Articles in PresS. J Appl Physiol (November 2, 2017). doi:10.1152/japplphysiol.00964.2017

Emerging Wearable Physiological Monitoring Technologies and Decision Aids for Health & Performance

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Running Head: Wearable Physiological Sensor Monitoring and Decision Aids

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Wearable physiological monitoring systems are useful research tools for studies outside of the laboratory with free-living individuals, and such systems have found early applications for improving safety and effective performance of occupational tasks as well as for the remote monitoring of patients with chronic diseases (14, 16, 17). Development of wearable physiological monitoring systems has involved a technology pull from several federal agencies such as the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD), that established development programs that address specific needs to track the health and performance status of astronauts and soldiers (2, 6). Commercially available wearable physiological monitoring systems that are widely used for physical fitness assessments have been largely driven by technology push, these commercial products provide minimally actionable information and have tended to be short-lived fads for most purchasers.

Many current wearable physiological monitoring systems measure conventional vital signs (e.g., heart rate, blood pressure, body temperature) as well as activity patterns, but in themselves, these are of limited value. There is an unfilled need to develop and validate wearable physiological monitoring systems and their algorithms that convert data into useful and actionable information for medical management, safety monitoring and performance optimization (8, 12, 13). Recent technological advances in miniaturized sensors, material sciences, robust embedded computing and artificial intelligence are empowering state-of-art systems to leap forward beyond measurement and telemetry of conventional vital signs to provide “smart” and personalized decision aids to monitor and improve health and performance. Such “smart” physiological

monitoring systems will use real-time physiological data fusion to predict changing status (improving or worsening) and will eventually allow ubiquitous use in every-day activities, health care monitoring, as well as use in austere and remote environmental conditions.

There are many bioengineering, physiological, bioinformatics challenges in developing valid and useful, personalized “smart” wearable physiological monitoring systems and decision aids regarding health and performance capabilities. These challenges relate to the data quality that can be collected comfortably on humans often engaged in vigorous activity and perhaps with heavy sweating; the development of algorithms which provide meaningful information which produce timely and useful decision aids; and both security and safety of the system. These “smart” wearable physiological monitoring systems at a minimum will require sophisticated algorithms to interpret often complex physiological signals. Predictive algorithms regarding health and performance often provide only static population-based information (3, 11). Real-time physiological data and artificial intelligence (machine learning) now permit us to move from “group” to “personalized” real-time decision aids. Of course, rigorous studies must be conducted to validate the physiological signals and algorithms that can provide relevant and valid decision aids; this has been lacking in the physiological literature and there is a need for more collaborative efforts involving bioengineers and mathematicians with physiologists to advance the field.

Many wearable physiological monitoring systems have been primarily published in engineering journals, with minimal physiological data and often not demonstrating their future potential for health and performance optimization. We wish to introduce a highlighted topic series of “Emerging Wearable Physiological Sensing Technologies & Decision Aids for Health & Performance” to provide a forward-looking analysis of recent advancements and possible applications, and the physiological / biomedical challenges that need to be resolved to achieve their full potential for a broad range of applied physiology problems. These mini-reviews and articles represent a range of applications for wearable physiological monitoring systems to identify adaptation and maladaptation, acute and chronic health issues, recovery in rehabilitation medicine, and decision support tools in performance monitoring.

This series features seven invited mini-review manuscripts by:

Dr. Mark Buller and colleagues (1) present “Wearable Physiological Sensors for Human Thermal-Work Strain Optimization” which measures heart rate and estimates core temperature to calculate Physiological Strain Index. This approach has been validated to predict work capabilities in a variety exercise-heat strain conditions and is used by specialized Army teams where physiological assessment is critical.

Drs. Victor Convertino and Michael Sawka (4) present “Wearable Technology for Compensatory Reserve to Sense Hypovolemia” which reviews a system that analyzes arterial pressure wave analogs with machine learning to predict impending circulatory shock from hemorrhage, heat stress and dehydration conditions. This approach is based on concepts well known to physiologists and has been advanced to a testable system that is being validated.

Drs. Mozziyar Etemadi and Omer Inan (5) present “Wearable Ballistocardiogram and Seismocardiogram Systems for Health and Performance” which describes wearable systems that measure cardio-mechanical movements and employ machine learning for the longitudinal monitoring for cardiovascular health and perhaps performance optimization. These authors highlight recent technology advances, validation studies and additional novel applications.

Dr. Wei Gao and colleagues (7) present “Wearable Physiological Systems and Technologies for Metabolic Monitoring” which reviews emerging wearable sensors that can conveniently monitor glucose, metabolites and other analytes from the skin and other body fluids as sweat, tears and saliva. The authors delineate the exciting potential for these wearable sensors to provide automatic real-time continuous monitoring for sports medicine, clinical medicine and physiological investigators.

Dr. Omer Inan and colleagues (9) present “Wearable Knee Health System Employing Novel Physiological Biomarkers” which reviews a system that enables quantification of joint health based upon acoustics, bioelectrical impedance, joint position measures with machine learning algorithms. These authors present validation studies and a vision for using these novel “digital” biomarkers that reduces risk of joint re-injury, helps manage treatment, optimizes recovery time for quicker return to activity and reduces health care costs.

Dr. Stephen Muza (10) presents “Wearable Physiological Sensors and Real-Time Algorithms for Detection of Acute Mountain Sickness” which reviews potential physiological measures and algorithms that are being considered and evaluated to enable real-time decision aids to manage altitude sickness. Although this effort is relatively less mature, altitude sickness is an important military problem and sensor algorithm development is a DoD priority.

Dr. Gary Strangman and colleagues (15) present “Wearable Brain Imaging with Multi-Modal Physiological Monitoring” which reviews easy to use wearable prototypes that enables robust monitoring brain physiology in remote settings and austere environments including space exploration. They review their near-infrared scanning prototypes that provide brain imaging while simultaneously supporting multi-model physiological highlighting recent technology advances, validation studies and future challenges.

We hope this highlighted topic series encourages collaboration among physiologists, engineers and mathematicians to develop wearable physiological monitoring systems and algorithms that convert data into useful and actionable decision aid information for health and performance optimization. We believe that such collaborations empowered by recent advances in miniaturized sensors, material sciences, embedded computing and artificial intelligence provide an opportunity for improved health and optimized performance.

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