age dependent parameter total power
TL – training load level
F – flight
C – competition
CC – control competition
BF – training before flight
S – sojourn

TABLE 1
Values of the SA HRV parameters together with recommendations for training during the training preparation and acclimatization period in athlete A

Days	TS *[points]*	VA *[points]*	SVB *[points]*	P_T *[points]*	Recommendation TL
1st BF	1.46	2.12	0.19	4.33	Decrease
2nd BF	3.09	3.03	3.21	4.76	Increase
3rd BF	1.39	1.87	0.48	4.74	Decrease
4th BF	2.40	2.78	1.67	4.93	Optimal
5th BF	2.45	3.02	1.35	4.92	Optimal
6th CC	2.47	2.70	2.01	4.94	Optimal
7th BF	3.35	3.06	3.92	4.86	Increase
F	ND	ND	ND	ND	
1st S	0.67	1.08	−0.09	4.98	Decrease
2nd S	1.30	2.00	−0.05	4.99	Decrease
3rd S	1.91	2.05	1.63	4.99	Optimal
4th S	3.48	3.60	3.25	4.92	Increase
5th S	3.29	3.21	3.45	4.93	Increase
6th S	3.17	2.90	3.68	4.98	Optimal
7th S	2.40	2.07	3.02	4.98	Optimal
8th S	1.26	1.91	0.02	4.95	Decrease
9th S	3.24	3.63	2.49	4.94	Increase
10th C	1.45	2.01	0.39	4.70	Decrease

Legend:
TS – complex index of the total score
VA – complex index of the vagal activity
SVB – complex index of the sympathovagal balance
P_T – age dependent parameter total power
TL – training load level
F – flight
C – competition
CC – control competition
BF – training before flight
S – sojourn
ND – no data

The values of complex SA HRV indexes were lower in athlete B compared to values of complex indexes in athlete A. In the case of the complex index of the TS and VA and parameter P_T, values occurred within physiological or above the physiological range. The value of TS was classified as above average in three cases (23%), the VA in eight cases (62%) and P_T in seven cases (54%) (TABLE 2). The values of the complex SVB index were more frequently negative than positive, and they decreased twice (13%) under the physiological range level.

During the entire ANS activity monitoring period it was recommended to athlete B, ten times (77%), to make small or no changes to the training intensity and for the training load to be decreased three times (23%). In the night, immediately after arrival, a pronounced decrease in value of the complex SVB index occurred, while values of the other assessed SA HRV parameters did not change markedly. The expected pronounced decrease in the values of all the assessed complex SA HRV indexes was identified as far along as on the third day of this sojourn in Columbia. To the end of that sojourn, a slow increase in the values of the SA HRV parameters occurred. However, the values did reach such a level, neither at the end of the training preparation before the flight, nor at the level achieved at the beginning of the acclimatization period.

TABLE 2
Values of the SA HRV parameters together with recommendations for training during the training preparation and sojourn in athlete B

Days	TS *[points]*	VA *[points]*	SVB *[points]*	P_T *[points]*	Recommendation TL
1st BF	2.29	2.73	1.46	2.37	Optimal
2nd BF	0.03	1.11	−2.02	2.05	Decrease
3rd C	ND	ND	ND	ND	
4th C	ND	ND	ND	ND	
5th BF	0.95	2.10	−1.22	2.08	Optimal
6th BF	ND	ND	ND	ND	
7th BF	0.00	−0.07	0.13	0.32	Decrease
8th BF	1.01	2.16	−1.17	3.71	Optimal
9th BF	ND	ND	ND	ND	
10th BF	1.44	2.13	0.30	2.80	Optimal
F	ND	ND	ND	ND	
A	1.36	2.89	−1.56	4.44	Optimal
1st S	1.76	2.10	1.11	3.21	Optimal
2nd S	2.01	2.50	1.08	3.50	Optimal
3rd S	−1.09	−0.64	−1.95	1.13	Decrease
4th S	0.48	1.82	−2.06	3.35	Optimal
5th C	ND	ND	ND	ND	
6th C	ND	ND	ND	ND	
7th S	0.77	1.36	−0.37	3.07	Optimal
8th S	1.29	2.00	−0.06	1.82	Optimal
9th C	ND	ND	ND	ND	
10th C	ND	ND	ND	ND	

Legend:
TS – complex index of the total score
VA – complex index of the vagal activity
SVB – complex index of the sympathovagal balance
P_T – age dependent parameter total power
TL – training load level
F – flight
C – competition
BF – training before flight
S – sojourn
A – measurement immediately after arrival
ND – no data

DISCUSSION

Scientists and coaches have been trying to solve the problem with the optimizing of training intensity after rapid transition across time zones for several decades

(Aschoff et al., 1975; Manfredini, R., Manfredini, F., Fersini, & Conconi, 1998; Reilly, Waterhouse, & Edwards, 2008; Waterhouse et al., 2002). Therefore, any approach to the diagnosis of the relevant information about the time course of the acclimatization to the time shift plays a fundamental role. The processes of both disadaptation and adaptation have been widely assessed throughout the dynamics of plasmatic cortisol (Härmä, Laitinen, Partinen, & Suvanto, 1994; Piérard et al., 2001), heart rate (Ariznavarreta et al., 2002), blood pressure (Barattini, Dolci, Montaruli, Roveda, & Carandente, 2001), or body temperature (Hauty & Adams, 1966; Lemmer, Kern, Nold, & Lohrer, 2002). In addition, the spectral analysis of heart rate variability (SA HRV) method has been presented only in a few studies (Stejskal, Jakubec, Přikryl, & Salinger, 2004; Tateishi & Fujishiro, 2002; Tateishi et al., 2000), as an alternative way of how to assess the process of acclimatization.

According to our results, athlete A had above average levels of autonomic cardiac activity during the whole monitored period. Depending on the training intensity and other uncontrolled effects, the peak values of spectral power shifted from the high frequency area to the lower frequency area (for example on the first and the third day of the training preparation period), and conversely (for example the second and the last day of the training preparation period). Thereby both the complex VA index as well as TS increased (that is, an increase in vagal activity) or decreased (a decrease in vagal activity), but the level of total spectral power was still highly above average. It is possible that high levels of autonomic activity before the flight could have a beneficial influence on the restoration of impaired homeostasis due to rapid transience across time zones.

The first day after arrival, a significant decrease in vagal activity was found in athlete A, whereas his total spectral power reached almost its maximum values. It follows that autonomic activity did not decrease (!), but only shifted from vagal to sympathetic activity. The persisting high level of autonomic activity was probably the basis for a rapid adaption of athlete A to new environmental conditions. The autonomic system did not significantly decrease in its activity even during the days to follow. In the following three days, vagal activity increased over its preflight level. We considered that the process of acclimatization to time shift (jet lag syndrome) was fully completed on the fourth day after his arrival at China.

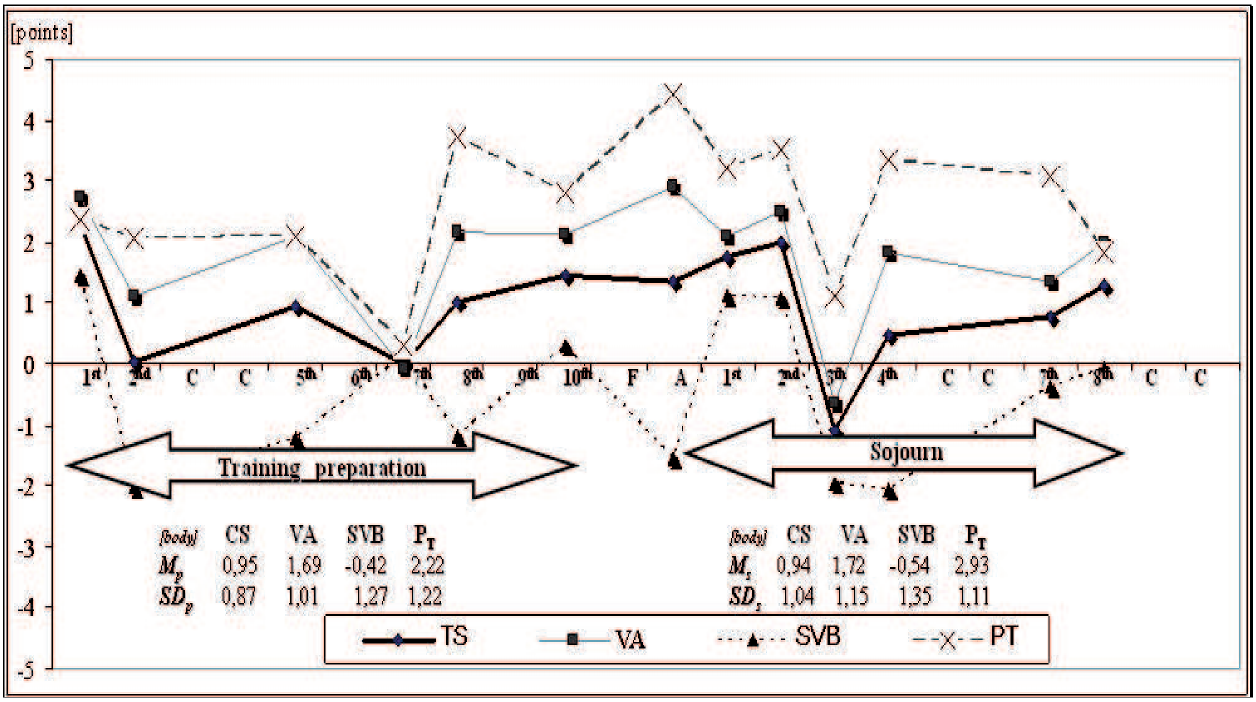
The first two days after arrival, athlete A obtained a recommendation to reduce his training load. However, after the next two days when a homeostatic adjustment was probably achieved, athlete A was ready to start again with very intensive training at the same level as he underwent before the flight. In spite of his excellent subjective feeling, he did not accept the recommendation to begin with intensive training. The main reasons for his refusal were both his positive experiences with a long term decrease in training load after rapid transience across time, and his fears about the results in this most crucial competition of the season. However, it is possible that autonomic activity and subsequent sport performance could have also been influenced negatively by a uselessly long term interruption of the training process which this athlete used to perform for many years.

This opinion is in agreement with Stejskal, Jakubec, Přikryl and Salinger (2004) who observed the time course of the acclimatization process after an eastward flight across eight time zones in an elite swimmer. They assumed that full acclimatization occurred about three or four days later due to the absence of an intensive training bout on fifth and sixth day after arrival. Also Lemmer, Kern, Nold and Lohrer (2002) discuss the application of intensive training bouts during acclimatization periods in their study. They suppose that the fourth day of acclimatization after a westward flight across 6 time zones seems to be the optimal time for starting with intensive training. However, athlete A did not utilize the possibility to train hard in spite of his consistently high level of autonomic activity. According to this, it is possible that the following SA HRV results could be negatively affected just by the decision to keep to a low training intensity together with increases in psychological stress from the approaching competition.

Vagal activity was continuously decreasing over the next four days. The lowest vagal activity was detected on the eighth day of the acclimatization period. For the reason that the total spectral power still remains at a high level, it is obvious that sympathetic activity should increase at the expense of the vagal activity. In addition, athlete A temporally interrupted his training preparation due to health complications (respiratory difficulties) the eighth day after arrival. The following day, an increase in vagal activity enabled him to undergo an intensive pre-competition warming up session. However, the absence of the intensive training bout at the eighth day of acclimatization was probably reflected in the following dramatic decline in vagal activity together with a slow decline in total spectral power (the lowest value of the P_T parameter after the athlete's arrival in China). Classified according to the complex TS index, ANS activity was lower on the day of the challenge than on the third day of the acclimatization period. Unfortunately, this find was not linked to any optimal sport performance.

The assessment of ANS activity during the first week in the Czech Republic was strongly under the influence of the two day competitions in athlete B. The activity of both branches of the ANS was decreased and the

Fig. 3
Dynamics of the SA HRV parameters during training preparation and during sojourn after flight in athlete B



Legend:

M – mean value	SVB – complex index of the sympathovagal balance
SD – standard deviation	P_T – age dependent parameter total power
p index – training preparation	F – flight
s index – sojourn after the flight	C – competition
TS – complex index of the total score	BF – training before flight
VA – complex index of the vagal activity	A – measurement immediately after arrival

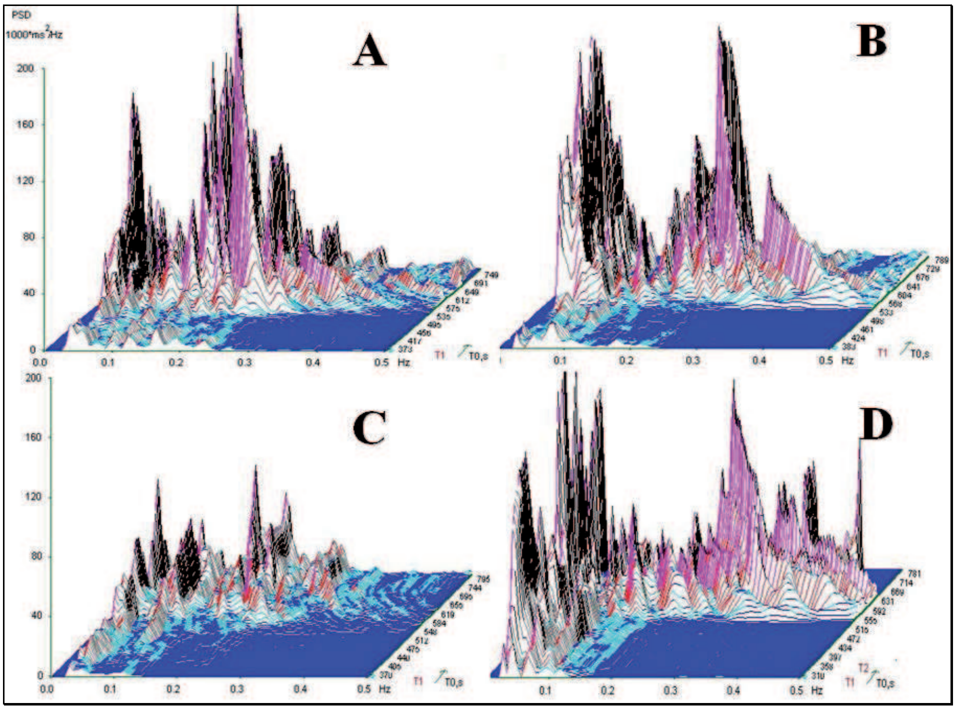
lowest autonomic activity level was reached on the last day of this week (TABLE 3, Fig. 3). For the five days before her flight, the training intensity was partly reduced based upon this information. Manipulation with the training load led to the enhancement of ANS activity, especially vagal activity (Fig. 3).

An expected decrease in ANS activity did not occur after the westward flight over seven time zones in athlete B. Conversely, the total spectral power achieved the highest level for the whole monitored period immediately after arrival. At this time, vagal activity played a dominant role and the complex VA index, as well as the total spectral power level reached its maximal value. The changes in ANS activity probably reflected a training fault in athlete B who used to train for several hours per day. However, the level of total spectral power decreased (there was declined activity of both branches of the ANS), but it still occurred above the physiological level. Athlete B was already in the training process during this time.

According to her coach, she underwent highly intensive training sessions with a highly reduced volume. The third day after arrival, a dramatic decline in vagal activity was revealed, and the markedly blunted total spectral power shifted from the high frequency area into the area with lower oscillatory frequency. The impairment of ANS activity brought a decrease in training intensity. This adjustment in the training process was followed by an increase in the activity of both branches of the ANS, and athlete B seemed to be in a good sport condition before the competition which started the next day. In addition, athlete B achieved very positive results in the competition. After two days of competition, ANS activity did not change markedly, only activity in the lower fluctuation area declined. It could have been a reaction of the ANS to the low intensive training sessions which should have served as preparation for a further competition. Just as well as two days before, athlete B achieved excellent results.

According to changes in ANS activity, the adaptation process to new environmental conditions to which the athlete was unaccustomed and could not get used to so quickly after rapid air travel across time zones took place in athlete B. Indeed it is known that westward flights are followed by faster recovery than eastward flights. Aschoff, Hoffmann, Pohl and Wever (1975) and

Fig. 4
Example of a 3D graph of SA HRV (standing and lying position) during both the preparation and acclimatization periods in athlete B



Legend:
A – before flight
B – immediately after the flight
C – 3rd day of acclimatization
D – 4th day of the acclimatization

others supposed that subjects who flew over several time zones still need some time for recovery. However, it is possible that athlete B belongs among those subjects who, according to Winget et al. (1992), are resistant to the jet lag syndrome. Nevertheless, the training capacity of athlete B was somewhat reduced during the first days after her arrival, because ANS activity declined due to the training sessions more than in the Czech Republic. From this point of view, a one-day reduction in training intensity was fully sufficient for ANS recovery. It appears that, according to changes in ANS activity during both training preparation and the acclimatization period in both elite athletes, athlete B had a better initial position in order to achieve a maximal performance in comparison to athlete A. Except for a couple of times, the high activity of both branches of ANS was maintained due to short, high intensive training sessions during the whole assessed period in athlete B. It seems that a high level of autonomic activity is necessary for rapid recovery and maximal sport performance. On the other hand, as a counterproductive element for the acclimatization of the athlete after flight across several time zones, it seems that a repeated application of low intensity training sessions or canceling the training is not a good idea. Rapid air travel across several time zones is usually linked with tapering which is based upon a radical decrease in the training volume and remaining high training intensity of an athlete (Bouquet, Montpetit, Arvisais, & Mujika, 2007; Mujika & Padilla, 2003). Therefore, an excessive recovery without any intensive training stimulation may lead to the loss of current sport form in athletes who used to have a long term high intensity training preparation.

The time of the application of the intensive training will be highly variable in athletes during acclimatization, because it is influenced by several factors. However, it is possible that athletes with a higher level of ANS activity will adapt more quickly to pronounced changes in the external environment than athletes with lower ANS activity.

CONCLUSION

Based on the monitoring of ANS activity by the SA HRV method it was revealed that the adaptation to new environmental conditions after a rapid transience across several time zones may occur very soon (from the first to the fourth day after arrival) in long term intensively trained elite athletes. The early application of intensive training sessions, which athletes are accustomed to, may help them to maintain their performance at the appropriate level. On the other hand, a long lasting reduction in training load may yield the loss of sport form. It is evident that the SA HRV method enables one to provide essential diagnostic information about the time course of adaptation capacity during acclimatization in elite athletes. Based upon this information, both athlete and coach have a chance to operatively change the training load level so that the cumulative fatigue and the extension of acclimatization process did not occur. It appears that, in future, the SA HRV method may be used as a guiding method for solution of the problems which are linked with both, acclimatization strategy, and optimizing of the performance in elite athletes.

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AKTIVITA AUTONOMNÍHO NERVOVÉHO SYSTÉMU BĚHEM AKLIMATIZACE PO RYCHLÉM PŘESUNU PŘES ČASOVÁ PÁSMA: KAZUISTIKA

(Souhrn anglického textu)

Vlivem rychlého přesunu přes časová pásma dochází k poruše vnitřních regulací organismu, které mohou být u sportovců příčinou přechodného poklesu jejich tréninkové adaptační kapacity. Cílem práce bylo ověřit možnost využití metody spektrální analýzy variability srdeční frekvence (SA HRV) jako nástroje pro hodnocení aktivity autonomního nervového systému (ANS), který se podílí na regulaci těchto změn souvisejících s aklimatizací.

U dvou vrcholových sportovců, kteří absolvovali přelet přes poledníky (jeden východním směrem +6 hodin, druhý západním směrem –7 hodin) byly metodou SA HRV monitorovány změny v aktivitě ANS a byl posuzován průběh aklimatizace.

První sportovec, který absolvoval let z Prahy do Pekingu (Čína), mohl začít s intenzivním tréninkem již čtvrtý den po příletu. V druhé případové studii (sportovkyně) nebyl bezprostředně po přeletu z Prahy do Bogoty (Kolumbie) pozorován žádný aktuální pokles aktivity ANS. K úpravě tréninkového zatížení bylo u této sportovkyně nutné přistoupit až třetí den pobytu.

Práce potvrdila, že reakce organismu na rychlý přesun přes poledníky je založená na změnách aktivity ANS a je individuálně variabilní. Proto se u vrcholových sportovců může v budoucnu stát metoda SA HRV vodítkem při řešení otázky aklimatizační strategie a optimalizace sportovní výkonnosti.

Klíčová slova: spektrální analýza variability srdeční frekvence, syndrom jet lag, adaptace, tréninkové zatížení, sportovní výkonnost.

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