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Integrating Wearable Sensors into Recreation and Competitive Sports

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Abstract

Wearable technology is going through a remarkable period of development by an ever-increasing number of small start-ups to large established companies and an exciting array of new applications in a variety of fields including exploration, fashion, gaming, military, medical, sport and fitness are being introduced to the marketplace. Despite this considerable interest the application of wearables, there are also well-founded concerns among sport regulatory bodies and exercise scientists. For example, there is a lack of empirical evidence to support the numerous and sometimes outlandish claims made by some manufacturers of wearable companies. The potential partnerships between wearable technology companies and the scientific community would help in the further advancement and adoption of this technology across sports. Live streaming of real-time physiologic and kinematic data is an advancement in wearable technology that shows great promise in many aspects of health, fitness and sport. Backing up these advancements and claims with rigorous scientific evidence will positively impact athletes, sports, scientists, the wearable technology industry and sport.

Background

A variety of wearable sensor technologies (hereon in referred to as “wearables”) are being developed by an ever-increasing number of companies and receiving considerable attention from the athletic community. Wearables can be defined as small, lightweight devices worn on, close to, or even in the body where they monitor, analyze, transmit and/or receive data from other devises and/or cloud services to provide biofeedback real time to the user (1). Wearables can be used by a wide range of individuals engaged in activities of daily living or training and competing as amateur or professional athletes. Wearables may be used to monitor and analyize physiological parameters and individualize training programs to enhance performance and/or health (2-4). Pedometers were amongst the first wearables developed to measure physical activity by the polymath Leonardo da Vinci some 500 years ago (5). da Vinci’s mechanism was designed to measure vertical movements by moving a lever up and down, resulting in the rotation of a gear and this remains the basis of modern day devices. Major advances in technology over the past two decades have resulted in the triaxial accelerometer that measures movements in the anteroposterior, mediolateral, and vertical direction, alleviating the limitations of previous devices (6). Accelerometry-based wearables are currently the recommended method to objectively assess physical activity and interventions aimed at improving health-related outcomes (7).

In professional rugby union, a device that incorporates global navigation satellite systems (GNSS), accelerometry, and gyroscope technology is now routinely fitted to the underside of each player's jersey between the shoulder blades. These wearable microsensors allow player movement to be recorded and reported live during match-play, providing team coaches with key performance "metrics" such as total distance covered by a player in match-play, number of accelerations and decelerations, and "impact" (26) during any given contact or tackle. It is claimed that these performance metrics enable team coaches to track and plan the match play strategy. Changes in sporting rules and regulations have facilitated the use of these devices. For example, the Competition Rule 144 d of the International Association of Athletics Federations (2018-2019) on assistance allows "Heart rate or speed distance monitors or stride sensors or similar devices carried or worn personally by athletes during an event, provided that such device cannot be used to communicate with any other person" (8). Rules such as this promote the use of wearables in elite sport and encourage companies to develop these tools to facilitate high-level performance.

Wearable technology emerged as the top fitness trend in a worldwide survey conducted recently by the American College of Sports Medicine (ACSM) (9), predicting sales of $1.5 to $2.5 billion for some devices and prompting the statement that "it is unpredictable how wearable technology will advance through the next decade". Advances in wearable innovations are being presented by an increasing number of companies at international wearable technology conferences (e.g., Medical Wearables 2018 (10)). The main marketing claim being low cost and easy to use wearables that allow non- or minimally-invasive monitoring of a variety of physiological and biomechanical parameters which in the past were simply not possible without sophisticated, time consuming and costly laboratory procedures. For example, contact lenses can continuously monitor glucose levels (11), soccer shoes may be used to improve kicking accuracy (12), and fabrics may be commercially available to monitor vital signs such as respiratory rate (13).

Despite the revolutionary potential of wearables, there are well-founded concerns about the wearable industry (14). The main criticisms relate to the lack of evidence for the beneficial effects of analysing a specific parameter in a given context or isolation, the quality of hardware and provided data, information overload, data security, and exaggerated marketing claims (1,14-16). For these reasons, athletes, regulatory bodies, and relevant stakeholders are becoming increasingly sceptical about wearables. The shaky reputation of some wearables is having a detrimental effect on the reputation of evidence-based devices. Aggressive and exaggerated marketing claims and the hasty launch of wearable products with only internal validation and reliability studies, and no external evaluation, is highly problematic (14). Wearable devices that employ biological data for health purposes ought to be required to undergo rigorous evaluation prior to being launched on the market similar to the process pharmaceutical industries use to test their products (14). Backing up the marketing claims of non-invasive wearable technology developers with independent scientific evidence would positively impact sports, fitness, and health market. Failure to do so should be subject to financial and other penalties (17,18). Wearable technology that is backed by quality science will be more profitable and sustainable in the long run and the companies involved will have a much higher return on their investment.

Current applications

A recent example used in elite sport and associated with the International Federation of Sports Medicine (FIMS) is the mobile application developed by sport scientists and engineers for the Sub2hrs marathon project (19,20). The Sub2hrs project is the first dedicated international multidisciplinary research initiative to include scientists from academia, elite athletes, and strategic industry partners with the aim of running a sub two-hour marathon while promoting doping-free and fair sport. The Sub2 mobile application (Figure 1) was developed to serve as a "hub" to aggregate a range of data feeds to assist elite runners and their support teams to improve athletic performance. In addition, the "hub" is intended to improve the experience of spectators through real time broadcasting of information pertaining to the "live" performance. This application can provide highly precise real-time measures for athletes and their support teams, such as distance run and speed using a proprietary algorithm. A number of sensors to measure heart rate, running economy, and core temperature along with other physiological and kinematic parameters (e.g., contact time, cadence, strike angle) can be integrated to provide a holistic and compressive overview of the activity and its impact upon the athlete. The app provides a live data feed of land and air temperature based on geostationary satellite data as well as state-of-the-art machine learning techniques. This is facilitated through a Cloud-based portal allowing the athlete support team to view the data on a desktop, tablet, or a smartphone in real time anywhere around the globe with internet access. The Sub2 mobile application runs on smartwatches with the Android Wear 2.0 operating system and standalone connectivity, overcoming the need for the smart watch to be paired to a smartphone (Figure 1). Historically, such capacity to transmit biometric data such as body temperature, pace, cadence, heart rate, and breathing rate in real-time during a race was only possible using tablets held by nearby cyclists following the runners at all times (21) or by recording singular data points at predetermined distances or times along the course. The app performance was tested on an elite female athlete during the recent Seville marathon (Figure 2). Physiological and biomechanical parameters were monitored and transmitted live to scientific support staff in the UK, South Korea, and Ethiopia through the Sub2 mobile application.

Daily life is becoming increasingly sedentary, and physical inactivity is a global pandemic. Applications and wearables have great potential as tools to promote and increase the levels of daily physical activity (22). Although the use of this technology is a promising alternative to combat inactivity, the efficacy of this approach remains to be determined. In a recent review of 111 studies (23), less than one-third were optimized for effectiveness, engagement, and acceptability and the review concluded that guidelines were needed to facilitate the synthesis of evidence across disciplines.

Scientific basis of wearable parameters

The potential to measure almost every foreseeable parameter with a wearable is real. However, not every parameter is meaningful to either the recreational and/or competitive athlete (16). Using the prior Rugby Union example, monitoring the covered distance during match play and/or training using GNSS may provide some interesting information but knowing the covered distance *per se* is unlikely to optimize performance and/or reduce the likelihood of injuries as claimed by the manufacturer. There are increased efforts to understand the relationship between covered distances in different intensity zones and the likelihood of injury (24,25,27,28). In this context, it is important not to confuse the association between a parameter (in this case the covered distance) and an outcome (the likelihood of injury) with the ability of a parameter to predict injury (29,30).

Research to develop evidence-based algorithms that support the use of specific parameters to predict injuries and potentially aid in injury prevention is needed. It is important to investigate the interaction between monitored parameters and aspects of performance and/or health that wearables may detect. Collaborative efforts between sport practitioners, engineers, data analysts, sports medicine personnel and other relevant groups will form a science base for the application of this technology. Easy access to raw data from wearable devices would speed advances and benefit the athlete, scientific community, manufacturer, and practitioner. Wearable companies typically work in isolation to safeguard their intellectual property. In the future, if wearable companies are to become more evidence-based in their approach, they will need to develop multidisciplinary teams that place greater value on research and development.

Quality control

Quality control of the hardware and the data generated is crucial for wearables to improve athlete performance and health. While there are many wearables that claim to deliver reliable and valid data to the user (31,32), few wearables have had rigorous independent testing (1). Independent research institutions should validate the reliability of wearable technology prior to releasing the products on the market (1,33). Recommendations exist for the assessment of reliability, sensitivity and validity of data provided by wearables (34). Hardware should also be tested to reduce the risk of harm to the user. Third party, independently verified quality assurance, durability (battery life), survivability (water resistance) and data protection would significantly enhance a products reputation and potentially use (35,36). Good quality control of the hardware, the safety and privacy of the data would increase the reliability of the data generated and improve the comparison between devices.

Improving user interface

Wearables need to be simple and time-efficient for a high level of compliance and usage (33). Monitoring simple subjective data (e.g., ratings of perceived exertion) can be done with a touch interface and advancements in voice recognition allow more complex data to be gathered verbally (37). Collaboration with athletes is needed to determine the most suitable form of instant feedback, i.e. what information do they need to know to improve performance while not being distracted from their surroundings. Regardless of the presentation medium, smartwatch, phone/tablet, or computer screen, the information needs to be in an informative and easily understandable format (39). This is critical when elite athletes are the target and the slightest distraction may decrease performance in disciplines where concentration is paramount to success (e.g., Formula 1, MotoGP, and cycling) and participant safety. In the future, biofeedback that is not provided instantly could possibly be provided in a virtual reality environment allowing the athlete to receive the feedback and implement strategies and see if it makes a positive impact on performance (38). Future studies are needed to evaluate the most useful and suitable form of feedback for different athletic tasks and disciplines and to present the data in an understandable and attractive format (39).

Data collection and handling

To enhance high-level performance a variety of multiple wearables will likely need to be connected to gather the relevant data within a single database for interpretation. Data that is standardised and easy to share will enhance and facilitate collaboration and big data analytics may identify new relationships between the parameters measured, further enhancing sports performance and health (1,40,41). Developing such large databases and the algorithms they may produce will require the collaborative effort of data service providers, exercise scientists, athletes, and data analysts to generate meaningful and useful information. The motivation to use wearables varies between the populations using them. However, if production of the device is not sustainable and the data is not reliable, valid and/or actionable, no one will ever benefit from this technology.

Concluding remarks

In the future, athletes will have the option to use an increasing number of wearables and each new device should add beneficial information to the training process with the goal of helping sports scientists and health care providers improve their athlete’s or patient’s performance. Sharing data between the athletes, exercise scientists, hardware and software engineers, and other stakeholders has the potential to improve wearable devices and technology for competitive athletes.

Conflict of interest

Wearable Technologies AG offers, together with TÜV SÜD, commercial quality control of hardware employed by wearables.

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