

Article

On the Reliability of Wearable Technology: A Tutorial on Measuring Heart Rate and Heart Rate Variability in the Wild

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Abstract: Wearable sensors are quickly making their way into psychophysiological research, as they allow collecting data outside of a laboratory and for an extended period of time. The present tutorial considers fidelity of physiological measurement with wearable sensors, focusing on reliability. We elaborate on why ensuring reliability for wearables is important and offer statistical tools for assessing wearable reliability for between participants and within-participant designs. The framework offered here is illustrated using several brands of commercially available heart rate sensors. Measurement reliability varied across sensors and, more importantly, across the situations tested, and was highest during sleep. Our hope is that by systematically quantifying measurement reliability, researchers will be able to make informed choices about specific wearable devices and measurement procedures that meet their research goals.

Keywords: wearables; measurement reliability; heart rate; heart rate variability

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1. Introduction

A bathroom scale is a reliable measure of one's weight, provided one stands still on the scale for several moments. Yet, one is likely to discard the measurement shown by the scale if one is startled by a spider during these moments. Trying to measure cardiac signals with a wearable sensor is similar to trying to measure one's weight while dancing on the scale. The fidelity of the measurement will depend not only on the sensor's accuracy but also on the environmental conditions under which the measurement was taken.

The recent rapid proliferation of wearable sensing technology has been accompanied by many tests of their validity [1–7], usually by examining the correlation of the wearable's signal with that of trusted laboratory equipment [8]. A lot of effort has been put into developing hardware and processing algorithms to ensure high correspondence with benchmark equipment [9–14]; for latest reviews, see [15,16]. What is usually overlooked in these tests is that most laboratory measurement procedures severely limit participants' bodily movements and cognitive activities [17]. In sharp contrast, wearable devices promise to measure the same physiological signals across a wide variety of environments and bodily states. Yet, without further testing, there is no guarantee that wearables will yield accurate measurements in all contexts.

For example, Empatica's electrodermal activity (EDA) measurement showed high agreement with the EDA measurement taken under laboratory conditions. Yet, in a study that measured EDA with Empatica for 20 hrs per participant in their daily lives, 78% of the measurements were artifacts and no meaningful analysis could be performed with the remaining data [18]. In another study, which aimed to establish the validity of Empatica's HRV measurement against a Holter ECG monitor in 24-hour ambulatory monitoring, the

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