

Shoe Insole ballistocardiography as a Tool for Heart Rate Variability Estimation in Smart Insoles

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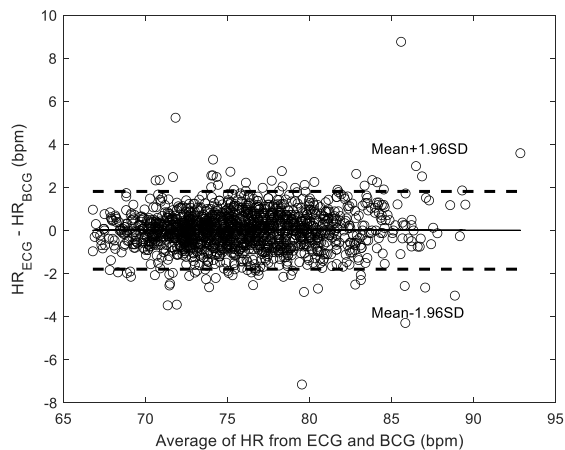
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Aims: Heart rate variability (HRV) has been established as a noninvasive tool for assessing the cardiovascular system. The Electrocardiography (ECG) and Photoplethysmography (PPG) are the gold standard techniques for measuring HRV, but they require the use of electrodes and direct skin contact. Ballistocardiogram (BCG) is a noninvasive method for measuring whole-body recoil forces in reaction to cardiac ejection of blood through the vascular tree at each heartbeat. BCG can be measured by embedding a piezoelectric sensor on the heel area of a shoe insole, eliminating the need to remove socks as it does not require direct skin contact unlike ECG and PPG. This work demonstrates the potential use of shoe insole BCG to estimate HRV in seated position from short-term recordings of at least 5 min.

Methods: ECG and BCG were simultaneously recorded for 7 min from 3 seated subjects. For heartbeat detection, a template matching technique was used, through an automatic template generation without a reference signal. In addition, an automatic correction of incorrect heart rate (HR) values due to false positives or negatives was performed. Finally, both temporal and spectral HRV parameters from BCG and ECG were calculated and compared.

Results: A Bland-Altman plot was used to evaluate the agreement between HR values obtained with BCG and ECG. The 95% confidence interval obtained was ± 1.80 bpm, which is lower than the accuracy limits recommended by the AAMI standard for HR meters of ± 5 bpm (Figure). This agreement between the time series is evidenced by high statistical correlation in both temporal and frequency parameters of HRV with both techniques (see table).



Parameter	r
RR _{mean} (ms)	0,999
SDNN (ms)	0,995
RMSSD	0,908
PVLF (ms ²)	0,999
PLF (ms ²)	0,996
PHF (ms ²)	0,991
LF/HF (ms ²)	0,998

Conclusion: HRV analysis measured from the BCG obtained from a shoe insole has shown to be a noninvasive, comfortable, reliable, and skin contact-less tool for ambulatory monitoring and assessment of cardiovascular system.