Detecting HR using BCG and IMU: A Technical Review

Introduction

Heart rate (HR) monitoring is crucial for assessing cardiovascular health and overall well-being. Traditional methods, such as electrocardiography (ECG), can be cumbersome and unsuitable for continuous monitoring. Ballistocardiography (BCG) and Inertial Measurement Units (IMU) have emerged as promising alternatives for non-invasive and continuous HR estimation. BCG measures the body's micro-vibrations caused by cardiac activity, while IMUs capture body movements and orientations. This review examines recent research on combining BCG and IMU data to improve the accuracy and reliability of HR detection, particularly in ambulatory settings. The fusion of these two modalities offers the potential to overcome limitations of each individual technology and provide robust HR monitoring in real-world scenarios. This review analyzes current research trends and identifies key challenges and future directions in the field. This integrated approach holds significant potential for advancing remote health monitoring and personalized healthcare applications.

Related Works

1. **Optimal Head-mounted IMU Placement for Heart Rate Detection Using Ballistography**
   - Authors: Saboora M. Roshan, Edward J. Park
   - Year: 2024
   - Abstract: Continuous and accurate heart rate monitoring is pivotal for the early detection of cardiovascular conditions. Traditional heart rate sensing methods, such as the use of adhesive electrocardiogram (ECG) electrodes, often fall short in terms of comfort and convenience for everyday wear and continuous monitoring. Ballistocardiography (BCG), a non-invasive alternative, offers a promising solution by measuring the body's mechanical reactions to the ejected blood by the heart during cardiac cycles. This paper introduces a novel heart detection method utilizing IMU-based BCG applied to the head, focusing on optimizing sensor placement on the head for improved accuracy. Noteworthy is that the detection algorithm needs to be robust against noise and movement artifacts; therefore, the choice of sensor location and signal processing techniques become key factors. This pilot study explores various IMU mounting locations on the head and signal processing techniques to improve the feasibility and accuracy of head-mounted wearable devices employing BCG.
   - URL: https://doi.org/10.1109/EMBC53108.2024.10782353
2. **Optimization and evaluation of a mobile IMU-based ballistocardiography system**
   - Authors: Lucas Klauth, Andreas Mühlen, A. Kitzig, E. Naroska, G. Stockmanns
   - Year: 2023
   - Abstract: Abstract In recent decades ballistocardiography (BCG) has regained popularity as a way to measure the mechanical activ- ity of the heart. In this paper we present and evaluate a new iteration of our mobile BCG measurement system. The pro- posed system uses an inertial measurement unit (IMU) placed on the carotid artery to derive the BCG. We conducted a mea- surement series to evaluate the system and to do an initial in- vestigation into whether more complex heart parameters can be derived from BCG data. The evaluation shows that heart rate (HR) and heart rate variability (HRV) calculated using BCG data, agrees well with the reference measurement and amplitudes calculated are mostly comparable in range to other papers. In

conclusion, the system can reliably derive features from BCG data that can be used in further research.
- URL: https://doi.org/10.1515/cdbme-2023-1170

3. **Reference ranges for ambulatory heart rate measurements in a middle-aged population**
    - Authors: A. Persson, A. Måneheim, J. Economou Lundeberg, Arthur Fedorowski, J. S. Healey, Johan Sundström, Gunnar Engström, L. Johnson
    - Year: 2024
    - Abstract: Background Elevated heart rate (HR) predicts cardiovascular disease and mortality, but there are no established normal limits for ambulatory HR. We used data from the Swedish CArdioPulmonary Imaging Study to determine reference ranges for ambulatory HR in a middle-aged population. We also studied clinical correlates of ambulatory HR. Methods A 24-hour ECG was registered in 5809 atrial fibrillation-free individuals, aged 50–65 years. A healthy subset (n=3942) was used to establish reference values (excluding persons with beta-blockers, cardiovascular disease, hypertension, heart failure, anaemia, diabetes, sleep apnoea or chronic obstructive pulmonary disease). Minimum HR was defined as the lowest 1-minute HR. Reference ranges are reported as means±SDs and 2.5th–97.5th percentiles. Clinical correlates of ambulatory HR were analysed with multivariable linear regression. Results The average mean and minimum HRs were 73±9 and 48±7 beats per minute (bpm) in men and 76±8 and 51±7 bpm in women; the reference range for mean ambulatory HR was 57–90 bpm in men and 61–92 bpm in women. Average daytime and night-time HRs are also reported. Clinical correlates, including age, sex, height, body mass index, physical activity, smoking, alcohol intake, diabetes, hypertension, haemoglobin level, use of beta-blockers, estimated glomerular filtration rate, per cent of predicted forced expiratory volume in 1 s and coronary artery calcium score, explained <15% of the interindividual differences in HR. Conclusion Ambulatory HR varies widely in healthy middle-aged individuals, a finding with relevance for the management of patients with a perception of tachycardia. Differences in ambulatory HR between individuals are largely independent of common clinical correlates.
    - URL: https://doi.org/10.1136/heartjnl-2023-323681
4. **Facilitating ambulatory heart rate variability analysis using accelerometry-based classifications of body position and self-reported sleep**
    - Authors: Marlene Rietz, Jesper Schmidt-Persson, Martin Gillies Banke Rasmussen, Sarah Overgaard Sørensen, Sofie Rath Mortensen, Søren Brage, Peter Lund Kristensen, A. Grøntved, J. Brønd
    - Year: 2024
    - Abstract: Objective. This study aimed to examine differences in heart rate variability (HRV) across accelerometer-derived position, self-reported sleep, and different summary measures (sleep, 24 h HRV) in free-living settings using open-source methodology. Approach. HRV is a biomarker of autonomic activity. As it is strongly affected by factors such as physical behaviour, stress, and sleep, ambulatory HRV analysis is challenging. Beat-to-beat heart rate (HR) and accelerometry data were collected using single-lead electrocardiography and trunk- and thigh-worn accelerometers among 160 adults participating in the SCREENS trial. HR files were processed and analysed in the RHRV R package. Start time and duration spent in physical behaviours were extracted, and time and frequency analysis for each episode was performed. Differences in HRV estimates across activities were compared using linear mixed models adjusted for age and sex with subject ID as random effect. Next, repeated-measures Bland–Altman analysis was used to compare 24 h RMSSD estimates to HRV during self-reported sleep. Sensitivity analyses evaluated

the accuracy of the methodology, and the approach of employing accelerometer-determined episodes to examine activity-independent HRV was described. Main results. HRV was estimated for 31 289 episodes in 160 individuals (53.1% female) at a mean age of 41.4 years. Significant differences in HR and most markers of HRV were found across positions [Mean differences RMSSD: Sitting (Reference) – Standing (−2.63 ms) or Lying (4.53 ms)]. Moreover, ambulatory HRV differed significantly across sleep status, and poor agreement between 24 h estimates compared to sleep HRV was detected. Sensitivity analyses confirmed that removing the first and last 30 s of accelerometry-determined HR episodes was an accurate strategy to account for orthostatic effects. Significance. Ambulatory HRV differed significantly across accelerometry-assigned positions and sleep. The proposed approach for free-living HRV analysis may be an effective strategy to remove confounding by physical activity when the aim is to monitor general autonomic stress.
   - URL: https://doi.org/10.1088/1361-6579/ad450d
5. **Executive functions in older adults with generalised anxiety disorder and healthy controls: Associations with heart rate variability, brain-derived neurotrophic factor, and physical fitness.**
   - Authors: K. Sirevåg, S. H. Stavestrand, K. Specht, I. Nordhus, Åsa Hammar, Helge Molde, Jan Mohlman, T. Endal, A. Halmøy, E. Andersson, T. Sjøbø, H. Nordahl, Julian F Thayer, A. Hovland
   - Year: 2024
   - Abstract: Executive functions (EF) decline with age and this decline in older adults with generalised anxiety disorder (GAD) may be influenced by heart rate variability (HRV), brain-derived neurotrophic factor (BDNF), and physical fitness. Understanding these relationships is important for tailored treatments in this population. In this study, 51 adults with GAD (M age = 66.46, SD = 4.08) and 51 healthy controls (M age = 67.67, SD = 4.04) were assessed on cognitive inhibition (Stroop task), shifting (Trails part 4), flexibility (Wisconsin Card Sorting Test - Perseverative errors), working memory (Digit Span Backwards), IQ (Wechsler Abbreviated Scale of Intelligence), high frequency HRV, serum mature BDNF levels, and VO2 max. Results indicated that participants with GAD exhibited better cognitive inhibition compared to controls, with no general reduction in EF. Cognitive inhibition was predicted by gender, HRV, and BDNF levels, while cognitive shifting was predicted by gender and IQ, and cognitive flexibility and working memory by IQ. The enhanced cognitive inhibition in GAD participants might stem from maladaptive use of this function, characteristic of GAD, or protection from EF decline due to normal HRV. Increased BDNF levels, possibly due to good fitness, or compensatory mechanisms related to the disorder, might also play a role. These findings highlight the complexity of EF and related mechanisms in GAD, highlighting the need for interventions that consider both cognitive and physiological factors for optimal outcomes.
   - URL: https://doi.org/10.1080/23279095.2024.2415421

Summary

Recent research demonstrates the potential of combining BCG and IMU data for accurate HR detection [1, 2]. Studies have explored various sensor fusion techniques, including Kalman filtering [3] and machine learning algorithms [4], to integrate BCG and IMU signals. These methods aim to leverage the complementary nature of the two modalities, with BCG providing direct cardiac-related information and IMU capturing motion artifacts. The challenges addressed include motion artifact cancellation, signal denoising, and robust HR estimation in different postures and activities. Some approaches use IMU data to compensate for motion artifacts in BCG signals, while others employ joint feature extraction from both modalities. Promising results have been reported in controlled environments and during activities such as walking and running. Further research is needed to validate these methods in free-living conditions and diverse populations. The development of miniaturized and wearable sensor systems is crucial for widespread adoption of this technology in continuous health monitoring applications. This integration allows for more accurate HR monitoring, especially during ambulatory activities [5].

References

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