Complex Demodulation of Baroreflex during Parabolic Flight

K Couckuyt, B Verheyden, F Beckers, J Liu, AE Aubert

Dept of Cardiology, University Hospital Gasthuisberg, KU Leuven, Belgium

Abstract

In this study we evaluated the usefulness of complex demodulation (CDM) for the assessment of baroreflex sensitivity (BRS) and time delay during dynamic changes of autonomic cardiovascular regulation induced by changing gravity during parabolic flight.

BRS and time delay data assessed with CDM in the HF band are influenced by non-baroreflex coupling of heart rate and blood pressure variations. LF band estimates reflect baroreflex coupling. BRS estimates obtained with complex demodulation correlate well ($r = 0.92$; $p < 0.01$) with estimates obtained with power spectrum analysis. Our results show no postural differences in normo- and hypergravity. In microgravity, standing BRS estimates are higher than supine estimates.

It can be concluded that CDM, applied on LF band variations of heart rate and systolic blood pressure, provides reliable estimates of baroreflex characteristics in dynamic autonomic cardiovascular control.

1. Introduction

The baroreflex is a short-term control mechanism contributing to the blood pressure (BP) homeostasis by buffering pressure changes with appropriate heart rate (HR) adjustments. Different methods have been developed to assess closed-loop baroreflex sensitivity (BRS) from spontaneous fluctuations of BP and HR in time- and frequency domain. Frequency domain transfer function analysis (TFA) and α-method have proven to be usefull tools in the analysis of BRS for the evaluation of the baroreflex feedback mechanism in different physiological conditions [1-4]. These methods however only provide averaged features of time series and are based on the assumption that the system is stationary during the whole analysed period.

Complex demodulation (CDM) has been introduced as a time-local version of harmonic analysis in the field of HRV [5]. CDM assumes that periodic oscillations exist within a certain frequency band and quantifies the instantaneous amplitude and phase of these oscillations as a function of time [6]. Therefore, CDM gives access to the study of dynamic changes of cardiovascular variability and BRS [7].

Parabolic flight is used to create short successive periods of changing gravity in a range between 0 Gz and 1.8 Gz (1 Gz = 9.81 m/s²). Autonomic reflex adjustments of heart rate are shown to preserve cardiovascular homeostasis during gravitational challenges in the upright position. However, the short duration of gravity phases (±20s) imposes limitations to classical HRV, BPV and BRS analysis methods [8]. We propose to use CDM analysis to unravel time-dependent changes in baroreflex characteristics during gravity transitions of parabolic flight. Baroreflex gain as well as time delay were obtained. We compared results from CDM analysis in healthy subjects to the corresponding values obtained with zero-padded TFA.

2. Methods

2.1. Study protocol

Data were obtained during the 36th ESA parabolic flight campaign in 2004, at the SOGERMA center in Bordeaux, France. Flight sessions were performed with an Airbus A300 aircraft on three consecutive days and during each session thirty parabolas were performed preceded by one test-parabola. Between parabolas, at least one minute rest was allowed and between groups of five parabolas, at least five minutes rest was given.

Instantaneous gravity was measured using an aircraft Gz-accelerometer. Each parabola can be split up into five phases of about 20 seconds based on the Gz-force (Figure 1) : Phase I or normogravity (1 Gz) before each parabola, Phase II or hypergravity (1.8 Gz) at the ascending leg of the parabola, Phase III or microgravity (0 Gz) at the top of the parabola, Phase IV or hypergravity (1.8 Gz) at the descending leg of the parabola and Phase V or normogravity after the parabola.

Five healthy male subjects (age 43±14 years) participated in the parabolic flight. Each subject was in supine position during 15 parabolas and was standing during the other 15 parabolas. Subjects were asked to

breath at a fixed rate of 15 breaths per minute (respiration frequency 0.25 Hz). Tidal volumes were not controlled.

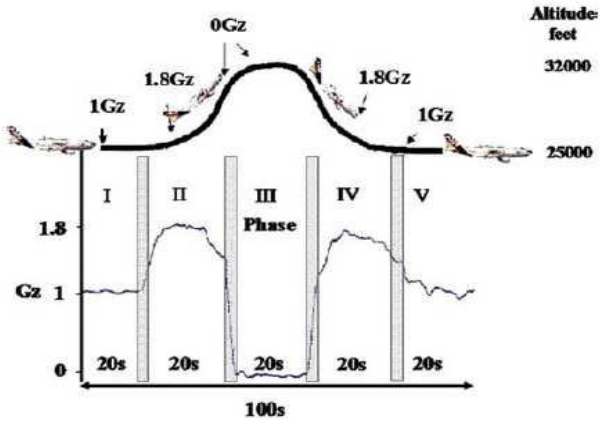


Figure 1. Schematic of the parabolic flight profiles in each flight session. Parabola phases are separated based on the instantaneous gravity level.

2.2. Data acquisition

ECG signals were continuously monitored with a lead II derivation (Medtronic 9690 Amplifier, Minneapolis, MN, USA). Continuous non-invasive BP recordings were obtained with a servo-controlled photoplethismograph (Portapres, TNO, Amsterdam, the Netherlands) placed on the middle finger. Respiration rate was monitored by an abdominal pressure sensor (MR10 Respiration Monitor, Graseby Medical Limited, Hertfordshire, UK). The analogue signals were A/D converted (Dataq Instruments Inc., Akron, OH, USA) and sampled at 1000 Hz per channel.

2.3. Data analysis

All data processing was performed offline. RR-interval tachograms were generated using peak detection on the ECG-signals and were inspected on artefacts and ectopic beats. Blood pressure signals were processed with beatscope (Finapress Medical Systems BV, the Netherlands) resulting in systolic, mean and diastolic time series. Parabolic flight data per phase were analysed both using transfer function analysis and complex demodulation. For both methods, BRS and time delay between heart rate and blood pressure oscillations were derived from the tachogram and the systogram in both low- (LF) and high-frequency (HF) bands, resp. 0.05 to 0.15 Hz and 0.15 to 0.45 Hz.

Matching 20s fragments of the tachogram and systogram were isolated for each phase of each parabola and analysed by TFA in the frequency domain. Resampling, detrending, tapering with a Hanning-window and a stationarity test were executed on each fragment [8]. Non-stationary fragments were excluded from analysis. TFA on short time segments results in poor frequency domain resolution. This was solved by zero-padding the short time series to obtain 256 equally spaced (0.5s) data points before TFA was performed. BRS values were estimated by averaging the gain of the transfer function between SPB and RR-interval oscillations at frequencies where the coherence was greater than 0.5. Time shifts between SBP and RR-interval oscillations were obtained from the transfer function phase characteristics.

BRS (ms/mmHg)			
Phase	Method	Supine	Standing
I	CDM	6.0 ± 1.1	5.5 ± 1.6
	TFA	6.7 ± 1.0	6.5 ± 2.5
II	CDM	4.7 ± 0.7	3.8 ± 1.0
	TFA	4.8 ± 0.6	2.6 ± 0.4
III	CDM	4.3 ± 0.6	9.1 ± 2.0
	TFA	4.9 ± 0.9	8.1 ± 1.8
IV	CDM	5.1 ± 0.5	3.6 ± 0.5
	TFA	4.3 ± 0.7	2.4 ± 0.5
V	CDM	6.4 ± 1.0	6.0 ± 1.6
	TFA	6.7 ± 1.6	6.5 ± 2.4

Table 1. BRS values (ms/mmHg) assessed in LF band with CDM and TFA. Data are mean ± SEM.

Time delay (s)			
Phase	Method	Supine	Standing
I	CDM	2.0 ± 0.5	1.4 ± 0.6
	TFA	1.9 ± 0.3	1.3 ± 0.4
II	CDM	1.8 ± 0.4	1.8 ± 0.5
	TFA	1.4 ± 0.4	1.7 ± 0.3
III	CDM	1.4 ± 0.2	2.0 ± 0.2
	TFA	1.8 ± 0.2	2.5 ± 0.3
IV	CDM	2.3 ± 0.7	2.1 ± 0.7
	TFA	1.4 ± 0.5	2.2 ± 0.3
V	CDM	1.9 ± 0.1	1.4 ± 0.4
	TFA	1.7 ± 0.4	1.5 ± 0.4

Table 2. Baroreflex time delay values (s) assessed in LF band with CDM and TFA. Data are mean ± SEM.

CDM can be used to provide a continuous and reliable assessment of cardiovascular parameters [5,6]. Instantaneous amplitudes of the RR-interval and systolic BP oscillations were obtained for LF and HF bands. Instantaneous BRS was defined by the ratio of the instantaneous amplitude of the RR-interval oscillations to the instantaneous amplitude of the SBP oscillations within a specific frequency band. Mean BRS per phase was calculated by averaging the instantaneous BRS

values in the corresponding time segment. Time shifts were obtained from the instantaneous phase differences.

2.4. Statistical analysis

Given the skewed distribution of BRS values, geometric means were used to determine the BRS for each subject during each phase. The mean BRS for all five subjects was calculated as the arrhythmic mean. Paired sample t-test was used to evaluate the agreement between TFA and CDM results. Correlation between these data was expressed by Pearson's correlation coefficients. Two-way ANOVA for repeated measurements was performed to examine the influence of body position throughout different gravity phases. Paired sample t-test was performed to evaluate postural differences within each gravity phase.

3. Results

Table 1 and 2 list the results for BRS and time delay values assessed with TFA and CDM in the LF band. Positive time delay values are defined to represent a time lag of the heart rate variations compared to the blood pressure variations. No significant differences are found between BRS values of CDM and TFA (p=0.178 for standing ; p=0.312 for supine). Estimates assessed with both techniques correlate well (r=0.92 ; p<0.050). Time delay values are also comparable (p=0.592 for standing ; p=0.307 for standing). Time delay values calculated in HF band are small (between 0.0 and 0.5 seconds as well for TFA as for CDM in both supine and standing).

Figure 2 shows the evolution of BRS and time delay (mean ± SEM) as a function of gravity (parabolic phase), for supine and standing subjects. A significant difference between standing and supine data is observed for the BRS assessments in the 0 Gz phase (phase III ; p=0.039). There are no significant differences between standing and supine time delays (in 0 Gz time delays tend to be different with p=0.067). In standing, the BRS value in phase III is significantly higher than in all other phases (figure 2) while for supine data there are no differences between gravity phases.

Figure 3 shows the time-dependent evolution of BRS, systolic and diastolic blood pressure and RR-interval (mean values for all subjects and all parabolas + SEM) during a parabola for standing subjects. When gravity drops from 1.8 Gz to microgravity, RR-interval rises immediately while systolic BP first show a little increase and then decreases progressively. Diastolic pressure also decreases progressively but without initial increase.

4. Discussion and conclusions

This study examined the usefulness of CDM in analysing baroreflex functioning during dynamic autonomic cardiovascular control. We found that CDM, when applied to the LF band, allows reliable and continuous measurement of BRS and time delay between HR and BP fluctuations. Time delay values obtained in the HF band are below 0.5 seconds. The smaller values are attributed by some authors [9,10] to a mix of baroreflex and non-baroreflex coupling between BP and HR oscillations. We therefore restricted further analysis of baroreflex characteristics to the LF band assessments.

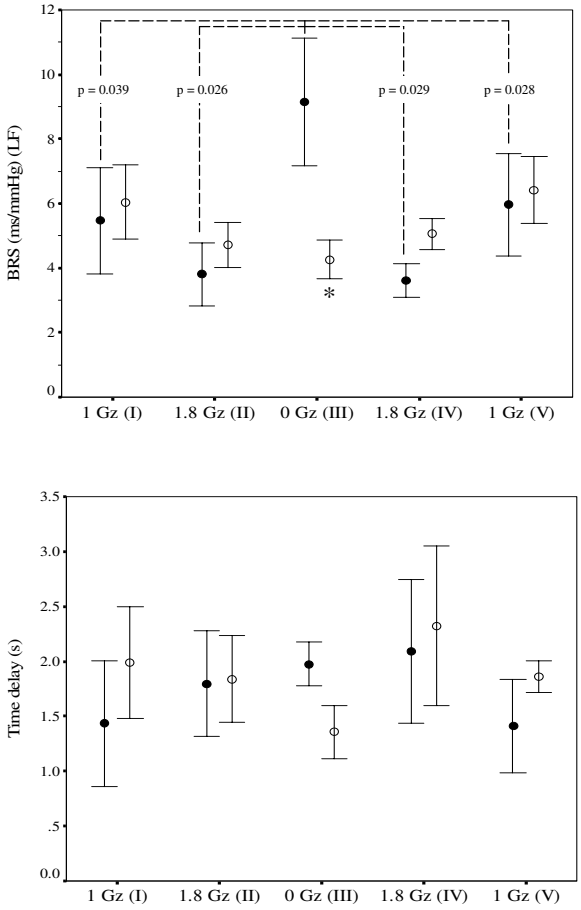
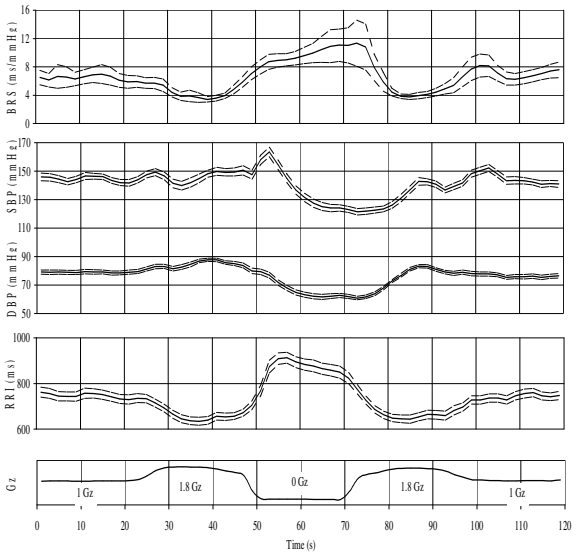


Figure 2. Evolution of BRS and time delay assessed with CDM (LF) as function of gravity during parabolic flight. Open and closed circles indicate values obtained during supine and standing position, respectively. * p<0.05 compared to standing in the same parabolic phase.

Both LF oscillations of BP and HR are influenced by slow responses to sympathetic autonomic activity. This questions the usefulness of LF estimates in dynamic settings. However, as shown in figure 3, there's a clear time-dependent variation of BRS during parabolic flight related to the parabolic phases. The 20s period of each phase is long enough to allow assessment of the BRS evolution by CDM applied in the LF band. This is in

agreement with previous validation studies of the use of CDM for HRV analysis requiring a time-resolution of about 16s [6].

In standing position, microgravity will induce an upward blood shift to the thorax and head. This enhances the vagal cardiac control leading to an increase in RR-interval (figure 3). Increased thoracic blood volume leads to an initial increase of systolic BP with an unchanged diastolic BP. This is counteracted by baroreflex feedback control to the heart and vasculature, leading to a progressive decrease of DSP and SBP and augmented BRS values. In hypergravity, a shift of blood to the lower limbs induces a withdrawal of vagal control, a decrease of RR-interval and BRS. Gravity changes do not induce a shift of blood volume for supine subjects. There are no differences in supine BRS values between all gravity phases. At normo- and hypergravity, BRS values in supine are expected to be higher than in standing. Our measurements show no differences between supine and standing. This is probably due to a suppressed vagal control due to excitement or anxiety of the subjects participating in the parabolic flight session.



Figuur 3. Time-dependent changes of BRS, systolic (SBP) and diastolic (DBP) blood pressure and RR-interval (RRI) during parabola. Data are represented as mean values for all parabolas and all subjects in standing position ± SEM.

Our findings agree with previous studies using other techniques for BRS assessment [6,8,11]. This favours the validity of CDM to quantify dynamic changes of BRS.

Acknowledgements

This work was funded by granting from ESA-PRODEX from the Belgian Federal Office of Scientific Affairs. Frank Beckers is a post-doctoral researcher of the Research Fund K.U.Leuven. Bart Verheyden and Kurt Couckuyt are supported from ESA-PRODEX grants. Jiexin Liu is supported from bilateral agreements Belgium-China from the Belgian Federal Office of Scientific Affairs.

References

[1] Akselrod S, Gordon D, Ubel FA, Shannon DC, Berger AC, Cohen RJ. Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. Science 1981; 213(4504):220-222.

[2] deBoer RW, Karemaker JM, Strackee J. Hemodynamic fluctuations and baroreflex sensitivity in humans: a beat-to-beat model. Am J Physiol 1987; 253(3 Pt 2):H680-H689.

[3] Robbe HW, Mulder LJ, Ruddel H, Langewitz WA, Veldman JB, Mulder G. Assessment of baroreceptor reflex sensitivity by means of spectral analysis. Hypertension 1987; 10(5):538-543.

[4] Pagani M, Somers V, Furlan R, Dell'Orto S, Conway J, Baselli G et al. Changes in autonomic regulation induced by physical training in mild hypertension. Hypertension 1988; 12(6):600-610.

[5] Hayano J, Taylor JA, Yamada A, Mukai S, Hori R, Asakawa T et al. Continuous assessment of hemodynamic control by complex demodulation of cardiovascular variability. Am J Physiol 1993; 264(4 Pt 2):H1229-H1238.

[6] Verheyden B, Couckuyt K, Beckers F, Aubert AE. Complex demodulation of heart rate variability during parabolic flight: an Exploratory study. Computers in Cardiology 32, 271-274. 2005.

[7] Kim SY, Euler DE. Baroreflex sensitivity assessed by complex demodulation of cardiovascular variability. Hypertension 1997; 29(5):1119-1125.

[8] Verheyden B, Beckers F, Aubert AE. Spectral characteristics of heart rate fluctuations during parabolic flight. Eur J Appl Physiol 2005; 95(5-6):557-568.

[9] Mancia G, Parati G, Castiglioni P, Di Rienzo M. Effect of sinoaortic denervation on frequency-domain estimates of baroreflex sensitivity in conscious cats. Am J Physiol 1999; 276(6 Pt 2):H1987-H1993.

[10] Seidel H, Herzel H, Eckberg DL. Phase dependencies of the human baroreceptor reflex. Am J Physiol 1997; 272(4 Pt 2):H2040-H2053.

[11] Beckers F, Seps B, Ramaekers D, Verheyden B, Aubert AE. Parasympathetic heart rate modulation during parabolic flights. Eur J Appl Physiol 2003; 90(1-2):83-91.

Address of correspondence

Kurt Couckuyt
Laboratory of Experimental cardiology
University Hospital Gasthuisberg O/N1
Herestraat 49, 3000 Leuven, Belgium
kurt.couckuyt@med.kuleuven.be