Merged Poincaré plot based heart rate analysis

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***Abstract*— Inter Beat intervals (IBI) in heart rate variability (HRV) are balanced by the actions of the sympathetic (SNS), parasympathetic neural systems (PSNS), and central cardiovascular plasticity. The neural systems are easy to reach by Photoplethymographic (PPG) means. PPG is also much used for fitness testing purposes. For the PPG pulse series analysis we used merged Poincaré plots parameters which have been much extended to evaluate pulse rate variability (PRV). The preliminary results demonstrated that the combination of merged Poincaré plots could show promise as a method for distinguishing between healthy individuals and different vascular disease groups. In addition, the hypothesis of this paper is that PPG pulse wave signals measured before and after the sauna exposure can lead to improve the understanding and estimation of the human body's healthy status.**

Keywords—Merged Poincaré plot, heart rate variability, Photoplethysmography, electrocardiography, sauna exposure

I. Introduction

Photoplethymographic (PPG) pulse series we used in the merged Poincaré plot analysis. This analysis was extended to evaluate pulse rate variability (PRV) as a surrogate of heart rate variability (HRV) changed by a sauna exposure (SE). High levels of HRV values are generally signs of healthy efficient autonomic mechanisms of sympathetic and parasympathetic neural systems that characterise individuals like sport people. Low or reduced HRV values often shows an autonomic nervous system malfunction and may imply becoming health problems. PPG recordings are typically affected by physiological factors related to the transmission of the pulse wave through the vascular bed. The accuracy of the PPG pulse wave detection depends on the pulse morphology, the recording site, and the sampling frequency. There is a need to define the most accurate fiducial point for performing a PRV analysis under non-stationary conditions based on different PPG sensor locations, finger or toe during the SE. However, in rest it is easily done. The most relevant fiducial points are found by the second derivative of PPG waves (SDPPG) [1]. In practice, Poincaré plots are an intuitive and commonly used nonlinear time based method to assess complex biosystems and biosignals time series. Our preliminary results demonstrated that the combination of two or more merged Poincaré plots could show promise as a method for distinguishing between different vascular functions. Using the merged Poincaré plots, both PPG and SDPPG technologies are in many medical devices that are available in clinics [2]. The ability of measuring heart rate variability, oxygen saturation, blood pressure, cardiac output, and blood stroke volume for assessing autonomic function, detecting peripheral vascular disease, and predicting the risk of atherosclerosis reflecting the importance of these techniques. Because atherosclerosis disease is not homogeneous phenomena, it can depend on the blood viscosity. On the other hand, viscosity depends on red blood cells, molecules, and body temperature in elderly. Clinically hematocrit and plasma viscosity influence on blood viscosity. The morphology of the PPG signal pulses could be significantly changed because of chemical substance. Red and infrared light of PPG gradually increased and the chemicals trigger to finally go to higher values in amplitude. During the SE several physiological mechanisms have been proposed for the positive health effects. The sauna exposure increases cardiac output and simultaneously reduces peripheral vascular resistance, which parameters are key things. Viscosity belongs to arterial elastic property which is chracterized as deformability of a material when a force is applied. Since red boold cells (RBC) cytoplasm mainly consists of Hb and HbOx components, the elastic properties of RBC is determined by RBC membrane structure. Other small physiological changes in cardiovascular parameters can be found such as decreased systolic and diastolic blood pressure, and increased HRV.

II. Materials and methods

A. Subjeccts

We measured by our photoplethysmographic (PPG) device the responses on 17 patients in the hospital, the healthy males and females (10 + 7) and 29 healthy volunteers among the departmental personnel during the SE tests.

B. Measurement and analysis techniques

The PPG sensors based on LEDs and photodetector, and optoelectronic amplifier circuit which make possible to consider the deep origins of the photoplethysmography waveform characteristics. Finger and toe PPG pulse waves were measured by LEDs of 660 (red) & 940 (infrared) nm in the PPG probes according to phase sensitive detection (PSD). For the PPG pulse signals there were determined the functions of inter beat intervals (IBI) based on the second derivatives of photoplethysmographic (SDPPG) waveforms. For the IBI functions we plotted with an Origin App with a Poincare plot confidence ellipse (Figure 1) by OriginPro2019b (OriginLab).

The measurement room temperature of 25°C within silent environment was setup for PPG signal acquisition at 1 kHz with a 16 bit A/D converter. To ensure the acquisition of fingertip PPG signal, subjects were asked to be in a supine position, but in sitting position during the sauna exposure. The sensor probe was connected to index finger of the left arm within 300 seconds of recording session. Subjects were asked to be at rest and to breathe with natural and normal breathing rate during the recording session. Measurements of resting HRV was before the sauna exposure, and stimulated HRV was obtained after 30 min of the sauna exposure. These results are presented on the Poincaré plots.

III. Results and discussion

For the comparison of the red and infrared PPG pulse wave in the merged Poincaré plots are shown in Figure 1 for a 31

years male person. When the triangles are merged, then they form a star, as in Figure 1. In merged Poincaré plot section it is also shown the number of the stars in each section. The total number is 50.

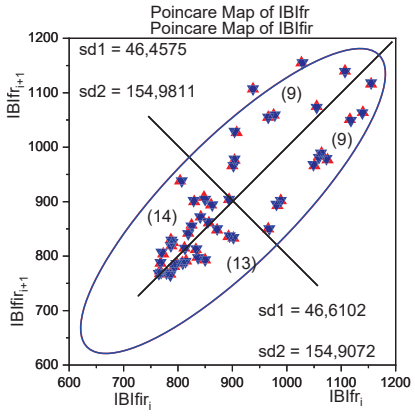
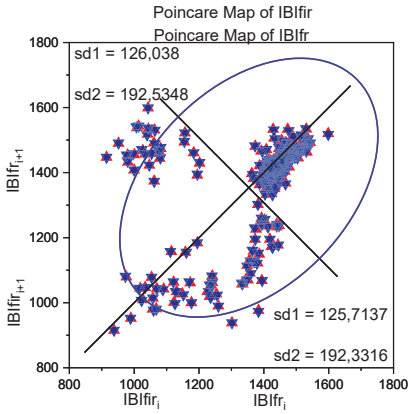


Figure 1. An example of a merged Poincare plot containing the infrared (red) and red (blue) IBI_i vs IBI_{i+1} values for a 31 year male subject. The Poincare parameters (SD1 & SD2 and a fitted ellipse) are shown for the subject's finger (red & infrared, fr and fir). The comparison of the red and infrared PPG pulse wave in the merged Poincaré plot is constructed so that the infrared PPG pulse inter beat intervals (IBI_{fir}) are shown by a red triangle pointing up, and the red PPG pulses, IBI_{fr}, are marked by a blue triangle pointing down. The unit of axis is 1 ms (=1/1 kHz).



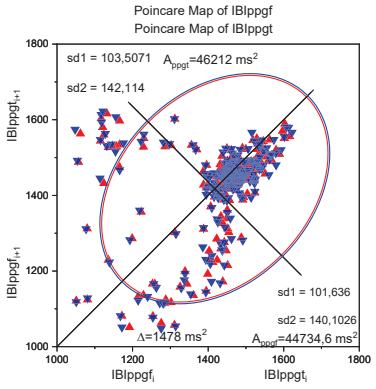


Figure 2. Example of a merged Poincare plot containing the infrared (red) and red (blue) IBI values for a 31 year male subject (upper). The Poincare parameters (SD1 & SD2 and a fitted ellipse) are shown for the subject's finger (red) and toe (blue) PPGs (below, IBIppgf, IBIppgt) with a fitted ellipse area. The toe ellipse has a little bigger area, because they have bigger SD1 and SD2 values.

The parameter values are shown by a red triangle (infrared PPG) and a blue triangle (red PPG). When the IBI values have equal standard deviation, then a star is the result, Figure 1, 2, and 3. Also the merged Poincaré plots show that the IBI values for the finger red and infrared totally overlap, however the finger infrared and the toe infrared do not completely overlap.

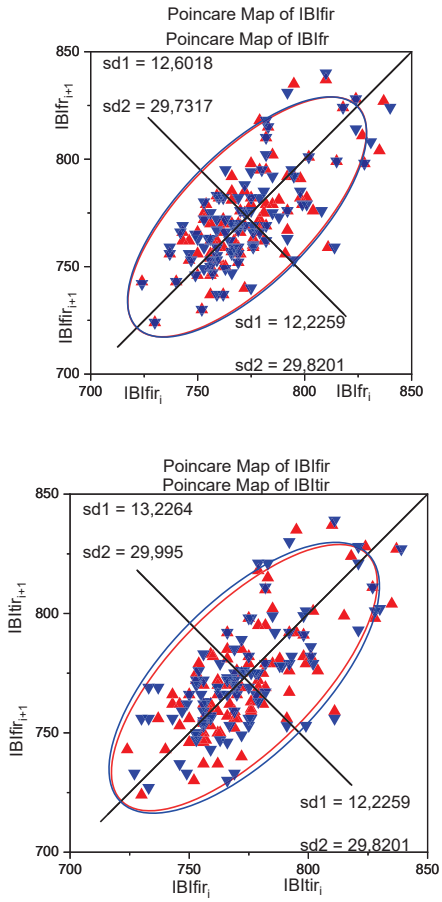


Figure 3. A merged Poincare plot for an over 60 years male subject (upper). The Poincare parameters (SD1 & SD2 and the fitted ellipse) are shown for the subject's finger and toe PPGs (below). Only a few stars are the results.

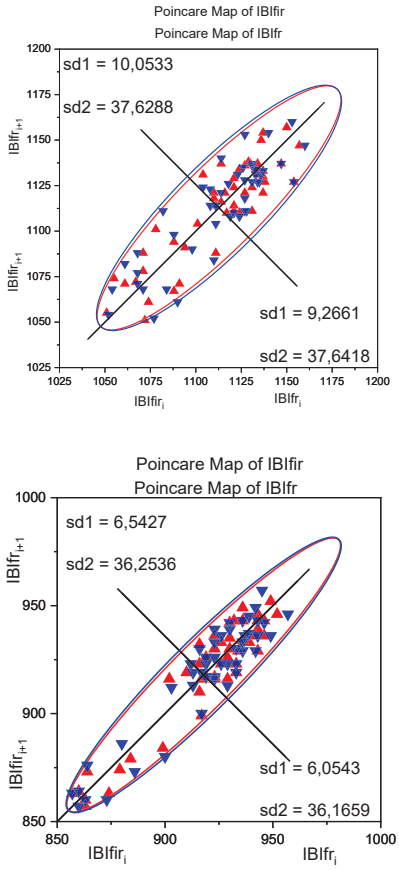


Figure 4. A merged Poincare plot for an over 60 years male subject (upper) before the SE, and after the exposure (lower). The Poincare parameters (SD1 & SD2 and the fitted ellipse) are shown for the subject's finger PPGs (below). The SD1 and SD2 values are smaller after the SE than at the resting state.

In Figures 1, 2, 3, and 4 the parameter values are shown by a red triangle (infrared PPG) and a blue triangle (red PPG) respectively. In Figure 2, the merged Poincaré plots show that the IBI values for both for the red and infrared PPGs and the finger and toe PPGs. Their IBI values seldom overlap. The exact mechanism causing the phenomenon for the overlapping or not overlapping is largely unknown, but it could depend on the central cardiovascular plasticity on the younger persons. This plasticity gradually disappears during aging. In biomedical engineering there is growing interest in understanding the mechanisms involved about HR, and HRV technology.

Poincare plot is the representation of non-linear analysis of the first maximum (a) of the second derivative of each PPG pulse signal, graphical illustration for the correlation between successive inter beat intervals (IBI) by plotting the values of IBI_{j+1} as a function of IBI_j. The plot for the nonlinear phenomena presents similarly as the linear correlation. This correlation is expected to give the information on the minimum number of dynamic variables for modeling the system under study. In Poincare plot, two dimensional analyses at any given dot is the combination of IBIs right next to each other. X axis IBI interval which represent the length of time and Y axis IBI_{j+1} next to it and therefore we shall get very crowded plot with full of dots. The shape of the plot depends on quantifying the different layer of distribution, like torpedo, comet, or meteor-like. Often it looks an ellipse and defined by two parameters SD1 (minor ellipse radius)) widening and SD2 (majos ellipse radius) length of ellipse. SD1 can be considered as short term variability and correlated with so called pNN50 in tradiotional HRV analysis and high frequency parameters in spectral domain. SD2 can be considered as long term variability measures and correlates with SDNN (standard deviation of IBI interval) and low frequency parameters.

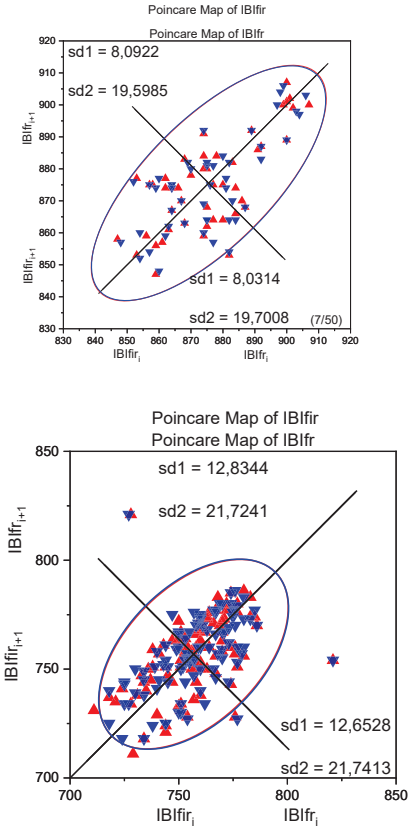


Figure 5. A merged Poincare plot for a 66 years male subject (upper) before the sauna exposure, and after the exposure (lower). The Poincare parameters (SD1 & SD2 and the fitted ellipse) are shown for the subject's finger PPGs (below). Both SD1 and SD2 values have been increased because of the sauna exposure and two extra inter beat intervals outside of the fitted ellipse.

Sauna exposure can enhance muscle strength and increase muscle capillary flow density after the SE. Frequent SEs were also found to be associated with a lowering of blood pressures in long term. The sauna – like exposures were associated with marked improvements in quality of life and reduced anxiety levels compared with intermittent light-intensity exercise which did not affect, e.g., quality of life as much as the heat exposure therapy. It may serve as an alternative therapy to recover skeletal muscle metabolic function and size, e.g., during leg immobilization. After the SE to normothermia can enhanced resting neural network relaxation in the brains followed by an increase in cognitive processing. A SE is safe and maintains good health condition both skin temperature compared to other bathing methods according to health status questionnaires. While sauna promotes health in practice, it is very good personal health care. It has been shown in Finland that frequent sauna exposures may prevent brain infarctions and the stroke rate by 60%. However, longitudinal studies

could open other effects which are caused by the SE. In Japan Waon therapy has been found to reduce cardiac events with cardiac failure patients. This therapy is a promising non-pharmacological treatment for these patients notwithstanding its low temperatures. In our preliminary SE test, the test persons responded to the queries that they have been doing really long time regular floorball around a couple of times per week. That is high-heart rate sport. In addition, the also included in the gym fairly regularly for many years, but now they do floorball perhaps about 5-10 per a week. Alcohol they were not consuming and do not have or use drugs. In addition, they enjoy some endurance sports, jogging, skiing, etc…

According to literature sauna exposures can be tolerated for half an hour immediately after a training run and provides an additional good training stimulus. Also endurance performance of sub-elite runners was enhanced by a useful 2%, probably via an increase in blood volume. Elite endurance athletes may experience smaller gains from such sauna exposures [3]. Finnish sauna exposure added with cold-water immersion were causing hemodynamic alterations in chronic heart failure patients similar like to control subjects and did not cause an excessive increase in adrenergic activity or complex arrhythmias [4].

This dual wave (red & infrared) PPG probes were firmly attached on the forefinger and second toe nail. After calculating the second derivative of PPG data maxima were found by the Peak Analyzer that offers a method to find the maxima of the SDPPG for the heart rate variability. Inter beat interval is a term used in reference to the time interval between individual beats of the heart. The clinical utility of the SE measured by PPG Poincaré plot analysis may indicate health impairment or predicting heart health. Poincaré plot or return map is graphed by plotting every IBI interval against the preceding interval, creating a scatter plot. However, Poincaré plot analysis is insensitive to changes during the SE trends in the IBI intervals. However, further investigations using larger subject number to determine even more variabilities in the vital health-related information. In the SE, dehydration could be contributors to the elevated of blood viscosity. Blood flow in the peripheral arteries is influenced by both viscosity and hematocrit. Many challenges remain with the technology, according to the literature [5].

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