# Wrist-Worn Photoplethysmography Data: Opportunities and Challenges

**Paul R. Hibbing, PhD**

Assistant Professor

University of Illinois Chicago

ADDS 2024 | ActiGraph

UI Health | UIC

# My General Background

ADDS 2024

# New Horizons in Sensor Development

STEPHEN S. INTILLE[1], JONATHAN LESTER[2], JAMES F. SALLIS[3], and GLEN DUNCAN[2]

*[1]College of Computer and Information Science, Northeastern University, Boston, MA; [2]University of Washington, Seattle, WA; and [3]San Diego State University, San Diego, CA*

**ABSTRACT**

INTILLE, S. S., J. LESTER, J. F. SALLIS, and G. DUNCAN. New Horizons in Sensor Development. *Med. Sci. Sports Exerc.*, Vol. 44, No. 1S, pp. S24–S31, 2012.

## EMERGING TECHNOLOGY AND METHODS

We expect to see a gradual improvement in overall device performance rather than the development of fundamentally new types of sensors in physical activity measurement devices. Breakthroughs will likely result from using multimodal sensor fusion—combining data from several types of sensors, sometimes located on different parts of the body or in the environment—into a single system that is then used to infer precise, second-by-second detail about physical activity type, amount, and location. These changes, in turn, will create new opportunities in methods. New monitors should permit longer term, lower cost, higher compliance deployments enabling a broader spectrum of physical activity concepts to be simultaneously measured in real-life settings.

## rizons in Sensor Development

STEPHEN S. INTILLE[1], JONATHAN LESTER[2], JAMES F. SALLIS[3], and GLEN DUNCAN[2]

*[1]College of Computer and Information Science, Northeastern University, Boston, MA; [2]University of Washington, Seattle, WA; and [3]San Diego State University, San Diego, CA*

**ABSTRACT**

INTILLE, S. S., J. LESTER, J. F. SALLIS, and G. DUNCAN. New Horizons in Sensor Development. *Med. Sci. Sports Exerc.*, Vol. 44, No. 1S, pp. S24–S31, 2012.

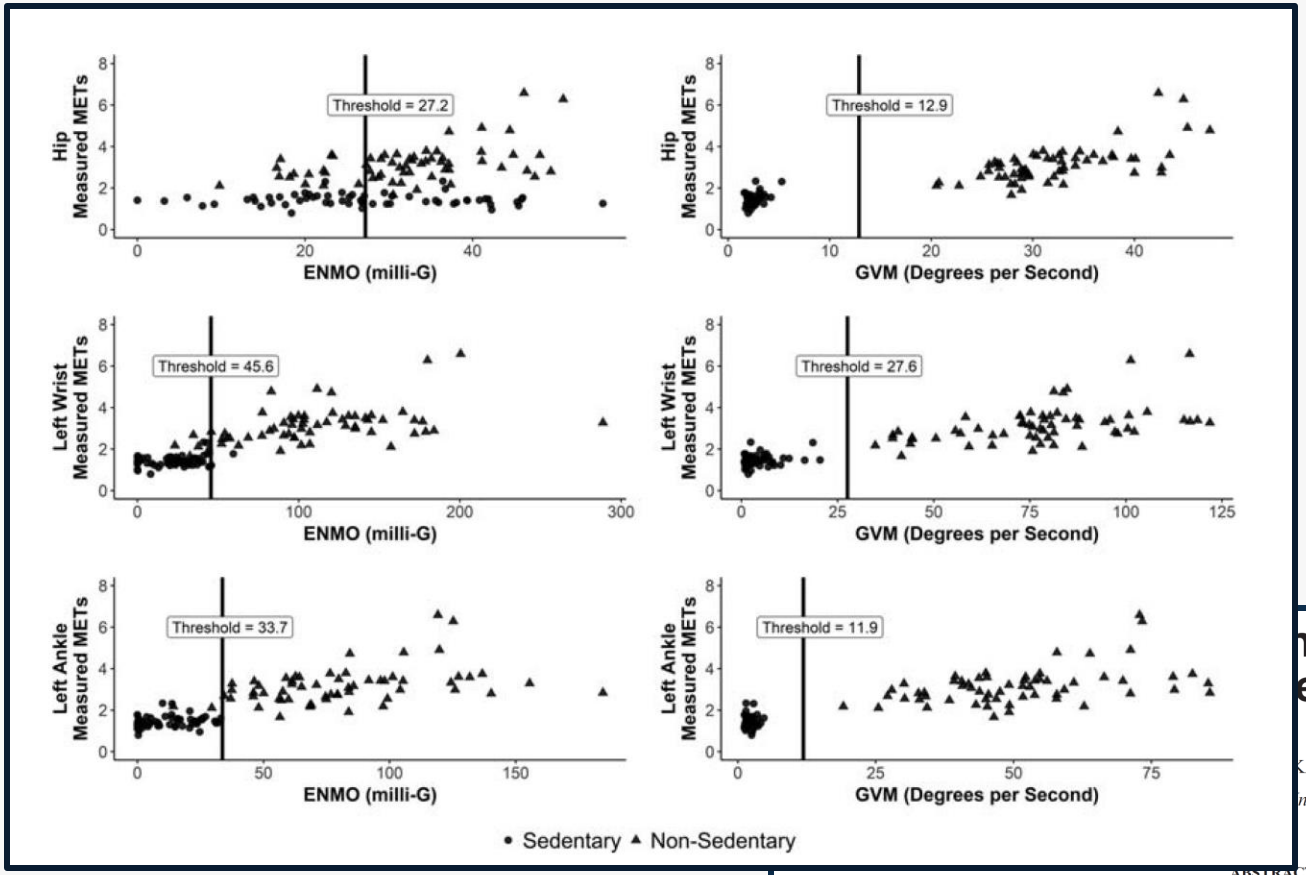
# Estimating Energy Expenditure with ActiGraph GT9X Inertial Measurement Unit

PAUL R. HIBBING, SAMUEL R. LAMUNION, ANDREW S. KAPLAN, and SCOTT E. CROUTER

*Department of Kinesiology, Recreation, and Sport Studies, The University of Tennessee Knoxville, Knoxville, TN*

**ABSTRACT**

HIBBING, P. R., S. R. LAMUNION, A. S. KAPLAN, and S. E. CROUTER. Estimating Energy Expenditure with ActiGraph GT9X Inertial Measurement Unit. *Med. Sci. Sports Exerc.*, Vol. 50, No. 5, pp. 1093–1102, 2018.




## nditure with ActiGraph ent Unit

KAPLAN, and SCOTT E. CROUTER

*niversity of Tennessee Knoxville, Knoxville, TN*

ABSTRACT

HIBBING, P. R., S. R. LAMUNION, A. S. KAPLAN, and S. E. CROUTER. Estimating Energy Expenditure with ActiGraph GT9X Inertial Measurement Unit. *Med. Sci. Sports Exerc.*, Vol. 50, No. 5, pp. 1093–1102, 2018.

# Redefining the Roles of Sensors in Objective Physical Activity Monitoring

KONG Y. CHEN[1], KATHLEEN F. JANZ[2], WEIMO ZHU[3], and ROBERT J. BRYCHTA[1]

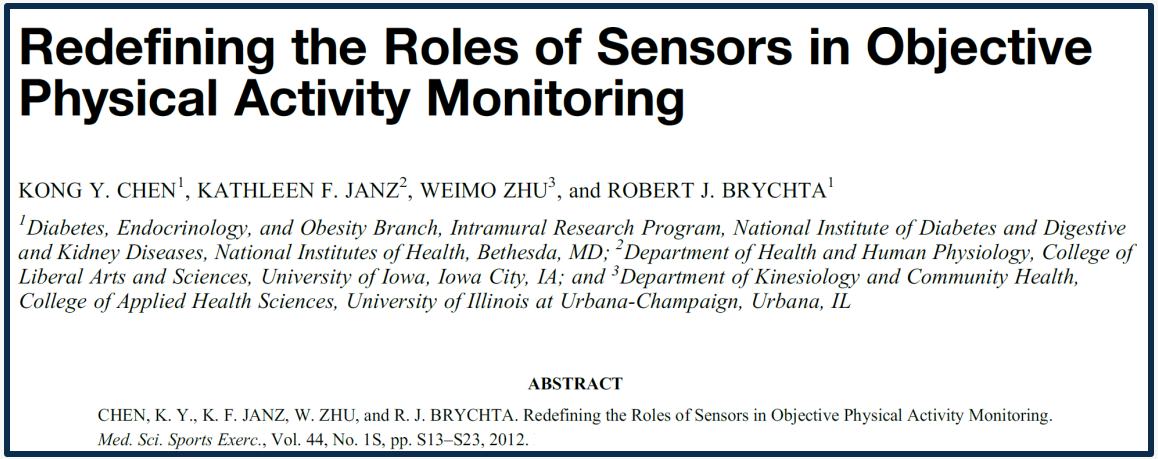
*[1]Diabetes, Endocrinology, and Obesity Branch, Intramural Research Program, National Institute of Diabetes and Digestive and Kidney Diseases, National Institutes of Health, Bethesda, MD; [2]Department of Health and Human Physiology, College of Liberal Arts and Sciences, University of Iowa, Iowa City, IA; and [3]Department of Kinesiology and Community Health, College of Applied Health Sciences, University of Illinois at Urbana-Champaign, Urbana, IL*

**ABSTRACT**

CHEN, K. Y., K. F. JANZ, W. ZHU, and R. J. BRYCHTA. Redefining the Roles of Sensors in Objective Physical Activity Monitoring. *Med. Sci. Sports Exerc.*, Vol. 44, No. 1S, pp. S13–S23, 2012.

# Types of Sensors (Chen et al., 2012)

- Movement (inertial)
- Physiologic
- Contextual



## Redefining the Roles of Sensors in Objective Physical Activity Monitoring

KONG Y. CHEN[1], KATHLEEN F. JANZ[2], WEIMO ZHU[3], and ROBERT J. BRYCHTA[1]

*[1]Diabetes, Endocrinology, and Obesity Branch, Intramural Research Program, National Institute of Diabetes and Digestive and Kidney Diseases, National Institutes of Health, Bethesda, MD; [2]Department of Health and Human Physiology, College of Liberal Arts and Sciences, University of Iowa, Iowa City, IA; and [3]Department of Kinesiology and Community Health, College of Applied Health Sciences, University of Illinois at Urbana-Champaign, Urbana, IL*

**ABSTRACT**

CHEN, K. Y., K. F. JANZ, W. ZHU, and R. J. BRYCHTA. Redefining the Roles of Sensors in Objective Physical Activity Monitoring. *Med. Sci. Sports Exerc.*, Vol. 44, No. 1S, pp. S13–S23, 2012.

# My Background with PPG

ADDS 2024

JOURNAL OF SPORTS SCIENCES, 2018
VOL. 36, NO. 15, 1734–1741
https://doi.org/10.1080/02640414.2017.1412235



# Comparative evaluation of heart rate-based monitors: Apple Watch vs Fitbit Charge HR

Yang Bai [a], Paul Hibbing [b], Constantine Mantis [c] and Gregory J. Welk [c]

[a]Department of Rehabilitation and Movement Science, University of Vermont, Burlington, VT, USA; [b]Department of Kinesiology, Recreation, and Sport Studies, University of Tennessee, Knoxville, TN, USA; [c]Department of Kinesiology, Iowa State University, Ames, IA, USA

## Introduction

The expanding market in wearable activity monitors for consumers has generated considerable interest within the physical activity (PA) research community (https://clinicaltrials.gov/ct2/results?term=activity+tracker&pg=1). Most monitors continue to predict energy expenditure (EE) and step counts, while newer versions of many wrist-worn consumer monitors have also begun incorporating heart rate measures using a technology called photoplethysmography (https://support.apple.com/en-us/HT204666; https://www.fitbit.com/pure pulse). This involves flashing green LED light through the skin, to detect the expansion and contraction of wrist capillaries with each pulse (Maeda, Sekine, & Tamura, 2011). Algorithms are then applied to estimate heart rate continuously from that information (Ahmadi, Moradi, Malihi, Karimi, & Shamsollahi, 2015).

Routledge
Taylor & Francis Group

Check for updates

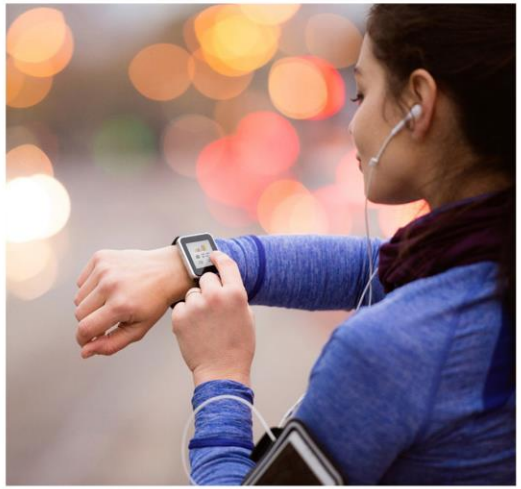
f heart rate-based monitors: Apple Watch vs Fitbit Charge HR

antine Mantis [c] and Gregory J. Welk[c]

[a]Department of Rehabilitation and Movement Science, University of Vermont, Burlington, VT, USA; [b]Department of Kinesiology, Recreation, and Sport Studies, University of Tennessee, Knoxville, TN, USA; [c]Department of Kinesiology, Iowa State University, Ames, IA, USA

# Fitness Trackers Can Be Fashionable and Functional

*Paul R. Hibbing, M.S.*
*Samuel R. LaMunion, M.S.*
*Lindsay P. Toth, M.S.*



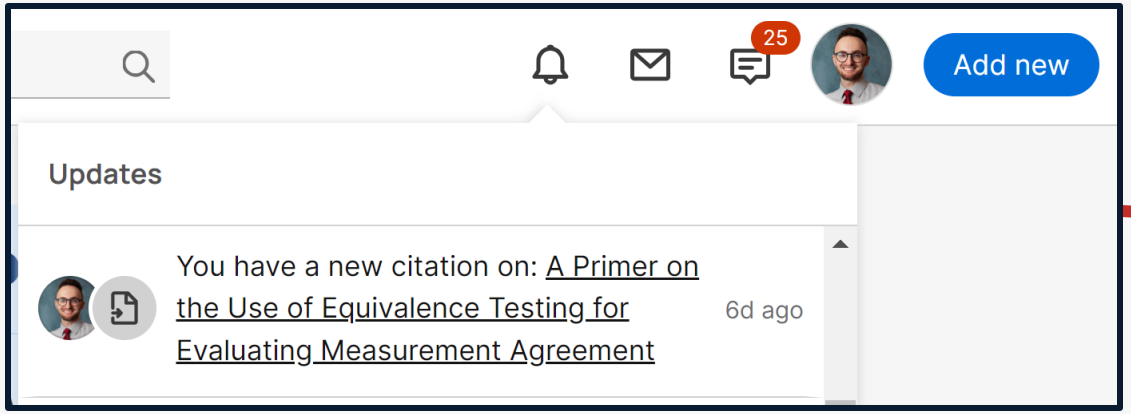
Halfpoint/iStock/Thinkstock

**Fitness tracking has become a major industry, with new devices that uniquely combine form and function constantly entering the market. The products range from**

Some monitors measure heart rate using a new technology called photoplethysmography, which shines LEDs through the skin to capture the expansion and contraction of blood vessels as blood moves through.

*(continued on page 4)*

2017 / 2018 . . . . . 2021

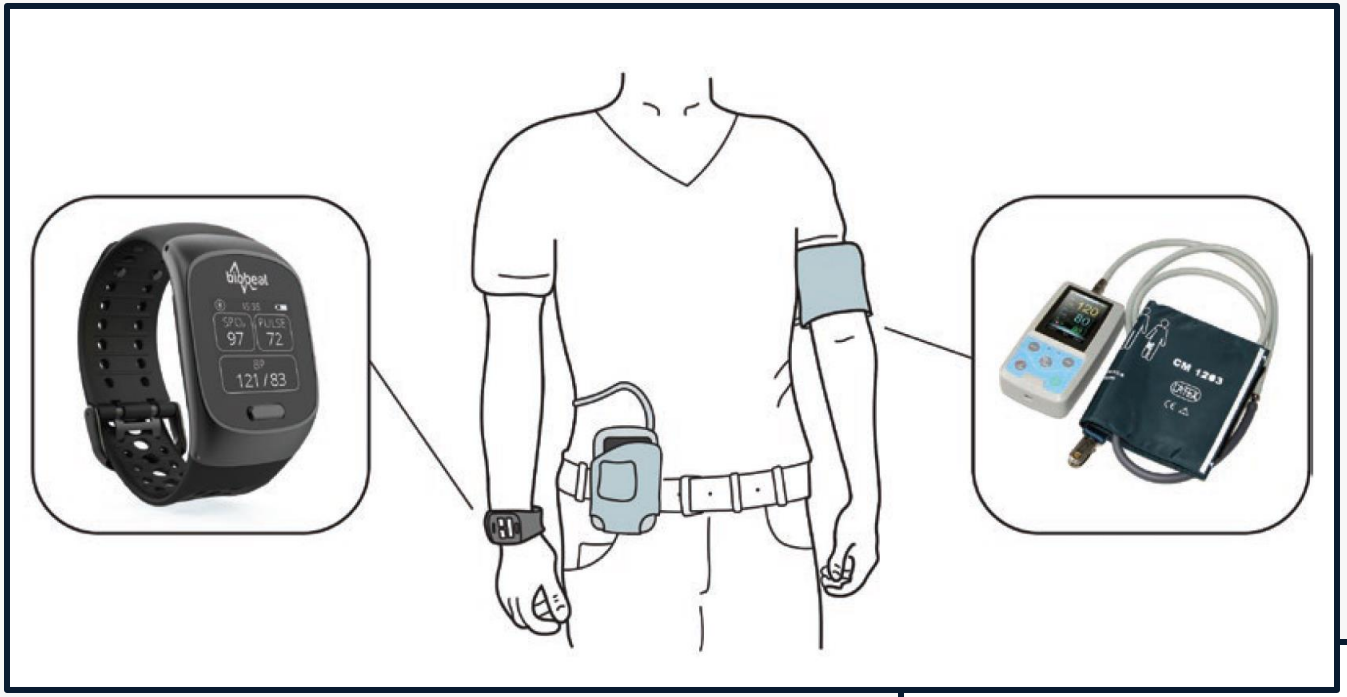



*Dramatization*

**ORIGINAL ARTICLE**

# Twenty-Four-Hour Ambulatory Blood Pressure Measurement Using a Novel Noninvasive, Cuffless, Wireless Device

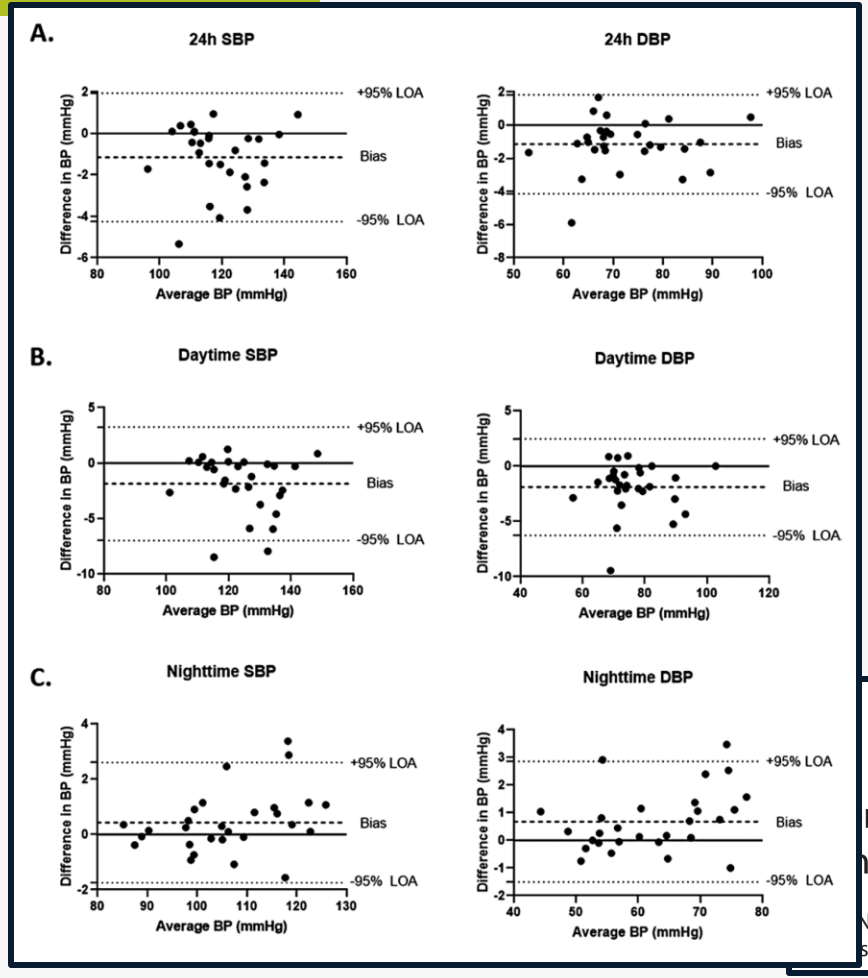
Dean Nachman,[1,2,*] Adi Gilan,[1,*,†] Nir Goldstein,[3] Keren Constantini,[3] Romi Littman,[4] Arik Eisenkraft,[1,4] Ehud Grossman,[3,5] and Yftach Gepner[3]




**ORIGINAL ARTICLE**

# Twenty-Four-Hour Ambulatory Blood Pressure Measurement Using a Novel Noninvasive, Cuffless, Wireless Device

Dean Nachman,[1,2,*] Adi Gilan,[1,*,†] Nir Goldstein,[3] Keren Constantini,[3] Romi Littman,[4] Arik Eisenkraft,[1,4,‡] Ehud Grossman,[3,5] and Yftach Gepner[3]




ORIGINAL ARTICLE

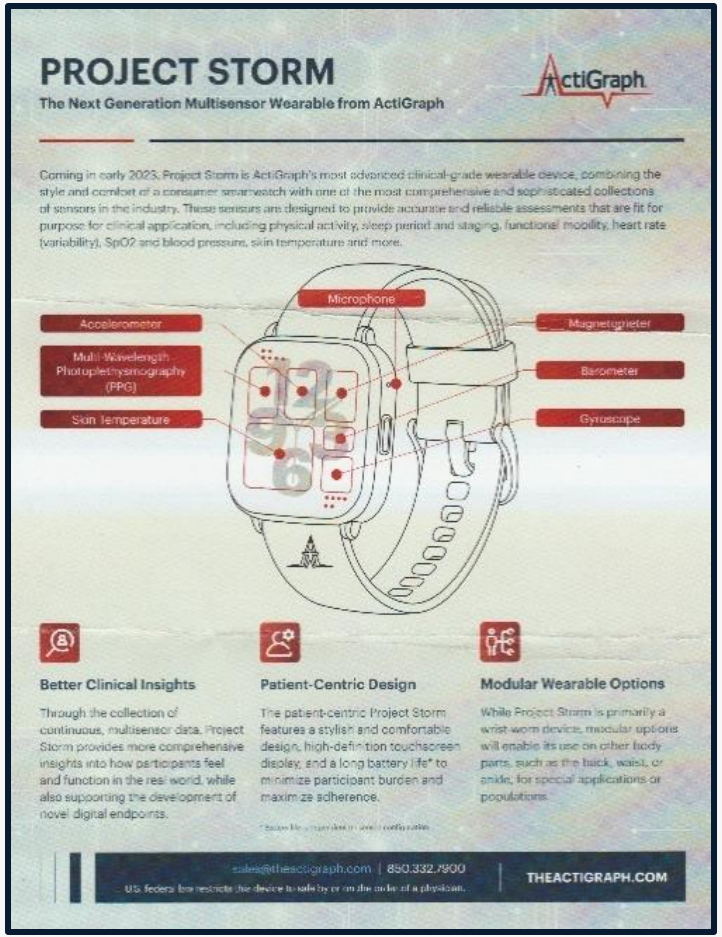
nty-Four-Hour Ambulatory Blood Pressure Measurement
g a Novel Noninvasive, Cuffless, Wireless Device

Nachman,[1,2,*] Adi Gilan,[1,*,†] Nir Goldstein,[3] Keren Constantini,[3] Romi Littman,[4]
senkraft,[1,4,©] Ehud Grossman,[3,5] and Yftach Gepner[3]

# The Quest for Raw Signals: A Quality Review of Publicly Available Photoplethysmography Datasets

Florian Wolling
Ubiquitous Computing, University of Siegen
Siegen, Germany
florian.wolling@uni-siegen.de

Kristof Van Laerhoven
Ubiquitous Computing, University of Siegen
Siegen, Germany
kvl@eti.uni-siegen.de


PROJECT STORM
The Next Generation Multisensor Wearable from ActiGraph
ActiGraph
Coming in early 2023, Project Storm is ActiGraph's most advanced clinical-grade wearable device, combining the style and comfort of a consumer smartwatch with one of the most comprehensive and sophisticated collections of sensors in the industry. These sensors are designed to provide accurate and reliable assessments that are fit for purpose for clinical application, including physical activity, sleep period and staging, functional mobility, heart rate (variability), SpO2 and blood pressure, skin temperature and more.
Microphone
Accelerometer
Multi-Wavelength Photoplethysmography (PPG)
Skin Temperature
Magnetometer
Barometer
Gyroscope
Better Clinical Insights
Through the collection of continuous, multisensor data, Project Storm provides more comprehensive insights into how participants feel and function in the real world, while also supporting the development of novel digital endpoints.
Patient-Centric Design
The patient-centric Project Storm features a stylish and comfortable design, high-definition touchscreen display, and a long battery life* to minimize participant burden and maximize adherence.
Modular Wearable Options
While Project Storm is primarily a wrist-worn device, modular options will enable its use on other body parts, such as the back, waist, or ankle, for special applications or populations.
sales@theactigraph.com | 850.332.7900
U.S. federal law restricts this device to sale by or on the order of a physician.
THEACTIGRAPH.COM

# The Light–Tissue Interaction of Pulse Oximetry

Paul D. Mannheimer, PhD

The underlying science of pulse oximetry is based on a simple manipulation of the Lambert–Beer law, which describes the attenuation of light traveling through a mixture of absorbers. Signals from detected red and infrared light that has traveled through blood-perfused tissues are used to estimate the underlying arterial hemoglobin oxygen saturation. However, light scatters in tissue and influences some of the simplifications made in determining this relationship. Under most clinical circumstances, the empirical process that manufacturers use to calibrate the system during its design readily accommodates this and results in accurate readings. The same tissue light scattering properties allow sensors to be configured for use on opposing or adjacent surfaces, provided that the placement sites offer sufficient signal strength and are absent factors known to influence accuracy. In this paper I review the light–tissue interaction in pulse oximetry and describe some of the assumptions made and their implications. Certain deviations from the nominal conditions, whether clinical in nature or misuse of the product, can affect system performance. Consequently, users should be cautious in modifying sensors and/or using them on tissue sites not intended by the manufacturer (off-label use). While perhaps helpful for obtaining pulsatile signals or extending the lifetime of a sensor, some practices can disrupt the optical integrity of the measurement and negatively impact the oxygen saturation reading accuracy.

(Anesth Analg 2007;105:S10–7)

# Heart Rate and Heart Rate Variability (obviously)

pcmag.com

# Other Cardiovascular Parameters


Figure 2: Taking a Measurement with the Digital Crown and the Watch App

The ECG rhythm will be classified into one of the following categories:

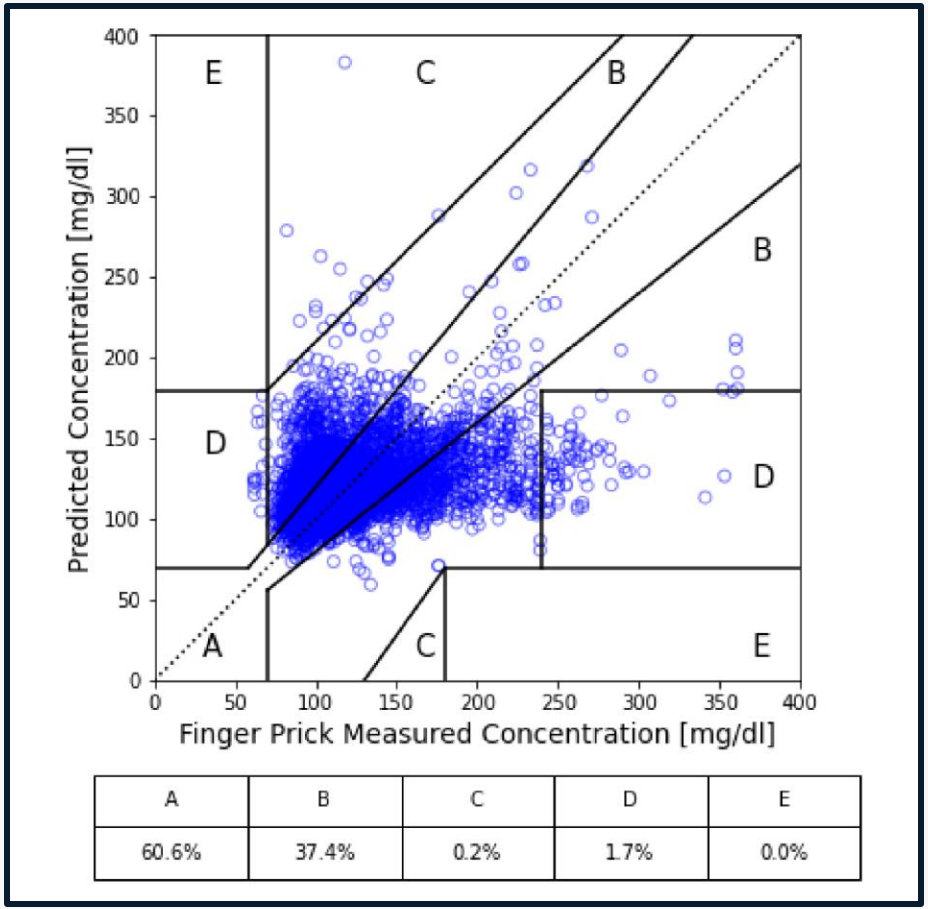
1. Sinus rhythm
2. Atrial Fibrillation
3. Inconclusive

accessdata.fda.gov

# Predicting Energy Expenditure and Activity Type

... It's stock alright? Are you reading this?

# Glucose Monitoring




| A | B | C | D | E |
|---|---|---|---|---|
| 60.6% | 37.4% | 0.2% | 1.7% | 0.0% |

doi: 10.3390/s21237815

npj | Digital Medicine

www.nature.com/npjdigitalmed

ARTICLE OPEN

# Investigating sources of inaccuracy in wearable optical heart rate sensors

Brinnae Bent[1], Benjamin A. Goldstein[2], Warren A. Kibbe[2] and Jessilyn P. Dunn[1,2*]

# Skin Type

- Age
- Sex
- Obesity status
- Skin tone

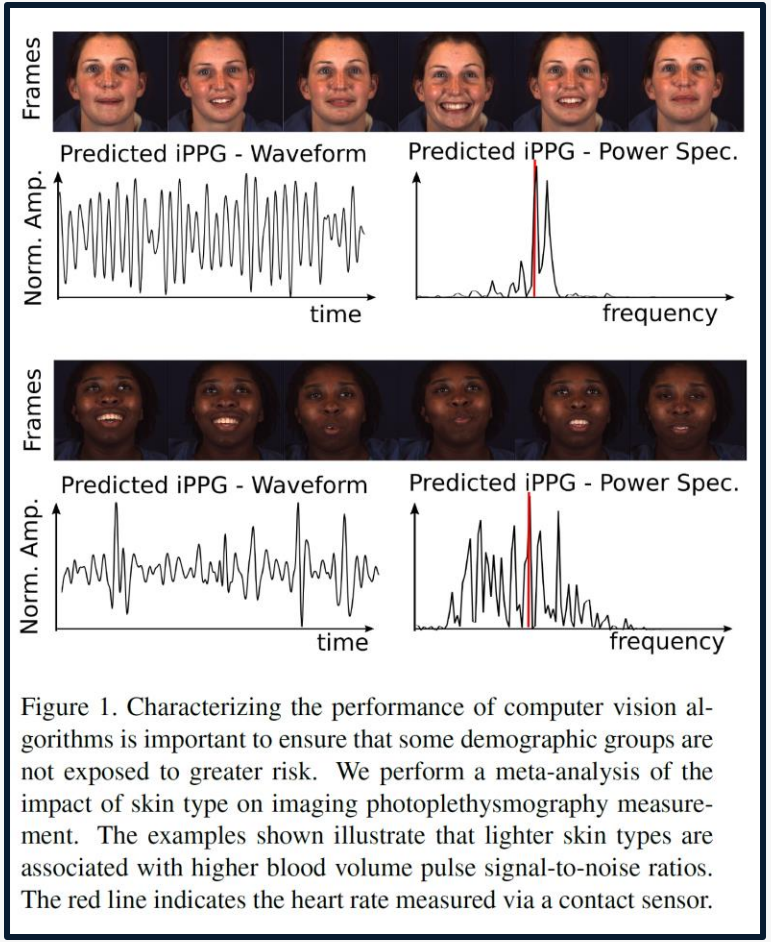
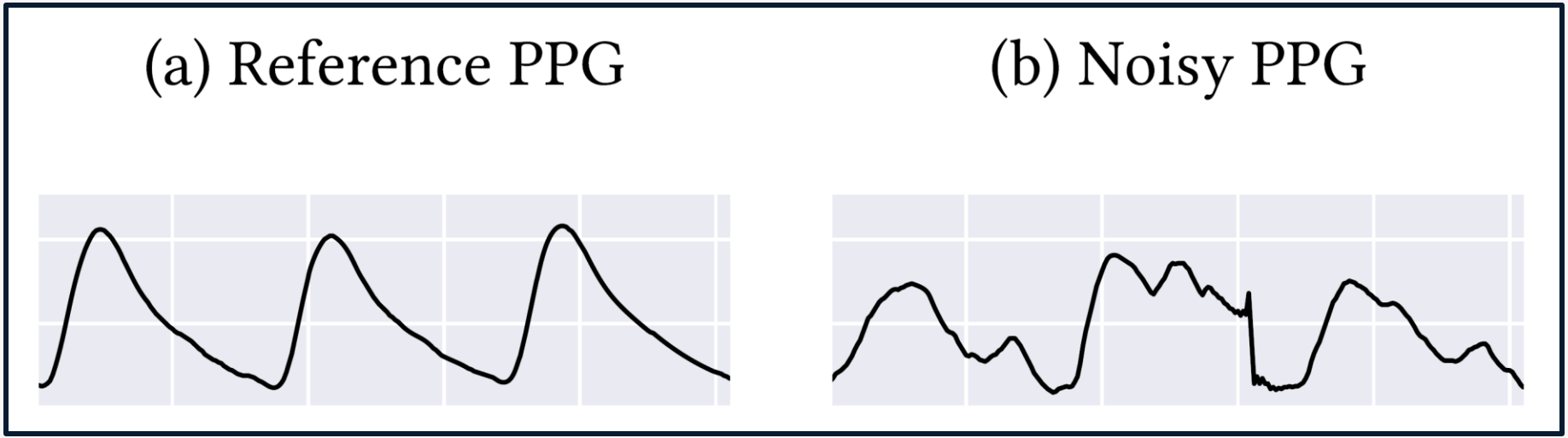



Figure 1. Characterizing the performance of computer vision algorithms is important to ensure that some demographic groups are not exposed to greater risk. We perform a meta-analysis of the impact of skin type on imaging photoplethysmography measurement. The examples shown illustrate that lighter skin types are associated with higher blood volume pulse signal-to-noise ratios. The red line indicates the heart rate measured via a contact sensor.

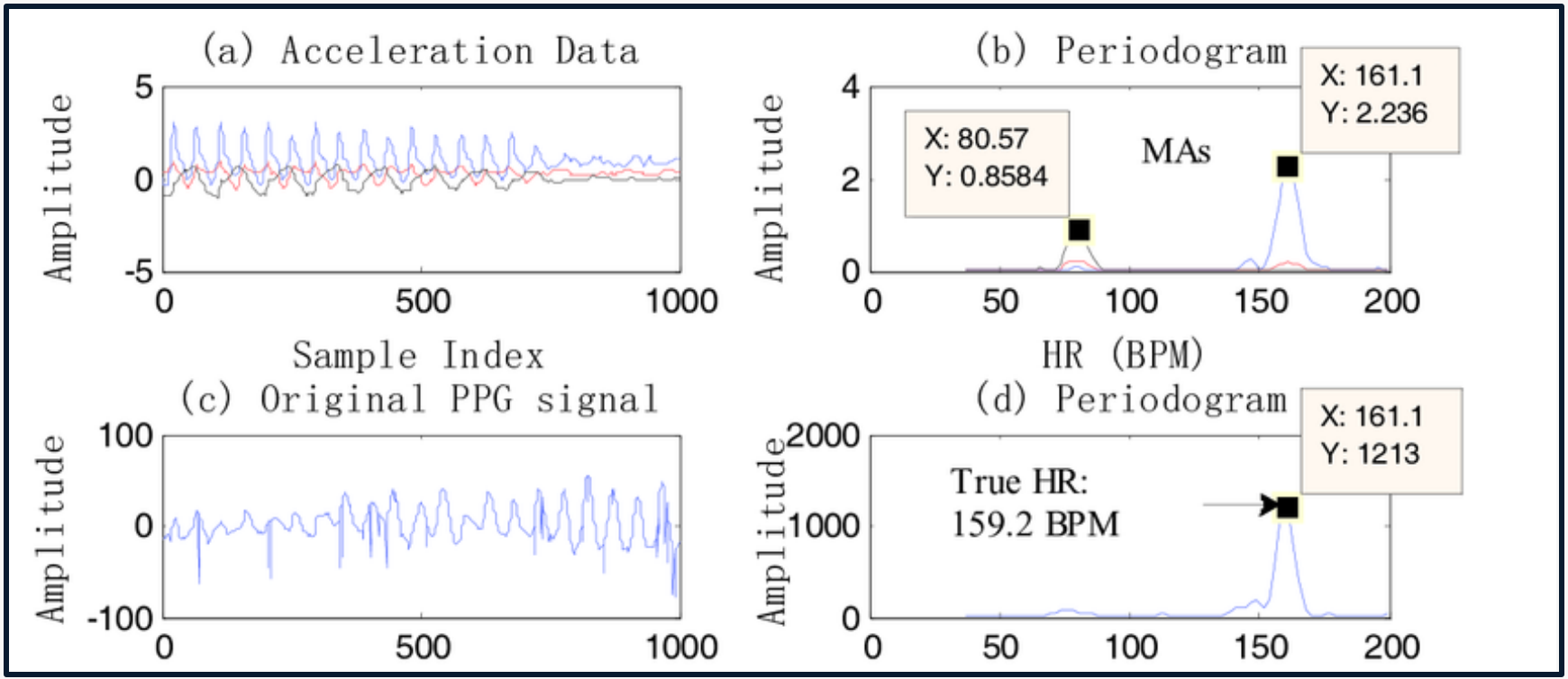
doi: 10.1109/CVPRW50498.2020.00150

# Motion Artifact




doi: 10.1145/3563949

# Signal Crossover




doi: 10.3390/s17112450

# Thank You!

phibbing@uic.edu

ADDS 2024