Nonlinear Investigation of the Frequency Response of Cerebral Autoregulation

Alexander B. Rowley[a,*], Stephen J. Payne[b],
Mark Ebden[b], Ilias Tachtsidis [c], Jonathan P. Whiteley[a], and David J. Gavaghan [a]

[a]Oxford University Computing Laboratory. [b]Department of Engineering Science, Oxford University.
[c]Department of Medical Physics and Bioengineering, University College London.

1 Introduction

Low frequency oscillations in cerebral haemodynamics can be observed using near-infra-red spectroscopy (NIRs) (1; 2). NIRs is an optical technique that can be used non-invasively to measure tissue oxygenation index (TOI). Currently the key techniques to assess dynamic cerebral autoregulatory capacity are based upon the assumption that the cerebral cortex behaves as a high pass filter, rejecting the large low frequency (baseline) changes in mean arterial pressure (MAP) and passing the much smaller (beat-to-beat) changes. The presence of low frequency content in TOI presents a problem for this method of assessment since it is difficult to ascertain whether the observed low frequency content is the result of slow pressure waves (Mayer Waves) passed through the cerebral vasculature, or spontaneous oscillations that can be observed in isolated vessels (termed Vasomotion) which are a result of instabilities in the mechanisms regulating vascular smooth muscle tone.

It is our hypothesis that non-linear interactions between these two oscillators result in the observed time series and that changes in the degree of interaction between these two control systems might serve as a useful assessment of the status of dynamic cerebral autoregulation. This abstract presents the preliminary results of Bispectral analysis of tissue oxygenation index for a healthy normal patient at the falls clinic in Oxford. Bispectral analysis is a higher order signal processing technique which can detect quadratic phase coupling (QPC) between different harmonics in a time series. The presence of QPC is a strong indicator that the time series is the output of a nonlinear system.

2 Methods

Clinical data was obtained from the falls clinic of the Radcliffe Infirmary in Oxford. The patient was subjected to a prolonged head-upright tilt table test of duration 30-60 minutes. $\mathrm{O_2Hb}$, HHb, CytOx, TOI and THI were measured noninvasively at 6Hz using NIRs, and Blood Pressure was measured beat-to-beat using a Finapres® device. Blood pressure was re sampled to a uniform sampling frequency of 6Hz using linear interpolation, and then processed to give mean arterial pressure (MAP) using a trough detection algorithm.

Analysis was performed using the MATLAB®Higher Order Spectral Analysis (HOSA) toolbox. A non-parametric power spectral density of TOI and MAP was computed using the Welch Periodogram with a sliding Hanning window of 256 samples, and overlap of 128 samples. Bispectral Density of TOI and MAP was computed via a window averaging method using a 256 point Parzen window and an overlap of 128 points.

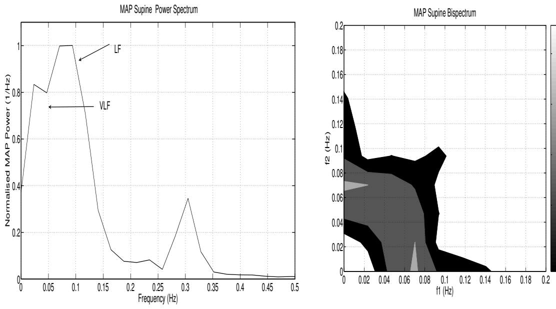
3 Results

Figure 1 shows the power and bispectral densities of MAP and TOI for one patient both before and during prolonged headup tilt. Figures 1(a) and 1(b) show the spectra computed from 1024 samples of data just before tilt. Figures 1(c) and 1(d) show the spectra of 1024 samples after haemodynamic parameters appeared to settle towards the end of the tilt.

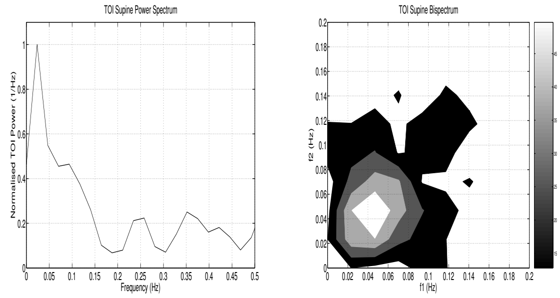
4 Discussion

The results obtained for one patient show that the relative increase in low frequency power in the TOI trace from the supine to the upright position upon tilting is much greater than the relative increase in MAP low frequency power which is in general agreement with (1). A more interesting result comes from comparison of the pre-tilt (supine) and post-tilt (upright) bispectra for TOI. As would be expected, no evidence for nonlinear interactions are

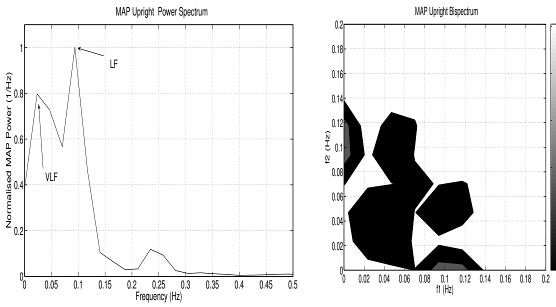
*Oxford University Computing Laboratory, Wolfson Building, Parks Road, OXFORD, OX1 3QD, UK. Telephone +44 (0) 1865 (2) 83568. Email: abr@robots.ox.ac.uk



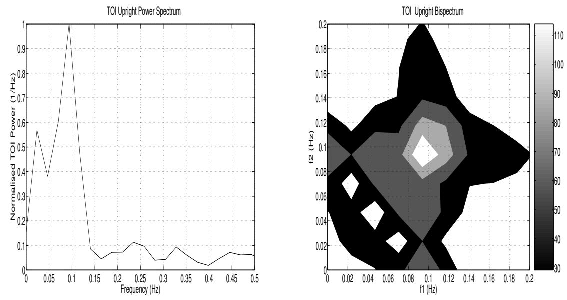
(a) Supine MAP Spectra



(b) Supine TOI Spectra



(c) Upright MAP Spectra



(d) Upright TOI Spectra

Figure 1. Polyspectral Analysis of TOI and MAP time series before and after tilt

observed in either the supine or upright *MAP* bispectra, however both the supine and upright *TOI* bispectra display evidence of nonlinear interactions. In the supine bispectrum, the interaction is less pronounced than the upright bispectrum and appears at around $0.05Hz$. In the upright bispectrum a strong interaction between frequencies at $0.1Hz$ is demonstrated. This supports the hypothesis that interaction between the systemic (Mayer Wave) oscillations and vasomotion of cerebral vessels is contributing to the observed frequency content in the upright TOI spectrum. The frequency component at $0.2Hz$ in this trace could be explained by the summation of the two oscillator frequencies, however this conclusion could not be identified just by looking at the power spectral densities of the traces in isolation.

Although statistically significant conclusions cannot be drawn from analysis of a single clinical trace, the recently discovered importance of the low frequency content of the NIRO parameters in assessing cerebral haemodynamics (1) suggests that analysis of the bispectrum could be a promising technique for assessing the dynamic autoregulatory capacity. Future work must concentrate on performing this analysis across more of the data collected by the IRC and development of a modelling framework allowing the results of these interactions to be interpreted physiologically. The idea that dynamical autoregulatory status can be assessed by measuring interactions between low frequency MAP and TOI content naturally suggests that data from techniques which can force certain input frequencies in MAP (such as sinusoidal lower body negative pressure) could provide valuable clinical information when analysed by this technique.

References

1. I. Tachtsidis, C. E. Elwell, T. S. Leung et al. “Investigation of cerebral haemodynamics by near-infrared spectroscopy in young healthy volunteers reveals posture-dependent spontaneous oscillations.” *Physiol Meas* **25(2)**, pp. 437–445, April 2004.

2. I. Tachtsidis, C. E. Elwell, C. W. Lee et al. “Spectral characteristics of spontaneous oscillations in cerebral haemodynamics are posture dependent.” *Adv Exp Med Biol* **540**, pp. 31–36, 2003.