CHANGES IN AUTONOMIC NERVOUS SYSTEM ACTIVITY IN CONNECTION WITH SCUBA DIVING

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The purpose of this study was to discover how the autonomous nervous system (ANS) responds to scuba diving with recreation parameters.

The sample consisted of 20 scuba divers, 17 men and 3 women, who submitted to measurement in Sharm El Sheikh, Egypt. ANS activity was evaluated before diving (immersion) in water (depth of 20 meters) and 20 minutes after the dive (the total time under water was 43.3 ± 2.2 minutes) by means of spectral analysis (SA) of heart rate variability (HRV). HRV was measured during a standardized orthoclinostatic manoeuvre (three times 300 beats or three times 5 minutes) by means of Varcor multi PF7 and Varcor PF6. The standard parameters and complex indexes of SA HRV were applied to assessments of ANS activity.

A significant increase in the total spectral power and parameters of vagal activity (MSSD and complex index of vagal activity) occurred 20 minutes after cessation of scuba diving. The spectral power shifted from slower to quicker fluctuations – the VLF/HF and LF/HF ratios nonsignificantly decreased and the complex index of sympathovagal balance significantly increased. All of these changes suggest that 30 minutes after scuba diving there was significant increased vagal activity.

Scuba diving at a depth of 20 meters led to an increase in vagal activity that persisted for 30 minutes after diving.

Keywords: Scuba diving, autonomous nervous system, vagal activity, heart rate variability.

INTRODUCTION

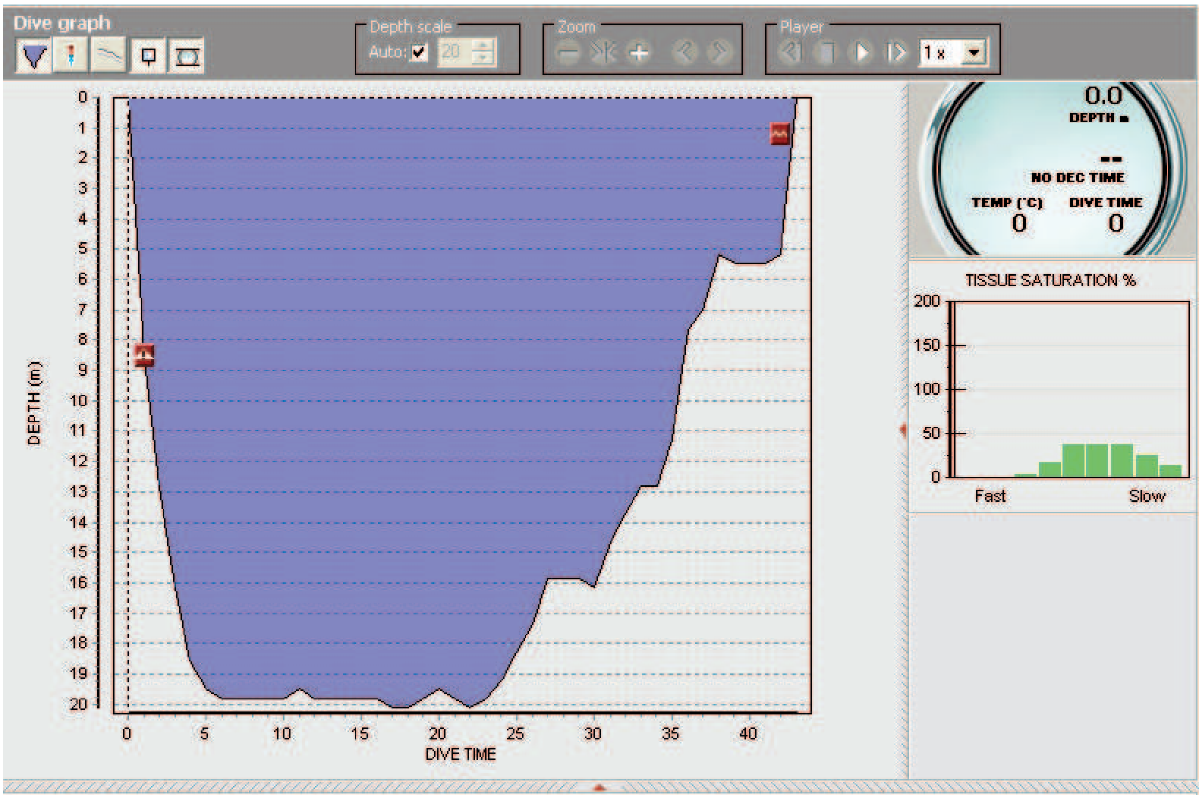
Scuba diving is an activity which is performed not only as a profession, yet also as a popular way of spending free time. However, there is a lack of information and research which could evaluate the changes in autonomous nervous system (ANS) activity, especially related to scuba diving. Through monitoring the autonomous regulation of the sino-atrial node by spectral analysis (SA) of heart rate variability (HRV), we are able to follow current ANS activity (Stejskal & Salinger, 1996; Malliani et al., 1991). This method is often used in medicine, especially for the timely diagnosing of diabetic autonomic neuropathy, for estimating the risks of cardiac arrhythmia and sudden death after an acute myocardium heart attack. Recently, the usage of SA HRV in sports medicine is limited even though there are some studies using this method for optimizing the intensity of exercise in sports training (Cipryan, 2008; Botek, 2006; Jakubec, 2005; Pichon et al., 2004; Stejskal, 2002; Stejskal, 2008).

In accordance with our previous experience (Klugar et al., 2008) SA HRV could become one of the methods used in the problematic areas of scuba diving. This would help evaluate changes in ANS activity under precisely defined scuba diving conditions. Moreover, this would help to evaluate the rules surrounding and the course of ANS adaptation for scuba diving. Also this would help to elaborate on the analysis of the physiological and pathophysiological states related to scuba diving. Furthermore this will more precisely define the diagnostics and interpretation of decompression sickness (DCS), central nervous system (CNS) oxygen toxicity, carbon dioxide poisoning, and other diving accidents. The purpose of this study was to follow the current changes in ANS activity related to scuba diving.

METHODS

The sample consisted of 20 scuba divers, 17 men and 3 women, who submitted to measurement in Sharm El Sheikh, Egypt in cooperation with Divers International, Sea and See, and The Wave diving centers. All of the tested individuals were certified scuba divers of an average age of 30.2 ± 10.4 years, who had completed an average of 698 ± 1152 dives. Each individual signed a document that he/she is healthy, however their health was not examined. The participants were acquainted with the study plan and the dive plan.

Fig. 1
Basic parameters of the dive from the dive computer Suunto Vytec by Suunto dive manager



Legend:
X axis – actual depth
Y axis – actual time
Tissue saturation % – actual tissue saturation by nitrogen

All participants were asked not to put too much strain on their bodies for at least 24 hours before the experiment. They were asked to avoid the consumption of less digestible food, tea, coffee, alcohol and drugs which could influence ANS activity for at least 2 hours before the ANS measurements were made.

The data collection took place on a boat, which was anchored in an area protected from waves during the measuring. The first SA HRV measurements took place at around 9 o'clock in the morning. The divers were then instructed before the dive concerning the maximum depth, duration of descent, currents, environment, dangerous creatures, and safety stops. The dive always started around 10 o'clock, and the repeated measuring of the SA HRV took place 20 minutes after diving. The dives, which took an average of 43.3 ± 2.2 minutes, took place where there was a minimum current to an average depth of 20.2 ± 1.4 m. The temperature of the water reached an average of 29°C and the air temperature equaled 36°C. Measuring the intensity of exercise during the descent was achieved through the Borg scale RPE 9.3 ± 1.5 points.

The Varcor multi PF7 and Varcor PF6 were used for recording SA HRV with sophisticated methodology arising from the orthoclinostatic manoeuvre (supine–standing–supine) with facilities for short EKG records (300 heart beats or 5 minutes) (Salinger et al., 1994, 1998). The results of SA HRV were evaluated by the standard parameters of SA HRV – the total power spectrum (P_T) (0.02–0.5 Hz), very low frequency power (P_{VLF}) (0.02–0.05 Hz), low frequency power (P_{LF}) (0.05–0.015 Hz), and high frequency power (P_{HF}) (0.015–0.5 Hz) (Salinger & Gwozdziewicz, 2008; Stejskal & Salinger, 1996; Task Force, 1996; Yamamoto & Hughson, 1991). Further analyzed parameters were the rations between the component powers (VLF/HF, LF/HF a VLF/LF) and the percentage of the component power from P_T (% VLF, % LF, % HF). The average of the square of successive R–R intervals (MSSD) was chosen from the parameters of the time domain of HRV. The mentioned parameters of SA HRV were supplemented by the complex indexes of the vagal activity (VA), sympathovagal balance (SVB) and total score (TS) (Stejskal et al., 2002; Šlachta, 1999), and age standardized P_T (TP). The

TABLE 1
Selected parameters of SA HRV in the second supine position of the orthoclinostatic test before and after scuba diving

	Before				After				Change		t-test
	M	SD	Min.	Max.	M	SD	Min.	Max.	M	SD	p
TP[ms^2]	2364.93	3380.60	85.17	15125.53	5032.02	7908.15	259.88	35112.61	2667.09	5280.29	**0.036**
P_{VLF}[ms^2]	243.69	199.73	17.75	627.83	329.22	363.36	34.60	1348.81	85.53	332.25	0.264
P_{LF}[ms^2]	1101.29	1938.06	38.78	8228.03	1389.92	2140.62	60.22	9353.27	288.63	2447.25	0.604
P_{HF}[ms^2]	1019.96	1366.14	19.30	6269.67	3312.89	6609.70	60.77	30366.74	2292.93	5344.85	0.070
% VLF	15.39	10.30	1.48	41.82	14.45	14.00	0.73	49.08	−0.94	15.33	0.788
% LF	38.43	20.40	3.28	66.98	31.92	20.14	5.21	75.65	−6.51	24.81	0.255
% HF	46.18	20.17	22.65	89.27	53.63	22.76	13.67	94.05	7.45	21.92	0.145
VLF/HF	0.43	0.41	0.03	1.43	0.40	0.49	0.01	1.77	−0.02	0.49	0.835
LF/HF	1.15	0.87	0.04	2.82	1.10	1.37	0.06	5.53	−0.05	1.43	0.879
VLF/LF	0.79	0.90	0.04	3.42	0.77	1.23	0.02	4.87	−0.02	1.66	0.961
RR [ms]	0.95	0.17	0.60	1.25	1.02	0.21	0.73	1.37	0.07	0.12	**0.015**
MSSD [ms^2]	3418.54	5098.17	21.71	23441.64	10500.35	19316.01	155.02	87853.58	7081.81	14540.91	**0.042**

Legend:
M – arithmetic mean
SD – standard deviation
Min. – minimum value
Max. – maximum value
Change – difference between value after and before diving intervention
p – level of statistical significance (paired t-test)

TABLE 2
Complex indexes of SA HRV before and after scuba diving

	Before				After				Change		t-test
	M	SD	Min.	Max.	M	SD	Min.	Max.	M	SD	p
TS	−1.373	2.088	−4.939	1.688	0.110	2.420	−4.245	3.749	1.483	0.915	**0.000001**
VA	−0.883	2.156	−4.076	3.438	0.756	2.352	−3.259	4.548	1.639	1.160	**0.000005**
SVB	−1.399	1.850	−3.869	1.520	−0.458	1.938	−3.617	2.421	0.941	1.765	**0.027698**
TP	−1.268	2.952	−4.939	4.668	0.908	3.423	−4.245	4.970	2.176	2.192	**0.000282**

Legend:
M – arithmetic mean
SD – standard deviation
Min. – minimum value
Max. – maximum value
Change – difference between value after and before scuba diving intervention
p – level of statistical significance (paired t-test)

complex indexes and standardized P_T were expressed by the points (range from −5.0 to +5.0 points).

The software Statistica 6.0 was used for data analysis. The basic characteristics of the study group are presented as means, standard deviations and maximal and minimal values. The paired t-test was used to compare the values before and after scuba diving. In all analyses the differences were considered significant at $p \leq 0.05$.

RESULTS

A significant slowing down of the heart rate occurred after diving (on average from 63.2 to 58.8 beats per min.). The spectral power of all three components nonsignificantly increased, the increases in P_T and MSSD were significant. The % of HF nonsignificantly increased at the expense of the % VLF and % LF. The shift of the spectral power from the slower fluctuations to the quicker fluctuations has been proven by the moderate decline in the VLF/HF, LF/HF, and VLF/LF ratios. The values of complex indexes increased significantly after scuba diving (TABLE 1 and 2).

DISCUSSION

Vagal activity occurs in all spectral components (Stejskal et al., 2001; Pichot et al., 2000; Task Force, 1996), still the P_{HF} is formed entirely by vagal fluctuations (Stejskal & Salinger, 1996; Malik & Camm, 1995; Hayano et al., 1991; Malliani et al., 1991). The increase in the spectral power of all three components, namely P_{HF}, suggests an increase in vagal activity after emerging from the water. The interpretation of the significant increase in the MSSD, the complex index of vagal activity and the total score of SA HRV (Stejskal et al., 2002; Šlachta et al., 2002) is similar. Significant increases in the complex index of sympathovagal balance and the nonsignificant decrease in the VLF/LF, VLF/HF and LF/HF ratios and in the percentage of components reflect a shift of the spectral power from the bands of slower frequencies to the HF component. This shift shows evidence of increase in vagal activity as well.

We can assume that the reason for the increase in vagal activity consists of pressure changes during scuba diving that persisted throughout the period of 30 minutes. Increased stimulation of the baroreceptors results in a lowering of the activity of the vasomotoric centre and consequently in peripheral vasodilatation. Increased vagal activity comes concurrently with the inhibition of sympathetic vasoconstriction activity, venodilatation, and a decrease in heart rate (Schipke & Pelzer 2001; Rokyta et al., 2000; Ganong, 1999).

The increased percentage of oxygen in the inhaled gas mixture has a similar effect. Shibata et al. (2005) found out that vagal activity increases with an increasing percentage of oxygen in the gas mixture. Consequently, breathing under high pressure around 3 ATA would increase ANS activity due to the increasing partial pressure of the oxygen. The studies of Lund et al. (1999) and Lund et al. (2000) support this consideration and describe the increase in vagal activity in an experiment in the hyperbaric chamber while breathing air at a pressure of 2,5 ATA against breathing air at a pressure of 1 ATA.

The influence of the cold water environment (Al-Ani et al., 1995; Le Blanc et al., 1975) is most probably not relevant as the temperature of the water in Sharm El Sheikh was approximately 29°C. Furthermore, water temperature has no influence on ANS activity in a longer time exposition (Bonde-Peterson et al., 1992).

Vagal activity decreases with increasing exercise intensity; from the determinate exercise intensity, the decrease in vagal activity is accompanied by an increase in sympathetic activity (Achten & Jeukendrup, 2003; Nakamura, Yamamoto, & Muraoka, 1993; Rowell, 1993; Perini et al., 1990). These changes in ANS activity during exercise evoke a decrease in the total power spectrum of SA HRV (Iellamo et al., 2002). It is likely that the exercise intensity during recreational scuba diving was low (at an average of 9.3 points on the Borg scale of RPE) and therefore could not significantly influence the changes in the power spectrum.

The limiting factors of our study include a) a gender imbalance (17 men and 3 women), b) different levels of scuba diving experience (from the level of being a beginner without experience up to the instructor level), c) a low number of participants. Thus, there is a lack of evidence to describe the influence of age, gender or preceding experience on the ANS reaction during scuba diving. Likewise, we were not able to identify individual acclimatization after a quick shift through time zones from Europe to Africa (Stejskal et al., 2004), although, the participants started with diving at least 3 days after landing. Unfortunately, it was not possible to measure ANS activity ashore under controlled resting conditions.

CONCLUSIONS

Scuba Diving with recreational parameters (immersion in 20 meters for a period of 43 minutes) probably led to an increase in ANS activity. The changes in standard, percentage and ratio parameters and complex indices of SA HRV documented an increase in vagal activity which persisted for 30 minutes after diving.

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REAKČNÍ ZMĚNY AUTONOMNÍHO NERVOVÉHO SYSTÉMU V SOUVISLOSTI S PŘÍSTROJOVÝM POTÁPĚNÍM

(Souhrn anglického textu)

Cílem předkládané studie bylo zjistit, jak reaguje autonomní nervový systém (ANS) na pobyt pod vodou při přístrojovém potápění s rekreačními parametry sestupu.

Experimentální skupina se skládala z 20 přístrojových potápěčů, 17 mužů a 3 žen, kteří byli podrobeni měření v egyptském Sharm El Sheikhu. Aktivita ANS byla hodnocena před ponořením do hloubky 20 m a 20 minut po vynoření (celková doba pobytu pod vodou byla 43,3 ± 2,2 minuty) pomocí spektrální analýzy (SA) variability srdeční frekvence (HRV), při které bylo použito přístrojů Varcor multi PF7 a Varcor PF6. Při měření HRV z krátkého záznamu EKG bylo použito standardizovaného ortoklinostatického manévru (třikrát 300 tepů nebo třikrát 5 minut) a byly interpretovány jednotlivé i komplexní parametry SA HRV.

Srovnáním hodnot před a po pobytu pod hladinou bylo zjištěno, že po vynoření došlo k vzestupu jednotlivých parametrů souvisejících s aktivitou vagu (spektrální výkon komponenty HF, ukazatel časové domény MSSD a celkový spektrální výkon), k přesunu spektrálního výkonu z pásem pomalejších fluktuací do pásma rychlých fluktuací, k vzestupu komplexního ukazatele vagové aktivity a k vzestupu komplexního ukazatele sympatovagové rovnováhy. Všechny tyto změny svědčí o tom, že při ponoření pod vodní hladinu došlo ke stimulaci vagu, která přetrvávala ještě 30 minut po vynoření.

Ponoření a pobyt v hloubce 20 m pod vodou a postupné vynořování se projevilo zvýšenou aktivitou ANS způsobenou stimulací vagu, která přetrvávala ještě 30 minut po vynoření.

Klíčová slova: přístrojové potápění, autonomní nervový systém, aktivita vagu, variabilita srdeční frekvence.

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