Physiology in the wild: BEATmonitor enables multi-participant PPG recording across naturalistic environments

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Motivation & overview

Gap: Physiology measures in the lab – limited generalizability

- Single participant
- Artificial & short stimuli
- Laboratory environment

Solution: "In the wild" studies

- Multiple participants
- Long duration stimuli (e.g., films, concerts)
- Real-world environment

Goals:
Ecological, Generalizable, Replicable. Capture rich dynamics: synchrony, social influence, group processes, attention, emotion, fatigue, etc.

What is BEATmonitor?

- Open source framework; privacy focused; uses low-cost (~$135 CAD) smartwatch hardware
- Record photoplethysmography (PPG[1]; HR, HRV) and acceleration (3-axis)
- Scales from single-participant (e.g., lab) to multi-participant (e.g., concert) studies.
- Synchronize timing; remote control; data management; analysis pipelines

System & workflow

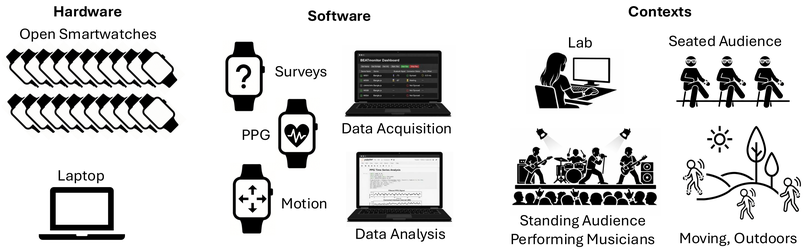


Figure 1. Hardware requirements consist of 1) open source smartwatch(es) (Bangle.js 2) and 2) a laptop computer. Open source **software** run on smartwatches (BEATwatch[3]) and the host laptop (BEATmonitor[3]). PPG and accelerometer data can be collected in many **contexts**: single-participant to multi-participant; in labs/at events, indoor/outdoor, standing/sitting.

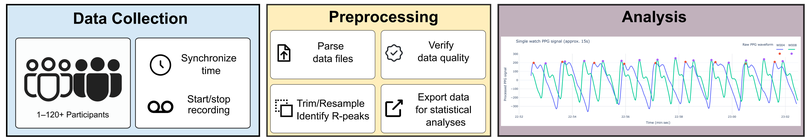


Figure 2. Typical workflow. **Data collection:** from 1–120+ participants. First attach devices, synchronize time, then start recording. **Preprocessing:** read raw data files, verify data quality, signal processing, identify R-peaks[2], export for data **analysis** (example of processed PPG signal).

Use cases & Validation datasets

McMaster LIVE Lab (theatre)
Music/dance/mime/gallery/ film/etc.
Ten+ studies / 16 sessions
600+ participants
500+ hours of data

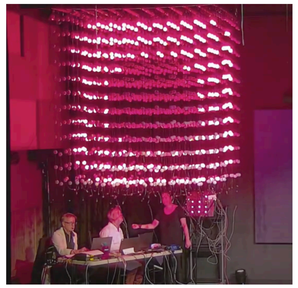
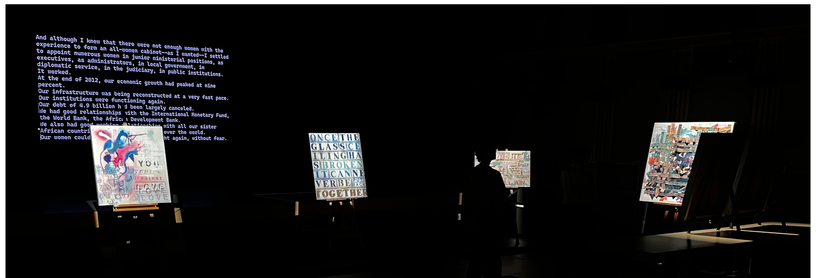
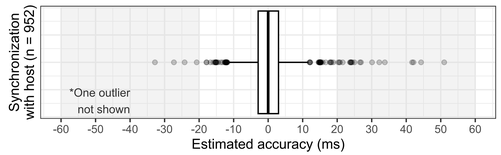


Figure 3. Above: McMaster LIVE Lab, a 100 person theatre that can host a variety of events. **Right:** Artists have integrated live HR data with their performance. **Below:** An art gallery. Participants were free to walk around the space and explore artwork while HR and movement activity were recorded.



Performance across studies

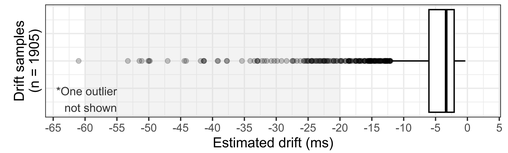
(A) BEATmonitor synchronizes device time with host



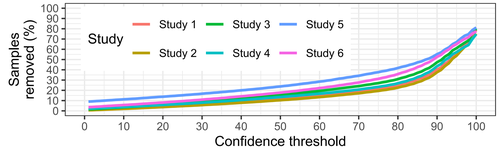
A. Estimated synchronization between Bangle.js 2 watches and host computer (NTP server). Estimated accuracy is the difference in time on host and device (n = 6 studies).

(B) Devices stay synchronized over long recordings

B. Drift is calculated periodically over an entire event (i.e., a music performance). Estimated drift is the difference between device time and host time in ms (n = 3 sessions).



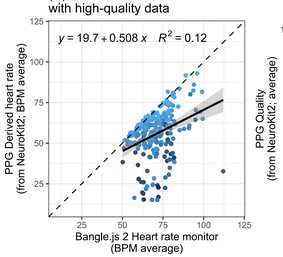
(C) Filter potential motion artifacts



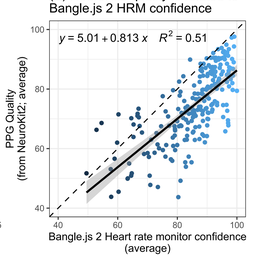
C. Bangle.js heart rate monitor assigns confidence values to samples, flagging potential motion artifacts. Number of samples filtered (y-axis) is affected by threshold (x-axis) (n = 6 studies).

D/E. *Preliminary.* PPG derived HR allows for higher resolution metrics (e.g., IBI, HRV, frequency domain, etc.). Average HR/quality (y-axes) extracted from PPG using NeuroKit2[2] are compared to values given by Bangle.js 2 heart rate monitor (x-axes). High confidence values produce better quality PPG metrics (n = 1 study).

(D) PPG derived HR is recovered with high-quality data



(E) NeuroKit2 quality is related to Bangle.js 2 HRM confidence



Outcomes

- Psychophysiology in large, naturalistic environments.
- Inexpensive, open, scalable to diverse populations and settings.
- Multimodal data (PPG, heart rate, accelerometer, surveys) with synchronized events.

References: [1] Choi & Shin (2017). Photoplethysmography sampling frequency: Pilot assessment of how low can we go to analyze pulse rate variability with reliability? https://doi.org/10.1088/1361-6579/aa5efa [2] Makowski et al. (2021). NeuroKit2: A Python toolbox for neurophysiological signal processing. https://doi.org/10.3758/s13428-020-01516-y [3] Flannery & Fink (2025). BEATmonitor (Version v0.2.250427) [Computer software]. https://doi.org/10.5281/zenodo.15297806