IOP Conf. Series: Journal of Physics: Conf. Series **882** (2017) 012016 doi:10.1088/1742-6596/882/1/012016

Measuring the human psychophysiological conditions without contact

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Abstract. Heart Rate Variability, HRV, studies the variations of cardiac rhythm caused by the autonomic regulation. HRV analysis can be applied to the study of the effects of mental or physical stressors on the psychophysiological conditions. The present work is a pilot study performed on a 23-year-old healthy subject.
The measurement of HRV was performed by means of two sensors, that is an electrocardiograph and a Laser Doppler Vibrometer, which is a non-contact device able to detect the skin vibrations related to the cardiac activity.
The present study aims to evaluate the effects of a physical task on HRV parameters (in both time and frequency domain), and consequently on the autonomic regulation, and the capability of Laser Doppler Vibrometry in correctly detecting the effects of stress on the Heart Variability.
The results show a significant reduction of HRV parameters caused by the execution of the physical task (i.e. variations of 25-40% for parameters in time domain, also higher in frequency domain); this is consistent with the fact that stress causes a reduced capability of the organism in varying the Heart Rate (and, consequently, a limited HRV).
LDV was able to correctly detect this phenomenon in the time domain, while the parameters in the frequency domain show significant deviations with respect to the gold standard technique (i.e. ECG). This may be due to the movement artefacts that have consistently modified the shape of the vibration signal measured by means of LDV, after having performed the physical task. In the future, in order to avoid this drawback, the LDV technique could be used to evaluate the effects of a mental task on HRV signals (i.e. the evaluation of mental stress).

1. Introduction

Several studies state that there is a significant relationship between autonomic nervous system and cardiovascular diseases, showing an association between arrhythmias and variations in the sympathetic and parasympathetic activities (1–5).
One of the most used markers of the relationship between cardiac activity and nervous system is Heart Rate Variability, HRV (6–9). It is the physiological phenomenon related to cardiac rhythm variability due to autonomic regulation; it is important not only for the prediction of cardiovascular risk (8), but also for the evaluation of different conditions, such as mental and physical stress (9–12), hypertension (13), diabetes (14) and pregnancy (10,15–17). The analysis of HRV allows to characterize the health and psychophysiological conditions of a subject, which cause changes in the balance between sympathetic and parasympathetic systems (18,19).
In the past, HRV has already been used to characterize the effects of physical or psychological stressors on the balance of the autonomic nervous system (20). In fact, stressors can be associated to

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an increase in sympathetic cardiac control and/or to a decrease in parasympathetic control. In particular, several studies have focused on the effects of a physical effort on HRV (21–24). In (25), an inverse proportion between the intensity of the physical task and the variability of the heart rate has been reported. Luft et al. (22) have investigated the effects of physical efforts on the execution of cognitive tasks and the correspondent HRV variations; they have found no overall difference in cognitive performance pre- and post- test condition, and the revealed differences in HRV suggest an increased stimulation of both the sympathetic and parasympathetic systems. On the other hand, according to (26), the subject, after the execution of a physical task (i.e. in stress conditions), is expected to show an increased Heart Rate; in addition, the High Frequency (HF) component of HRV signal is supposed to decrease.
The present work is a pilot study (carried out on a participant) with the aim of evaluating the effects of a physical task on HRV. The measurement procedure involved the use of an electrocardiograph (ECG) and a Laser Doppler Vibrometer (LDV) for the non-invasive and non-contact assessment of the cardiac activity; LDV technique has already been demonstrated as an accurate and reliable means to assess physiological parameters (16,17,27–30).

2. Materials and methods

2.1 Measurement setup

The experimental setup included the following instruments:

- Laser Doppler Vibrometer (PDV 100, Polytec (31), sensitivity of 0.2V/(mm/s));
- Electrocardiograph (ECG) (MLA2540, ADInstruments (32), 5 Lead, Shielded Bio Amp Cable).

A sketch of the measurement setup is reported in 'figure 1'. LDV and ECG signals were acquired simultaneously using a proper A/D board (PowerLab 4/25T, ADInstruments (33), 12-bit).
At first, a 23-year-old subject (male) was measured in rest conditions by means of electrocardiography and Laser Doppler Vibrometry, whose main advantage is being a non-contact sensor (27,30,34)); the signal (i.e. a velocity signal) had a time duration of 6 minutes, which is suitable for HRV analysis (20). Then, the subject was asked to make a 2-minutes run. ECG and VCG signals were recorded after having performed the task. During both the acquisition periods, the subject was asked to sit and stay relaxed. The LDV was placed on a tripod at distance of 0.5 m from the subject, with the laser beam directed perpendicularly to the skin surface, in correspondence of the carotid artery, so as to record the vibrations transmitted by the passage of the blood pulse in the underlying vessel.

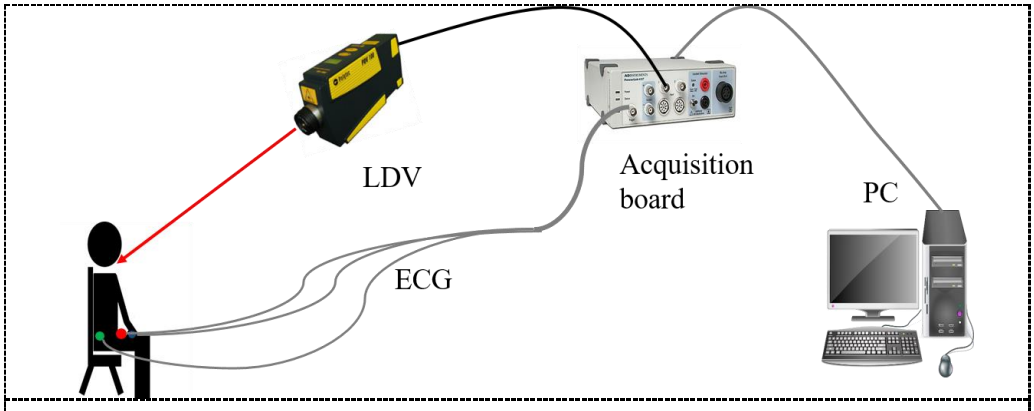


Figure 1. Sketch of the measurement setup

2.2 Data processing

The first step of data processing consisted in the detection of the main feature of ECG and LDV signals, that is the R-peak and the V-peak respectively, as shown in 'figure 2'.

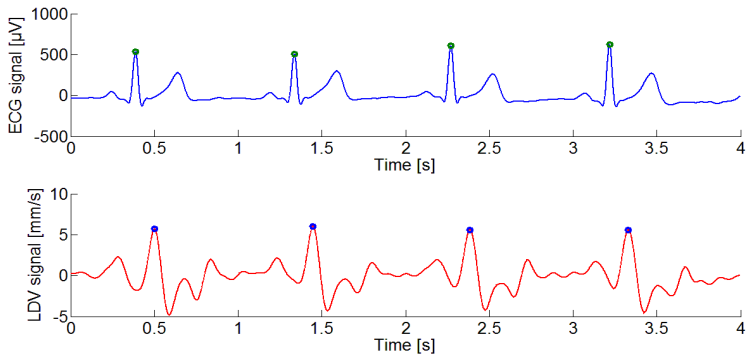


Figure 2. Example of main feature detection in ECG (top) and LDV (bottom)

The applied detection algorithm was developed by the authors on the basis of (35) and is based on the geometrical shape of the signals (36). In particular, it performs the computation of two straight lines on a small subset of points, by means of a sliding window. Then, the angle included between the two straight lines is computed; by detecting local minima of the angle, it is possible to locate the main peaks of the two considered signals (i.e. ECG and LDV).
The time location of ECG and LDV main peaks allowed to obtain the tachograms, i.e. the series of time intervals between two main features in a cardiac-related signal (37). Then, the HRV analysis was carried out by means of an open access software, named Kubios (38), considering both time and frequency domains.
Among all the obtainable parameters (30), in this work the authors considered the following features in time domain (13):

- RRavg [ms]: the average cardiac period;
- RMSSD [ms]: the square root of the mean squared differences of successive intervals between two main peaks;
- S^2 [ms^2]: the area of the ellipse obtained by means of Poincaré plot (14) (an example of this kind of representation is reported in 'figure 3').
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On the other hand, with regard to the frequency domain, the Power Spectrum Density (PSD) of the tachogram was computed, assuming equidistant sampling by means of interpolating techniques (39). In particular, the authors focused the attention on the following indices:

- LF (Low Frequency): the percentage of the tachogram spectral content in the range 0.04-0.15 Hz; it is commonly related to the activation of the sympathetic nervous system;
- HF (High Frequency): the percentage of the tachogram spectral content in the range 0.15-0.40 Hz; it can be considered characteristic of the parasympathetic nervous system activation;
- LF/HF: the ratio of LF to HF, describing the balance between sympathetic and parasympathetic branches of the autonomic nervous system.

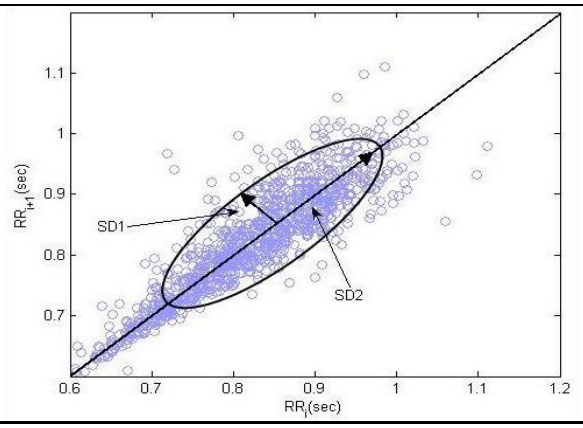


Figure 3. Example of Poincaré plot

3. Results

The chosen parameters (i.e. RRavg, RMSSD, S^2, LF, HF and LF/HF) were computed for both the signals, ECG and LDV, in both the studied conditions, i.e. at rest and after performing the physical task. This aimed to verify the effects of the physical task on the Heart Rate Variability, and to evaluate the capability of LDV technique in HRV analysis considering different operative conditions. In 'table 1' there are reported the results from ECG and LDV in time domain, while in 'table 2' the results in frequency domain are shown.

Table 1. HRV parameters in time domain, at rest and after the execution of the physical task

	Rest			**After physical task**		
	RRavg [ms]	**RMSSD [ms]**	**S^2 [ms^2]**	**RRavg [ms]**	**RMSSD [ms]**	**S^2 [ms^2]**
ECG	953	28	988	710	17	638
LDV	954	27	900	702	17	615

Table 2. HRV parameters in frequency domain, at rest and after the execution of the physical task

	Rest			**After physical task**		
	LF [%]	**HF [%]**	**LF/HF [ ]**	**LF [%]**	**HF [%]**	**LF/HF [ ]**
ECG	56	28	2.0	8	2	3.4
LDV	56	27	2.1	12	30	0.4

4. Discussion and conclusions

This pilot study aimed to evaluate the effects of the stress caused by a physical task on the heart rate variability and the capability of Laser Doppler Vibrometry, a fully non-contact technique, in assessing HRV in different conditions. The results from both the used sensors confirm the initial statements; in fact, after having performed the physical task, the subject showed a relevant percentage increase of the Heart Rate (i.e. 26 %) and a very significant decrease of HF content (i.e. 85 %) was computed in the PSD of the tachogram signal.
The measurement, performed on a 23-year-old healthy subject, at rest and after the execution of a physical task, showed variations in HRV parameters, in accordance with the literature (22,26).
Indeed, the comparison of HRV parameters derived from ECG signal in the two considered measurement conditions has put in evidence:

- a decrease of RRavg, RMSSD and S^2, which is consistent the reduction of HRV caused by the execution of the physical task;
- a decrease of HF content and an increase of LF/HF ratio, which is related to the reduced capability of the subject in varying the heart rate in response to the execution of the physical task.

LDV measurements provided results comparable with the gold standard method (i.e. ECG) in the time domain, while there are significant deviations in spectral parameters.
The aforementioned considerations allow the authors to state that HRV analysis in stress condition can be accurately performed in time domain by means of both ECG and LDV sensors. Anyway, the stress due to the physical task cannot be correctly quantified by considering the analysis of HRV in the frequency domain performed by means of LDV signals. This may be due to the movement artefacts caused by the strain of the subject after the execution of the physical task (in this case, the subject can be laboured, so that laser beam is not directed in a stable point).
However, it is of utmost importance to consider the LDV advantage of being a non-contact technique; in fact, this can be spent on carrying out measurements on particular subjects, such as (preterm) neonatal patients, who would be upset by the application of ECG electrodes.
Therefore, LDV technique should be further explored in the evaluation of stress through HRV analysis, trying to avoid the effects of movement artefacts; in this direction, another possible field of application could be the study of the effects of a mental task on HRV by means of the considered non-contact technique, so avoiding the problem linked to movement.

References

1. Lown B, Verrier RL. Neural activity and ventricular fibrillation. N Engl J Med. 1976 May 20;294(21):1165–70.
2. Du X-J, Dart AM. Role of sympathoadrenergic mechanisms in arrhythmogenesis. Cardiovasc Res. 1999 Sep 1;43(4):832–4.
3. Natali JES, Starzynski PN, Chaui-Berlinck JG. Oscillatory patterns in heart rate variability and complexity: A meta-analysis. Biomed Signal Process Control. 2017;33:66–71.
4. Cysarz D, Leeuwen PV, Edelhäuser F, Montano N, Somers VK, Porta A. Symbolic transformations of heart rate variability preserve information about cardiac autonomic control. Physiol Meas. 2015;36(4):643.
5. Akselrod S, Amitay Y, Lang RM, Mor-Avi V, Keselbrener L. Spectral analysis of left ventricular area variability as a tool to improve the understanding of cardiac autonomic control. Physiol Meas. 2000;21(2):319.
6. Kamath MV, Watanabe M, Upton A. Heart Rate Variability (HRV) Signal Analysis: Clinical Applications. CRC Press; 2012. 535 p.

7. Cerutti S, Baselli G, Civardi S, Furlan R, Lombardi F, Malliani A, et al. SPECTRAL ANALYSIS OF HEART RATE AND ARTERIAL BLOOD PRESSURE VARIABILITY SIGNALS FOR PHYSIOLOGICAL AND CLINICAL PURPOSES. In 1987. p. 435–8.
8. van Ravenswaaij-Arts CMA, Kollee LAA, Hopman JCW, Stoelinga GBA, van Geijn HP. Heart Rate Variability. Ann Intern Med. 1993 Mar 15;118(6):436–47.
9. Gang Y, Malik M. Heart rate variability in critical care medicine. Curr Opin Crit Care. 2002;8(5):371–5.
10. Lange S, van Leeuwen P, Geue D, Hatzmann W, Grönemeyer D. Influence of gestational age, heart rate, gender and time of day on fetal heart rate variability. Med Biol Eng Comput. 2005;43(4):481–6.
11. Calvo M, Gomis P, Romero D, Rolle VL, Béhar N, Mabo P, et al. Heart rate complexity analysis in Brugada syndrome during physical stress testing. Physiol Meas. 2017;38(2):387.
12. Visnovcova Z, Mestanik M, Javorka M, Mokra D, Gala M, Jurko A, et al. Complexity and time asymmetry of heart rate variability are altered in acute mental stress. Physiol Meas. 2014;35(7):1319.
13. Cardiology T force of the ES of, Pacing the NAS of, Electrophysiology. Heart rate variability standards of measurement, physiological interpretation, and clinical use. Eur Heart J. 1996;17:354–81.
14. Kamen PW, Tonkin AM. Application of the Poincaré plot to heart rate variability: a new measure of functional status in heart failure. Aust N Z J Med. 1995 Feb;25(1):18–26.
15. Carpenter RE, D'Silva LA, Emery SJ, Uzun O, Rassi D, Lewis MJ. Changes in heart rate variability and QT variability during the first trimester of pregnancy. Physiol Meas. 2015;36(3):531.
16. Scalise L, Morbiducci U. Non-contact cardiac monitoring from carotid artery using optical vibrocardiography. Med Eng Phys. 2008;30(4):490–497.
17. Morbiducci U, Scalise L, Melis MD, Grigioni M. Optical Vibrocardiography: A Novel Tool for the Optical Monitoring of Cardiac Activity. Ann Biomed Eng. 2007 Jan 1;35(1):45–58.
18. Friedman BH, Thayer JF. Autonomic balance revisited: Panic anxiety and heart rate variability. J Psychosom Res. 1998 Jan;44(1):133–51.
19. Miu AC, Heilman RM, Miclea M. Reduced heart rate variability and vagal tone in anxiety: Trait versus state, and the effects of autogenic training. Auton Neurosci. 2009 Jan 28;145(1–2):99–103.
20. Wiley: Dynamic Electrocardiography - Marek Malik, A. John Camm [Internet]. [cited 2017 Feb 24]. Available from: http://www.wiley.com/WileyCDA/WileyTitle/productCd-1405119608.html
21. Soares-Miranda L, Sattelmair J, Chaves P, Duncan G, Siscovick DS, Stein PK, et al. Physical Activity and Heart Rate Variability in Older Adults: The Cardiovascular Health Study. Circulation. 2014 May 5;CIRCULATIONAHA.113.005361.
22. Luft CDB, Takase E, Darby D. Heart rate variability and cognitive function: effects of physical effort. Biol Psychol. 2009 Oct;82(2):164–8.
23. Hottenrott K, Hoos O, Esperer HD. [Heart rate variability and physical exercise. Current status]. Herz. 2006 Sep;31(6):544–52.
24. Tonello L, Rodrigues FB, Souza JWS, Campbell CSG, Leicht AS, Boullosa DA. The role of physical activity and heart rate variability for the control of work related stress. Front Physiol [Internet]. 2014 Feb 21 [cited 2017 Feb 24];5. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3931195/
25. Heart Rate Variability Dynamics During Early Recovery After Different Endurance Exercises [Internet]. PubMed Journals. [cited 2017 Feb 24]. Available from: https://ncbi.nlm.nih.gov/labs/articles/17899162/
26. Vuksanović V, Gal V. Heart rate variability in mental stress aloud. Med Eng Phys. 2007 Apr;29(3):344–9.

27. Pinotti M, Paone N, Santos FA, Tomasini EP. Carotid artery pulse wave measured by a laser vibrometer. In: Third International Conference on Vibration Measurements by Laser Techniques: Advances and Applications [Internet]. International Society for Optics and Photonics; 1998 [cited 2015 Oct 12]. p. 611–616. Available from: http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=954179
28. Cosoli G, Casacanditella L, Tomasini EP, Scalise L. Evaluation of Heart Rate Variability by means of Laser Doppler Vibrometry measurements. J Phys Conf Ser. 2015;658(1):12002.
29. Casaccia S, Sirevaag EJ, Richter E, O'Sullivan JA, Scalise L, Rohrbaugh JW. Decoding carotid pressure waveforms recorded by laser Doppler vibrometry: Effects of rebreathing. In: AIP Conference Proceedings [Internet]. AIP Publishing; 2014 [cited 2015 Oct 28]. p. 298–312. Available from: http://scitation.aip.org/content/aip/proceeding/aipcp/10.1063/1.4879596
30. Cosoli G, Casacanditella L, Tomasini EP, Scalise L. The non-contact measure of the heart rate variability by laser Doppler vibrometry: comparison with electrocardiography. Meas Sci Technol. 2016;27(6):65701.
31. GmbH P. Polytec: PDV-100 Portable Digital Vibrometer [Internet]. [cited 2016 Nov 30]. Available from: http://www.polytec.com/it/products/vibration-sensors/single-point-vibrometers/complete-systems/pdv-100-portable-digital-vibrometer/
32. Bio Amp Cables [Internet]. ADInstruments. [cited 2017 Feb 24]. Available from: https://www.adinstruments.com/products/bio-amp-cables
33. PowerLab [Internet]. ADInstruments. [cited 2017 Feb 24]. Available from: https://www.adinstruments.com/products/powerlab
34. Castellini P, Martarelli M, Tomasini EP. Laser Doppler Vibrometry: Development of advanced solutions answering to technology's needs. Mech Syst Signal Process. 2006 Aug;20(6):1265–85.
35. Hu X, Liu J, Wang J, Xiao Z, Yao J. Automatic detection of onset and offset of QRS complexes independent of isoelectric segments. Measurement. 2014 May;51:53–62.
36. Cosoli G, Casacanditella L, Pietroni F, Calvaresi A, Revel GM, Scalise L. A novel approach for features extraction in physiological signals. In: 2015 IEEE International Symposium on Medical Measurements and Applications (MeMeA). 2015. p. 380–5.
37. Engineering Approaches to Study Cardiovascular Physiology: Modeling, Estimation, and Signal Processing. Frontiers E-books; 136 p.
38. Biosignal Analysis and Medical Imaging Group - Kubios HRV [Internet]. 09:22:52.849189 [cited 2015 Dec 1]. Available from: http://kubios.uef.fi/
39. Merri M, Farden DC, Mottley JG, Titlebaum EL. Sampling frequency of the electrocardiogram for spectral analysis of the heart rate variability. IEEE Trans Biomed Eng. 1990 Jan;37(1):99–106.