SPECTRAL ANALYSIS OF HEART RATE VARIABILITY DURING SCUBA DIVING

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***Abstract* - Power spectral analysis of heart rate variability (HRV) is a well known clinical and physiological analysis method. However, the role of the cardiovascular control systems during underwater swimming and SCUBA diving is not completely understood. This paper examines the HRV during SCUBA diving using a recently developed microcontroller based real-time underwater acoustic biotelemetry system. The telemetered results applied to autoregressive modelling for spectral estimation suggest that the methodology can detect changes within the neurorequlatory control systems in response to the different diving regimes . This new system provides wide functional versatility for users interested in real-time underwater heart rate variability and physiological monitoring studies.**

Keyword: Heart rate variability, underwater biotelemetry, diver physiology.

I. INTRODUCTION

In this paper, we apply power spectral analysis as a means of studying and interpreting the heart rate variability (HRV) of divers using SCUBA (self contained underwater breathing apparatus). This technique has been previously used to diagnose various syndromes such as myocardial infarction and diabetic neuropathy [1,2] and sudden cardiac deaths with unexplained syndromes have been reported for diving [3]. It is well known that the beat to beat variation of HRV is primarily controlled by several cardiovascular control systems: the sympathetic nervous system (SNS); the parasympathetic nervous system (PNS) and the renin-angiotensin system (RAS). The research in this area is vast, but has been generally focused on two prominent peaks in the HRV spectrum that consist of: a low frequency (LF) peak at about 0.1 Hz (Mayer rhythm), primarily attributed to the sympathetic nervous systems (SNS); and a high frequency (HF) peak at 0.25-0.35 Hz (respiratory sinus arrythmia),usually attributed to the (PNS) system. So far as is known no study has been attempted on the characterisation of HRV during SCUBA diving. This would allow direct correlation between the heart rate rhythms represented by the associated peaks in the power spectrum with specific activity or exercise.

2. METHODS

The ECG data used to generate the HRV power spectra were collected using a novel microcontroller based multichannel underwater acoustic biotelemetry system. This was developed for real-time monitoring and subsequent clinical analysis of physiological information from SCUBA divers [4,5]. The telemetered ECG data was obtained from a group of divers ranging in age from 19 to 51. Heart rate data were obtained during several open water dives to 6m depth which is the shallowest depth at which decompression stops are normally made by sport divers in the UK. From each subject the ECG was recorded using five experimental diving protocols: (1) Entering the water and submersion, (2) change posture , (3) slow swimming, (4) fast swimming at 6m depth and (5) ascending. The received ECG data was acquired using a portable PC and digitized using an 8-bit A/D converter at 200 sample/s for subsequent analysis. The R-R interval tachogram was generated and its reciprocal, the instantaneous HR, was computed. A linear interpolation technique was then applied to generate the evenly spaced HRV signals at 0.5 s intervals. A record length of 480 sample points (i.e. 4 minutes of data) for each phase was selected for the power spectral analysis. An autoregressive (AR) model, using the maximum entropy method (MEM) was used for calculating the power spectrum. A 17th order AR model was chosen for the analysis of the experimental data.

3. RESULTS and DISCUSSION

Fig.1 illustrates a typical heart rate tachogram sample obtained during the 20 minutes open water diving from an experienced diver aged 51 during phases (1) and (4). Fig.2 shows the corresponding power spectrum plots. Fig. (3) shows the 3-D plots of the power spectra for the whole open water dive protocols. In general the PSD results have shown consistent correlation with other experienced divers.

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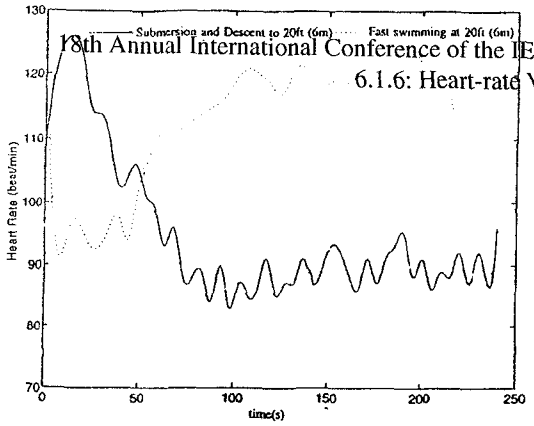

Fig.1 The heart rate variability during SCUBA dive

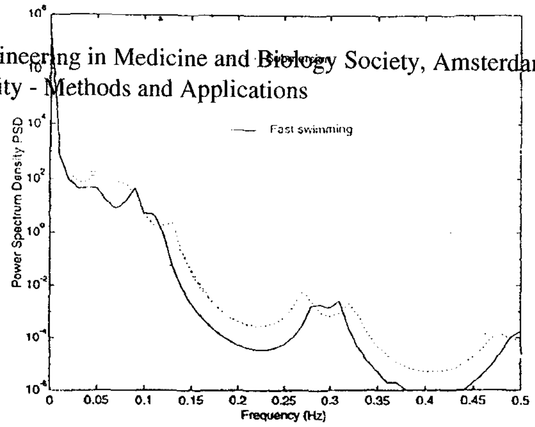

Fig.2 The corresponding power spectrum

The fall of the HR during the initial phase is reflected by an apparent LF and augmented HF components. This is mainly associated with the occurrence of bradycardia during submersion due to the stimulation of various receptors. It is also affected by increased activity of vagal intervention of the heart, and vasoconstriction in peripheral vascular beds [6]. However, the consistent LF oscillations might be caused by the transient tachycardia resulting from the descent, which is due to the muscle contractions accompanied by the rise in the SNS tone as shown in Fig.2. In the fast swimming phase an increase in both LF and HF peaks is apparent. However, these results support the concept of a reduction in vagal activity occurring during steady exercise and the restoration of the vagal tone at the end of intense exercise[8].The increase in the LF peak during underwater exercise also supports the concept of increased SNS activity to the sinoatrial node at higher rate of above 100 beat/min [9].

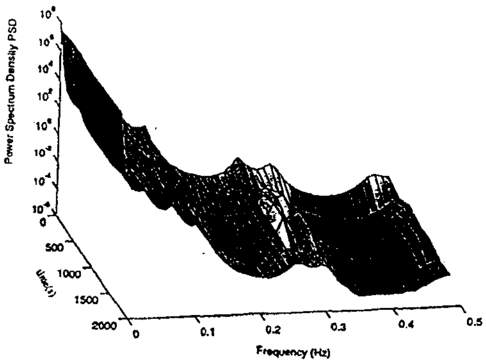

Fig.3 3-D plot of the PSD of the open water dive

5. CONCLUSIONS

This paper outlines a study of the power spectral analysis of heart rate variability associated with SCUBA diving from real-time biotelemetered ECG data in open water. The results indicate that the spectral parameters based on autoregressive analysis can be used to discriminate between the different frequency components of the heart rate rhythms.

The telemetered results also indicate that spectral analysis is a useful clinical method in understanding and interpreting the sympatho-vagal dynamical balance of the cardiovascular control systems under different real-time diving conditions.

4. REFERENCES

1. Lombardi, G. , Pernpruner, S. and Cerutti, S., 'Heart rate variability as an index of sympathovagal interaction after acute myocardial infraction' Am . J. Cardiol., Vol.60 , pp.1239-1245, 1987.

2. Pagani, M. Malfatto.,G., Pierini, S., and Poli A.,' Spectral analysis of the heart rate variability in the assessment of autonomic diabetic neuropathy', J. Auton Nerv., Sys., Vol.23, pp.143-153, 1988.

3. Eldridge, L." Sudden unexplained death syndrome in cold water SCUBA diving', Undersea Biomd. Res. (supplement), Vol.6, pp.41, 1979.

4. Woodward, B., and Habib Istepanian, R., ' Acoustic Biotelemetry of data from divers', Proc. 15th. Ann Int. Conf. IEEE Eng. Med.and Biology, San Diego, Vol.2., pp.100-1002, Oct. 1993.

5. Woodward, B., and Habib Istepanian, R., ' The use of underwater acoustic biotelemetry for monitoring ECG from a swimming patient', Proc. 1st. Regional Conf., IEEE Eng. Med. and Biology, New Delhi-India, Vo.4., pp.100-108, Feb.1995.

6. Hempleman, H., and Lockwood, A.,' The physiology of diving in man and other animals, Edward Arnold Pub., 1978.

7. Pomeranz, B., Macaulay, R., and Adam, D., 'Assesment of autonomic function in humans by spectral analysis', Am. J. Physiol., Vol428, pp.151-153, 1985.

8. Robinson, O., Epestain, S., and Bryan, W., Control of heart rate by autonomic nervous systems, studies in man and interrelation between baroreceptor mechanisms and exercise', Circ. Res., Vol.19, pp.400-411, 1966.

9. Rowell, L.B.,'Human circulation regulation during physical stress', N.Y. Oxford University Press, 1986.