Ahsan Habib Khandoker
Chandan Karmakar
Michael Brennan
Andreas Voss
Marimuthu Palaniswami

Poincaré Plot Methods for Heart Rate Variability Analysis

Springer

Poincaré Plot Methods for Heart Rate Variability Analysis

Ahsan Habib Khandoker • Chandan Karmakar
Michael Brennan • Andreas Voss
Marimuthu Palaniswami

Poincaré Plot Methods for Heart Rate Variability Analysis

Springer

Ahsan Habib Khandoker
Department of Biomedical Engineering
Khalifa University, Abu Dhabi, UAE

Department of Electrical and Electronic Engineering
The University of Melbourne, VIC, Australia

Michael Brennan
Electrical and Electronic Engineering
The University of Melbourne
Melbourne, VIC, Australia

Marimuthu Palaniswami
Electrical and Electronic Engineering
The University of Melbourne
Melbourne, VIC, Australia

Chandan Karmakar
Electrical and Electronic Engineering
The University of Melbourne
Melbourne, VIC, Australia

Andreas Voss
Department of Medical Engineering and Biotechnology
University of Applied Sciences Jena
Jena, Germany

ISBN 978-1-4614-7374-9   ISBN 978-1-4614-7375-6 (eBook)
DOI 10.1007/978-1-4614-7375-6
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2013939585

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Dedicated to students and researchers
of biomedical engineering.

Preface

Heart rate variability is the study of autonomic nervous activity through the information provided by fluctuations in heart rate. Autonomic activity is responsible for regulating heart rate. By studying the beat-to-beat variability in the intervals between heartbeats, it is possible to form a representation of autonomic nervous activity. Alterations in this activity can thus be quantitatively measured with a non-invasive technique. Accordingly, heart rate variability has become a very active field of research and the most popular biological signal by which the autonomic nervous system is studied. Heart rate variability can measure the individual levels of parasympathetic and sympathetic modulation of heart rate, and from this information one can make predictions on the state of the autonomic nervous system. Moreover, a deeper exploration of the physiological basis of the autonomic nervous system can be investigated.

The study of the autonomic nervous system from the information contained in heart rate relies upon mathematical models and techniques and the power of digital computers to achieve reliable and accurate results. In the past only simplistic mathematical techniques have been brought to bear due to the limited ability of clinical investigators in this regard. Recently, mathematicians, physicists and engineers have worked alongside cardiologists and physiologists to develop sophisticated models and mathematical techniques for the analysis of heart rate data. The development of more accurate models of heart rate variability and robust analysis techniques that are immune to the large levels of noise and artefact found in all biological signals is an active field of research currently. Advances in this area have direct benefits to clinical and physiological studies that employ heart rate variability to study disease and physiology.

Many of the mathematical techniques are only approximations and have defects that are not obvious except when analysed carefully with a mathematical formulation. Mathematical analysis allows one to investigate the limitations of analysis techniques. Further, the full potential of the analysis techniques is often only revealed by a full mathematical treatment. The theoretical study of models of the autonomic system has similar characteristics, with the limitations and full descriptive power of a model being largely unknown until studied mathematically.

The study of models also allows the development of optimal analysis techniques. Many of the mathematical algorithms and models applied in HRV analysis remain uninvestigated. The problem is, how do we quantitatively characterize (linear and/ or nonlinear) the heart rate time series to capture useful summary descriptions that are independent of existing HRV measures? Recent research on HRV has proven that Poincaré plot analysis (PPA) is a powerful tool to mark short-term and long-term HRV. Researchers have investigated a number of techniques: converting the two-dimensional plot into various one-dimensional views; the fitting of an ellipse to the plot shape; and measuring the correlation coefficient of the plot. In fact, they are all measuring linear aspects of the intervals which existing HRV indices already specify. The fact that these methods appear insensitive to the nonlinear characteristics of the intervals is an important finding because the Poincaré plot is primarily a nonlinear technique. This result motivates the search for better methods for Poincaré plot quantification. This provides the motivation for this book.

Chapter 1 gives an overview of the physiological concepts and necessary background in the field of heart rate variability, including the history, physiology, analysis techniques and the clinical significance of the field. This includes models of heart rate variability and the mathematical signals employed to characterize heart rate variability. Details of the time-domain and frequency-domain analysis of these signals are also covered.

Chapter 2 provides a mathematical analysis of a common heart rate variability technique known as the Poincaré plot. The Poincaré plot is an emerging analysis technique that takes a sequence of intervals between heartbeats and plots each interval against the following interval. The geometry of this plot has been shown to distinguish between healthy and unhealthy subjects in clinical settings by employing trained specialists to visually classify the plots. The Poincaré plot is a valuable HRV analysis technique due to its ability to display nonlinear aspects of the interval sequence. In particular we investigate the question of whether existing measures of Poincaré plot geometry reflect nonlinear features of heart rate variability. We show that methods of Poincaré quantification that summarize the geometrical distribution of the points with "moment-like" calculations, i.e. means and standard deviations, etc., are unlikely to be independent of existing linear measures of heart rate variability.

Chapter 3 of the book investigates Poincaré plot interpretation using a new oscillator model of heart rate variability. This chapter develops a physiologically plausible mathematical model of autonomic nervous control of heart rate based on a series of well-studied oscillations in heart rate. By employing the results described, the time series of intervals between heartbeats are able to be analytically determined. The properties of the Poincaré plot can then be derived. By analysing the Poincaré plot in terms of an underlying model of HRV, the theoretical basis of Poincaré plot morphology can be precisely related back to the model and therefore back to the physiological causes. This provides a deeper understanding of the Poincaré plot than has previously been possible. To validate the model, simulations of various autonomic conditions are compared to HRV data obtained from subjects under the prescribed conditions. For a variety of autonomic balances, the model generates

Poincaré plots that undergo morphological alterations strongly resembling those of actual heartbeat intervals.

Poincaré plot is valuable due to its ability to display nonlinear aspects of the data sequence. However, the problem lies in capturing temporal information of the plot quantitatively. The standard descriptors used in quantifying the Poincaré plot (*SD1*, *SD2*) measure the gross variability of the time series data. Determination of advanced methods for capturing temporal properties poses a significant challenge. Chapter 4 proposes a novel descriptor "Complex Correlation Measure (*CCM*)" to quantify the temporal aspect of the Poincaré plot. In contrast to *SD1* and *SD2*, the *CCM* incorporates point-to-point variation of the signal.

The asymmetry in heart rate variability is a visibly obvious phenomenon in the Poincaré plot of normal sinus rhythm. It shows the unevenness in the distribution of points above and below the line of identity, which indicates instantaneous changes in the beat-to-beat heart rate. The major limitation of the existing asymmetry definition is that it considers only the instantaneous changes in the beat-to-beat heart rate rather than the pattern (increase/decrease). Chapter 5 describes a novel definition of asymmetry considering the geometry of a 2D Poincaré plot. Based on the proposed definition, traditional asymmetry indices—Guzik's index (*GI*), Porta's index (*PI*) and Ehlers' index (*EI*)—have been redefined.

Chapter 6 of the book considers the segmented aspects of Poincaré plot remaining, on the one hand, the nonlinear properties of the system and, on the other hand, providing high resolution information about the time course and time correlations within a heart rate time series. These new approaches were successfully introduced in risk stratification.

This book should be of considerable help to researchers, professionals in medical device industries, academics and graduate students from a wide range of disciplines. The text provides a comprehensive account of recent research in this emerging field and we anticipate that the concepts presented here will generate further research in this field.

Melbourne, VIC, Australia	Ahsan Habib Khandoker
Melbourne, VIC, Australia	Chandan Karmakar
Melbourne, VIC, Australia	Michael Brennan
Jena, Germany	Andreas Voss
Melbourne, VIC, Australia	Marimuthu Palaniswami

Acknowledgements

The authors would like to gratefully acknowledge the contribution of Michael Brennan in Chaps. 2 and 3. The authors would also like to thank Claudia Fischer and Rico Schroeder of University of Applied Sciences Jena for their contributions in Chap. 6. The authors wish to gratefully acknowledge the financial support provided by the Australian Research Council and the Deutsche Forschungsgemeinschaft (DFG: Vo 505/8-1 and Vo 505/8-2) for the research presented in Chaps. 3–6, respectively.

Contents