Poster: Heart Rate Performance of a Medical-Grade Data Streaming Wearable Device

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***Abstract*—Wrist-worn devices afford convenient and unobtrusive heart rate sensing, however, motion artifacts can lead to unreliable data recordings. This paper evaluates heart rate estimates acquired during treadmill walking and 12 hours of everyday living from a medical-grade Empatica E4 data streaming wristband wearable compared to a Polar H10 chest strap ECG sensor. For treadmill walking, heart rate Mean Absolute Percentage Errors (MAPEs) were between 7.2% and 29.2%, and IntraClass Correlations (ICCs) between 0.6 and -0.5, indicating moderate agreement and strong disagreement, respectively. During 12-hour everyday living acquisitions, heart rate estimate MAPEs were between 5.3% and 13.5% and ICCs between 0.7 and 0.1, indicating good to poor agreements.**

***Index Terms*—wearable devices, heart rate monitoring**

I. Introduction

Optical heart rate acquisitions from wrist-worn photoplethysmography (PPG) sensors are known to lack reliability during periods of activity due to the interfering effects of motion artifacts [1], [2]. However, the opportunity to achieve continuous, unobtrusive, low-cost patient monitoring and to incentivize patients toward positive health behaviors has resulted in many clinical research and healthcare applications of consumer-grade wearables, despite manufacturers making no medical device claims.

The Empatica E4, at the time of writing, is a class 2a medical-grade device used in *"over 1000 studies and trials"* [3]. It is a data streaming device similar to Empatica's Embrace FDA-approved wearable epilepsy monitor, comprising PPG, temperature, conductivity and accelerometer sensors, and is used by researchers for physiological data acquisition for a variety of healthcare applications, as well as for epileptic seizure detection research. Despite many studies proposing novel and incremental contributions for seizure detection, there are few studies evaluating wearable seizure monitoring devices in the literature [4].

Improvements in version reporting [5], [6] and standardized reporting practices [7] have been recommended to support the reproducibility of findings from studies using wearable devices. Bent et al. [8] reported on the wearable heart rate recording accuracies of 'consumer-grade' Fitbit Charge 2, Apple Watch 4, Garmin Vivosmart 3, and Xiaomi Miband, wearables and 'research-grade' data-streaming Biovotion Everion and Empatica E4 devices, and observed that *"absolute error during activity was, on average, 30% higher than during rest"* and that *"Consumer-grade wearables were found to be more accurate than research-grade wearables at rest."* The study provides summarized statistics, but no examples of heart rate recordings or signal behaviors as provided here.

II. Method and Materials

Healthy participants were recruited with ethical approval (KUFREC NS-190021) for wearable data recording during i) treadmill walking at speeds of 3.2, 4.8 and 6.4 km/h for five minutes at each speed, and ii) 12 hours of everyday living. Participants wore a Polar H10 ECG chest strap sensor and an E4 wristband on their non-dominant wrist. Heart rate data was downloaded from the Polar Flow and Empatica E4 Connect apps. Other material details are provided in the Appendix.

III. Results

Acquired treadmill and 12-hour everyday living heart rate recordings are summarized for participants P_T01-04 in Figure 1 and P_D01-04 in Figure 2, and the corresponding Mean Absolute Percentage Errors (MAPEs) and IntraClass Correlations (ICCs) are summarized in Table I. Periods of data missingness affected the E4 and, to a lesser extent, the Polar recordings. Two E4 12-hour recordings failed to maintain connectivity and there were some periods of missing data for P_D01-4.

IV. Discussion and Conclusions

The disagreement between the E4 wristband and the Polar chest strap was large enough to be evident, even in this small study, with treadmill MAPEs ranging from 7.2% to 29.2%, and ICCs between 0.6 and -0.5, indicating moderate agreement and strong disagreement, respectively, and 12-hour everyday living MAPEs from 5.3% to 13.5% and ICCs between 0.7 and 0.1, indicating good to poor agreement [9].

In the absence of motion artifacts, PPG heart rate estimates may perform reliably and could be used, for example, to detect 'preictal' epileptic seizure onset heart rate variations. However, attempting to detect heart rate variations during activity or during a motor seizure could produce unreliable results as, for example, reported by Vandecasteele et al. [10].

Despite these challenges, wearable epilepsy seizure detecting devices offer important opportunities to reduce injuries

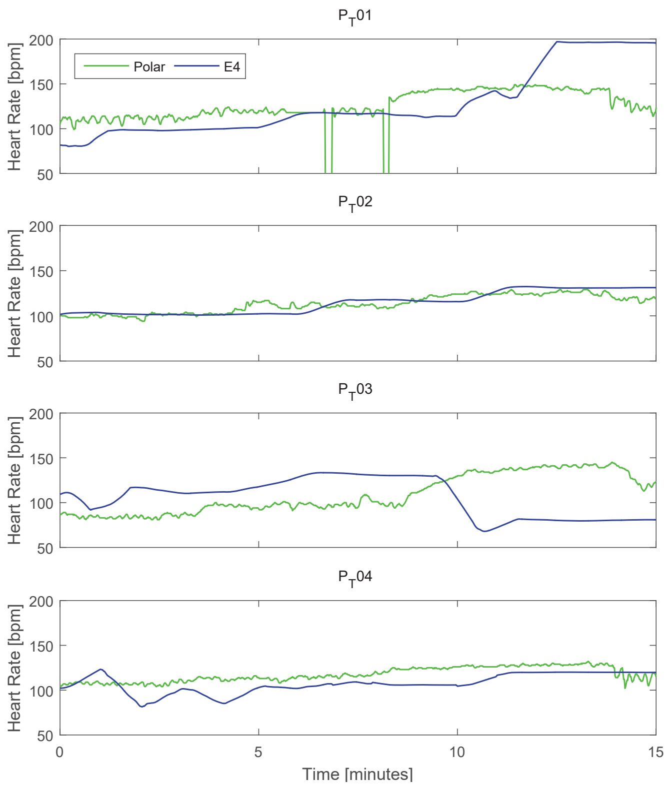

Fig. 1. Treadmill heart rates for participants P_T01-4.

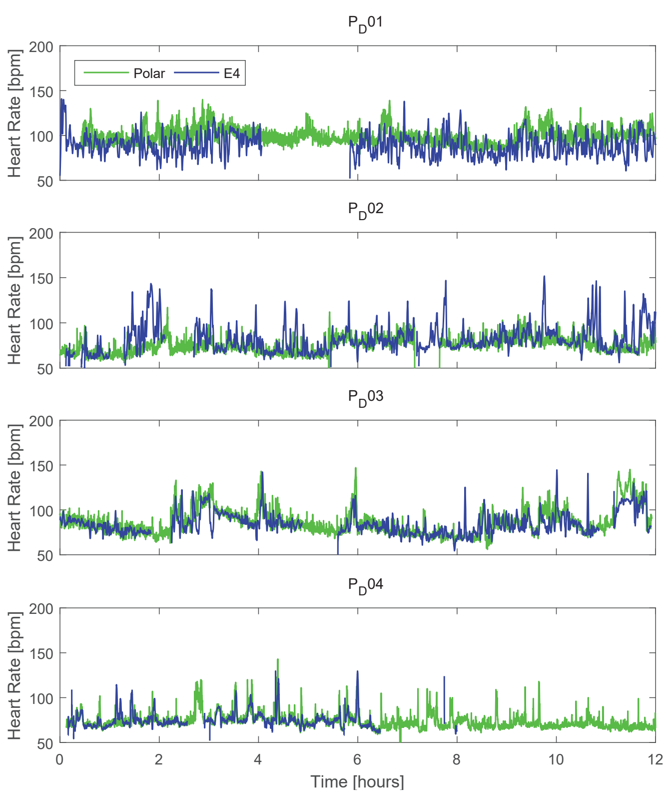

Fig. 2. 12-hour everyday living heart rates for participants P_D01-4.

TABLE I
MAPEs AND ICCs FOR TREADMILL AND 12-HOUR EVERYDAY LIVING

Participant	Activity	ICC (upper/lower bounds)	MAPE
P_T01	Treadmill	0.4 (0.44 / 0.36)	19.17%
P_T02		0.61 (0.64 / 0.58)	7.21%
P_T03		-0.53 (-0.44 / -0.61)	29.25%
P_T04		0.32 (0.54 / -0.02)	10.54%
P_D01	12-hour	0.11 (0.2 / 0.01)	13.45%
P_D02		0.21 (0.27 / 0.15)	13.54%
P_D03		0.66 (0.69 / 0.63)	7.86%
P_D04		0.59 (0.6 / 0.58)	5.32%

and save lives. However, researchers using data streaming research- and medical-grade wearables should be aware of device performance during periods of activity. As underlying technologies mature, we can hope to see improvements in both signal acquisition and algorithm performance.

APPENDIX

Materials details: (i) Empatica E4 wristband SP069-B-20150001, with E4 real-time app v 2.1.1 (8202), E4 Manager version 2.0.3 (5119) (ii) Polar H10 chest heart rate monitor FCC ID: INWIW, with Polar Flow and Polar Beat App version 3.4.0 (iii) Treadmill: h/p/cosmos Pulsar treadmill.

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