COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 122 (2015) 503–512

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Letter to the Editor

Frequency analysis of photoplethysmogram and its derivatives

ARTICLE INFO

Keywords:
Affordable healthcare
Hot environment
Heat stress

ABSTRACT

There are a limited number of studies on heat stress dynamics during exercise using the photoplethysmogram (PPG). We investigate the PPG signal and its derivatives for heat stress assessment using Welch (non-parametric) and autoregressive (parametric) spectral estimation methods. The preliminary results of this study indicate that applying the first and second derivatives to PPG waveforms is useful for determining heat stress level using 20-s recordings. Interestingly, Welch's and Yule–Walker's methods in agreement that the second derivative is an improved detector for heat stress. In fact, both spectral estimation methods showed a clear separation in the frequency domain between measurements before and after simulated heat-stress induction when the second derivative is applied. Moreover, the results demonstrate superior performance of the Welch's method over the Yule–Walker's method in separating before and after the three simulated heat-stress inductions.

1. Introduction

Body core temperature (BCT) is the gold standard criterion for assessment of an individual's heat stress response. The invasive nature of core body temperature assessment and the nuances of measurement render its application inappropriate for use in selected settings. While ingestible temperature sensors have vastly improved the individual thermal assessment in field settings, the requirement to obtain measurements immediately post consumption limit the application of this technology to non-acute emergency responses. Non-invasive alternatives to core body temperature assessment in such environments are warranted, with surrogate measures of core body temperature assessed in tropical field settings. In a previous study, heart rate (beats per minute), demonstrated a greater relationship to core body temperature than other commonly assessed physiological variables, inclusive of mean arterial pressure and tympanic temperature [1]. The relationship between body temperature and frequency of cardiac cycles is well known [2,3]. Furthermore, analysis of the arterial pulse wave has been shown to provide valuable information on aortic stiffness and elasticity [4–6]. It has been widely used to evaluate the vascular effects of aging, hypertension, and atherosclerosis [7–10].

Photoelectric plethysmography is the most commonly used method for pulse-wave analysis, which has been referred to as photoplethysmography (PTG/PPG), blood volume pulse (BVP), and digital volume pulse (DVP) analysis; however, the acronym PPG will be used exclusively in this study, according to the recommendations in Elgendi et al. [11]. Fingertip PPG is a non-invasive measurement that mainly reflects the pulsatile volume changes in the finger arterioles, as shown in Fig. 1(a) and (b). Analyzing the PPG wave contour is difficult; therefore, researchers have applied the derivative to emphasize and easily quantify the delicate changes in the PPG contour [12], as shown in Fig. 1(c)–(f).

Applying derivatives to PPG signals detect faster physiological changes (bigger gradient) in the PPG signal. For example, the first derivative of the PPG signal represents the velocity of blood and the second derivative represents the acceleration of the blood flow inside the fingertip. Therefore, it is expected that applying derivatives will magnify the differences between PPG signals measured before and after heat stress induction,

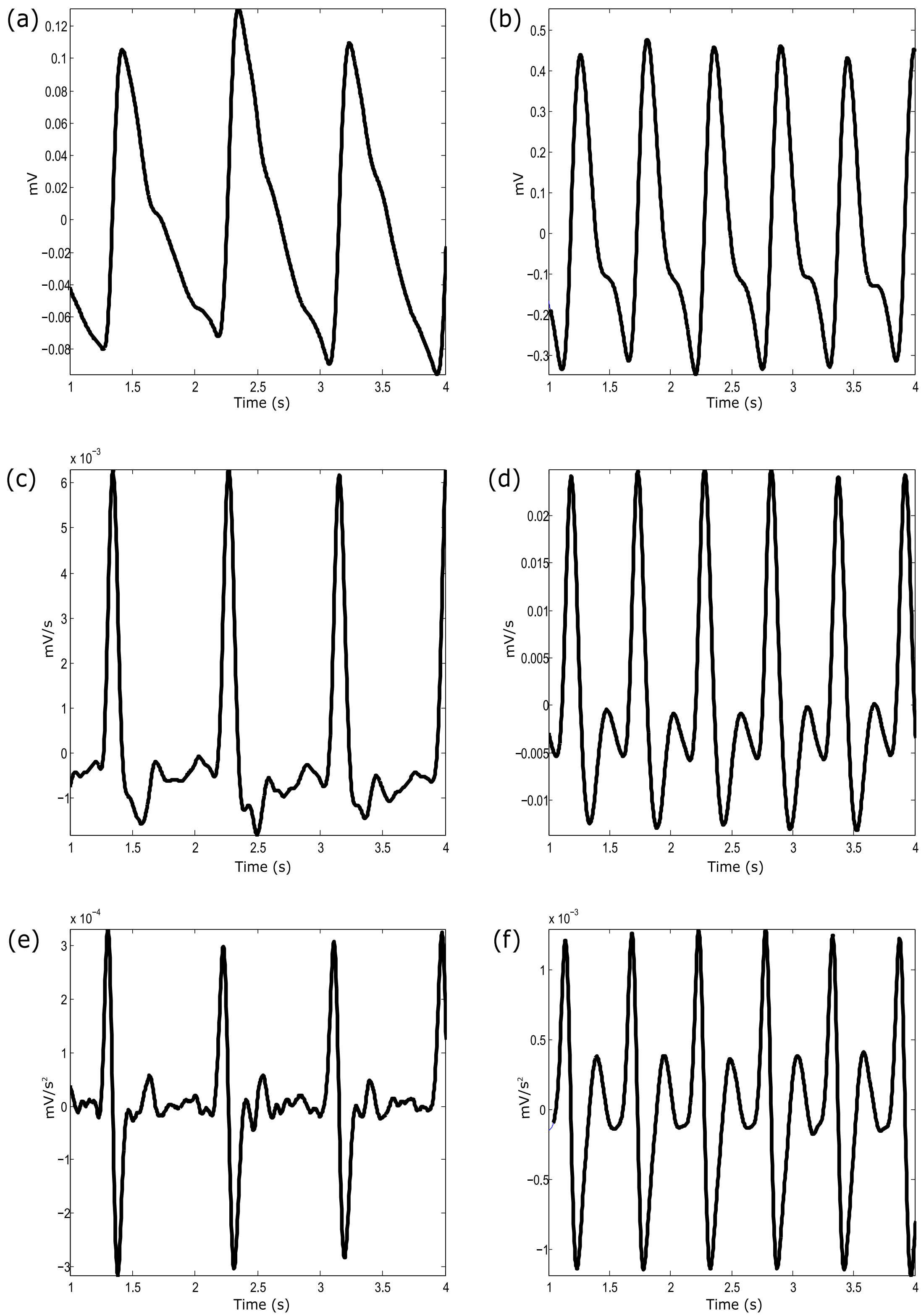

Fig. 1 – An example of 4-s PPG segment and its derivatives measured before and after simulated heat-stress induction. (a) PPG waveforms before simulated heat-stress induction; (b) PPG waveforms after simulated heat-stress induction (c) first derivative of (a); (d) first derivative of (b); (e) second derivative of (a); (f) second derivative of (b).