International Journal of
Sports Science
& Coaching

Original research

State-of-the-art review of athletic wearable technology: What 113 strength and conditioning coaches and athletic trainers from the USA said about technology in sports

International Journal of Sports Science
& Coaching
2020, Vol. 15(1) 26–40

DOI: 10.1177/1747954119885244
journals.sagepub.com/home/spo
SAGE

Tony Luczak[1], Reuben Burch[1], Edwin Lewis[2], Harish Chander[3] and John Ball[4]

Abstract

Wearables are a multi-billion-dollar business with more growth expected. Wearable technology is fully entrenched at multiple levels of athletic competition, especially at the National Collegiate Athletic Association (NCAA) and professional levels where these solutions are used to gain competitive advantages by assessing health and performance of elite athletes. However, through the National Science Foundation (NSF) Innovation Corps (I-Corps) training experience, a different story emerged based on pilot interviews from coaches and trainers regarding the lack of trust in wearables, and how the technology falls short of measuring what practitioners need. An NSF I-Corps project was funded to interview over 100 strength and conditioning coaches (S&CCs) and athletic trainers (ATs) regarding the current state of wearables at the NCAA and professional levels. Through 113 unstructured interviews, a conceptual map of relationships amongst themes and sub-themes regarding wearable technology emerged through the grouping of responses into meaning units (MUs). Interview findings revealed that discussions by S&CCs and ATs regarding wearables could be grouped into themes tied to (a) the organizational environment, (b) the athlete, and (c) the analyst or data scientist. Through this project, key findings and lessons learned were aggregated into sub-themes including: the sports ecosystem and organizational structure, brand development, recruiting, compliance and gamification of athletes, baselining movement and injury mitigation, internal and external loads, "return tos," and quantifying performance. These findings can be used by practitioners to understand general technology practices and where to close the gap between what is available versus what is needed.

Keywords

Performance analysis, sport analytics, sport technology, wearables

Introduction

In 2013, Hynes et al. predicted that the days of athletic training staff having little access to technologies that quantitatively measure and validate observations about athletes were coming to an end. "A new generation of affordable technology will be available in the next few years."[1] Hynes' assessment couldn't have been more accurate when considering the advancement of wearables. Wearables can be defined as technologies used to measure various physiological and kinematic parameters by being sported or borne by the user.[2]

Reviewers: Harvey Newton (Newton Sports, USA)
Mike Callan (University of Hertfordshire, UK)
Martin O'Reilly (Output Sports, UK)

[1]Industrial & Systems Engineering, Mississippi State University, Mississippi, USA
[2]Chemistry, Mississippi State University, Mississippi, USA
[3]Kinesiology, Mississippi State University, Mississippi, USA
[4]Electrical & Computer Engineering, Mississippi State University, Mississippi, USA

Corresponding author:
Reuben Burch, McCain Hall, Rm. 260, 479-2 Hardy Rd., P.O. Box 9542, Mississippi State, MS 39762, USA.
Email: burch@ise.msstate.edu

Wearables in athletics have increased in demand and function[3–5] and are predicted to experience extreme growth in the next few years[3,6,7] reaching $34 billion[8] to $40 billion[9] in global revenue by 2020.[8,9] This includes $2.8 billion in revenue from core athletic wearable technology companies, such as Zephyr, Catapult, Zebra, STATSports, and Adidas,[10] along with an overall athletic revenue projection of $15 billion by 2021 (Figure 1).[11,12] Also, the smart clothing market segment (sensors embedded into clothing) is expected to reach $4 billion by 2024.[13] With 240 million wearable athletic devices expected to ship by 2020[9] and an expected consumer surge in all wearable devices reaching 485 million devices in 2019,[7] demand will decrease the unit price of components involved with building and supporting wearable solutions. Most wearable technology spending is from sports associations attempting to mitigate athlete injuries as this can cost teams millions of dollars.[13] According to the National Athletic Trainers' Association (NATA) on deterrence of pediatric overuse injuries, it is expected that 50% of these types of injuries are preventable. There is the perception that wearable technology can be used to provide warnings thereby preventing the overuse, non-contact injuries.[14]

There are vast amounts of research on using wearable devices, inertial measurement unit (IMU) sensors, and Global Positioning System (GPS) devices in athletics. Analyzing the data collected during athletic training and competitions from wearable technology and then inferring standard biomechanical or physiological patterns based on sport type or position played are common amongst coaching and sports science journals.[15–17] But, as a recent article about wearables and trust shows[18] the story about wearable use in athletics is more complicated than looking at market share or technology saturation amounts. Exactly how widespread the use of wearable technology is for performance assessment across a broad range of coaching and a wide range of sports is currently not known.[19] Also not fully understood is the technology's usefulness or impact on athletic decisions about health and performance. The research team understands that studying practitioners' perceptions of wearable technology will paint a broader picture of wearable use and serve as potential recommendations for the use of wearable technology in athletics.

Pilot study on athletic practitioner perceptions of wearables

A preliminary National Science Foundation (NSF) Innovation Corps (I-Corps)[20] training site pilot grant was provided to this research team for the investigation of a new athletics wearable technology design. The intent of this preliminary pilot study was to understand if the wearable solution would meet the needs of the end user, the athletic training practitioner, via a series of unstructured interviews. The target customer segment of the wearables being investigated was strength and conditioning coaches (S&CCs) as well as athletic trainers (ATs) who would make decisions about what technology should be purchased for their teams. Twenty-five S&CCs and ATs from around the country, in all sports, and at the National Collegiate Athletic Association (NCAA) Division I and professional levels were interviewed regarding their use of wearables. While the goal was to investigate a specific wearable solution, the general feedback from 76% of the pilot interviewees ($n = 19/25$) was surprisingly very negative about all wearables used in athletics in general.

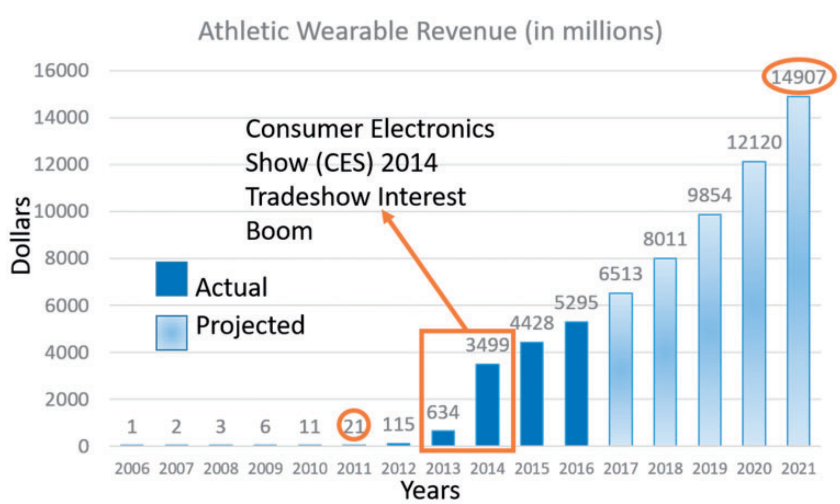

Figure 1. Athletic wearable market actuals and projections (note the projected increase of ~15 billion in revenue in a 10-year span between 2011 to 2021). Projections based off of a compilation of multiple sources.[3–9,12]

The primary negative themes repeated verbatim by most of the interviewees were (a) wearables don't measure what the practitioners need, and (b) there is a significant lack of trust with existing wearables solutions. The important finding for this initial pilot training study had nothing to do with the one wearable solution being assessed by this research team; instead the critical realization was that a multibillion-dollar industry appeared to be missing consumer expectations. Further investigation into understanding where wearables and athletic technology, in general, were deficient based on practitioner experience was required.

NSF I-Corps National level funding was awarded with the expectation that the research team would travel across the USA and interview at least 100 S&CCs and ATs in order to paint a more complete picture of wearable usage at the highest levels of competition. The purpose of this project was to interview S&CCs, ATs, sport coaches, medical professionals, and athletic administrators on the positives and negatives of sports wearables in collegiate and professional sports organizations. Based on these discussions, several themes regarding the use of sports wearable technology were identified. The purpose of this paper is to explore those themes put forth by practitioner perceptions of wearables and their influence on and integration into the world of competitive sports.

Methods

Design

To comply with the funding requirements defined by NSF, at least 100 interviews would need to be conducted within the USA with S&CCs, ATs, and other personnel holding decision-making influence within university athletic department and professional team front-office settings. The preference was for all interviews to be conducted in person with allowances made for phone interviews given the complex nature of S&CC and AT schedules during their respective sports seasons. During the pilot study, an unstructured interview methodology was found to work best with S&CCs and ATs given that this interviewee demographic has limited availability. S&CCs and ATs also have drastically different experiences based on the technologies they use (or don't use) as well as how they run their weight rooms and training programs. However, a general checklist of questions was followed to ensure that the critical information was consistently captured from each interviewee (when it applied). The question checklist was created through the pilot round of interviews where the interviewees were given an opportunity to inform the researchers of what they wanted to learn most from their peers in follow-up interviews. Questions were themed around the high-level topics presented in Table 1.

The researchers used an autoethnographic frame in outlining and executing these unstructured interviews. The first author is a professional golf coach and trainer who had a child play basketball at the NCAA Division I collegiate level. The second author played football at the NCAA Division I level as well. At least one of these two researchers was present for or conducted the interviews allowing for a greater connection between interviewers and interviewees.

Participants

Interviews began with the researchers' existing network of S&CC and AT contacts (as well as other athletic community connections) in order to get their feedback as well as to attain additional contact information from their peers whom they believed would be willing to share their opinions on athletic technology. Potential participants were contacted via email or text (based on candidates' preference) and informed of the research study. However, the local and extended networks only encompassed 53 of the interviewees; therefore, purposive sampling was required in order to conduct over 100 interviews. Purposive sampling consisted of calling and emailing potential participants directly to make them aware of the study in which they were being asked to participate. In total, 113 individuals from 46 athletic-based locations (universities, professional teams, and athlete training and medical centers) involved in the collegiate and professional sport ecosystems were interviewed. Those who wished to learn more were provided with an email detailing the intent of the study including (a) information about the interview format, (b) identity protection confirmation, and (c) incentives for participating in the study (receiving

Table 1. Themes for unstructured interview discussions amongst S&CCs and ATs.

Unstructured interview question themes
1. What wearables and other technologies do you currently use?
2. What are the pros and cons of your current wearable and athletic technology solutions?
3. Have you experienced any wearable deficiencies or have any concerns about the technologies you use?
4. What are your primary data requirements and preferences?
5. What are your biomechanical and physiological data needs?
6. What current athletic movement and baseline methodologies do you use?
7. What is the athletic culture surrounding the usage of technology and data analysis?
8. What are additional athletic landscape areas of interest you want to discuss?

an aggregate of the study findings). For many of the participants who agreed to participate, travel arrangements were then coordinated to conduct onsite interviews. Participants interviewed were men (n = 93) and women (n = 20) who represented collegiate (n = 76) and professional sports (n = 11) commonly played within the USA as well as other facilities such as training and medical venues tied to the high-level sports ecosystem (n = 26). Men and women sports were represented as were multiple institutions from NCAA Division I and II, the National Football League (NFL), the National Basketball League (NBA), Major League Baseball (MLB), the National Hockey League (NHL), and Olympic training facilities. All participants received an aggregate findings report upon the project completion.

Procedures

Interviews were unstructured to allow for natural conversational flow and to ensure that the most important information regarding the question themes (Table 1) was shared by the interviewees. Not all interviewees had personal experience or even opinions regarding each specific question theme and—given the limited time each interviewee had to share—the research team believed spending time discussing the themes of most concern or importance for each participant was the best use of that time. For example, some interviewees did not have current personal experience with wearables and so interview time would then be spent on other themes such as movement baselining methodologies. Also, given the uniqueness of the experience of this group of participants, if the interviewee either did not want to discuss a specific topic or if they wanted to discuss mostly a singular topic from the question themes, the researchers allowed the conversation to flow in this way. More important than trying to systematically touch upon each discussion theme was creating an environment where these highly specialized interviewees would feel comfortable sharing information about their profession. The unstructured interviews were conducted either in person (n = 75) or via phone (n = 38). Phone interviews were conducted if the participant was difficult to schedule due to in-season activities. Interviews were conducted either with individuals or with groups of participants. Fifty of the participants (44.2%; n = 50/113) were collected in a group interview session. In total, 13 group interviews were conducted and included between two and six participants in each group for a total of 76 separate interviews conducted for this study. For situations where multiple S&CCs and ATs were interviewed at once, researchers mitigated group think and bias as much as possible by eliciting feedback from all participants for each question. After an answer to a question was provided by one member of the interview group, all other interviewees present were directly asked if they agreed, disagreed, or had more to contribute based on their experience. Based on the experience of the research team when working with and competing in elite-level athletics, S&CCs and ATs are generally not reluctant to share their views and were therefore not hesitant in the interviews to voice any differences of opinion regardless of the authoritative level of the others in the group. Interviews lasted 75 ± 15 min and were documented by the researchers via digital notepad (e.g. Apple iPad and Samsung Galaxy Note). Audio recordings were not captured at the request of the interviewees. At least two researchers were present for the duration of the interviews such that one could converse with the interviewees while the other transcribed responses. Notes captured largely consistent of direct feedback to the questions, additional information that was deemed pertinent by the researchers, and quotes that could later be used to explain the practitioners' thoughts and considerations on the question themes. The Cornell Method of note taking was the preferred method by the researchers as the note pages were divided before the interview into three sections: (a) questions, (b) ideas, and (c) quotes.[21] Time was given to the transcriber to catch up if needed. Upon the completion of each interview, the researchers collectively reviewed the notes to ensure everything was captured correctly and that no important information was missed. Body language and voice tone were not captured in the original transcription, but upon review of the notes, if the researchers agreed they noticed a change in behavior during the interview, it was noted. Over 200 pages of original notes were captured throughout all interviews. After each interview was completed and vetted for completeness by the researchers present, notes were then coded into the Business Model Canvas (BMC), an NSF I-Corps curriculum tool and requirement of the NSF funding process. All researchers present at the interviews reviewed the BMC entries (a) to ensure all relevant points were captured and (b) to agree to the wording and intent of the interview content entered.

Data analysis

Analysis began with relevant data transcription of the interviews. Using the method defined by Teddlie and Tashakkori[22] and utilized in an athletic interview setting,[23] data coding was performed by three researchers and consisted of separating the interviewee quotes and notes from the unstructured interviews into meaning units or MUs. MUs were separated into themes based on their similarities and differences as identified

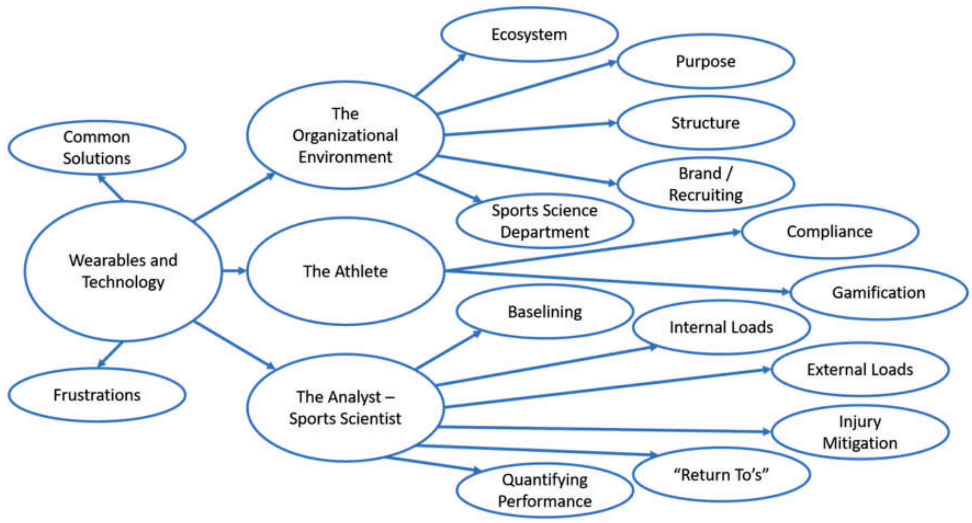

Figure 2. Conceptual map of relationships amongst themes and subthemes.

by the research team. As per Shipherd et al., all text segments were grouped into themes with maximum between-theme variation and minimum within-theme variation.[23] This process continued until no new themes emerged. All MUs and themes were agreed to by the researchers. Any discrepancies presented in discussions regarding which MUs interview notes should be placed were generally resolved by referring to the question theme that drove that segment of the discussion. Given the "free flow of thought" nature of some interviewees, not all notes could tie directly back to the originating question theme. In those instances, the MU selection was made through an agreement between the two researchers present for the interview. Through learning sessions with NSF I-Corps, the researchers were trained to be aware of biases, both in how the questions were asked, and how they were recorded. The largest risk of bias in this process was the researchers' assumption of what the interviewees were either going to say or "trying" to say . . . especially after dozens of interviews had already been conducted where similar sentiments had been expressed. To mitigate these biases, researchers would often repeat back answers to the participant on critical questions to ensure their opinions, and responses were correctly recorded and that no assumptions about what researchers thought the interviewees "meant to say" were being filtered into the data.

Results and discussion

Of the 113 practitioners interviewed, 72.6% (n = 82) of them were actively using wearable technology within their facilities. For the remaining 31 interviewees who were not actively using wearables, they either had used wearable technology at a previous institution, were well versed in the use of the technology, or were familiar with wearable solutions from conferences and peers.

Throughout all the interviews about wearables, comments made were largely within the context of one of three themes: (a) the organizational environment, (b) the athlete, or (c) the analyst or data scientist. Additional comments directly referenced technology usage. All themes and subthemes and their relationships are visualized in Figure 2.

Wearables and technology

Common solutions and general feedback (Table 2)

Frustrations. All interviewees with wearable experience (72.6%; n = 82/113) spoke to their frustration with wearables and sports training technology due to inaccurate data, lack of meaningful recommendations (or lack of meaning in general), and challenges in getting the technology to work consistently. Unfortunately, (a) some companies are not supplying answers to "what does the data mean," (b) athletes are concerned about "big brother always watching me," and (c) customer service is lacking when devices are not working as needed or advertised. This has caused dissatisfaction between the technology users and the technology providers. One prominent Olympic trainer bluntly stated:

> Wearables are fool's gold.

Trust is one of the biggest concerns about technology; can sports organizations trust that the data interpretation and collection from the technology is correct all the time, some of the time, or even part of the time? There is drift in IMUs. GPSs aren't as precise as needed in certain sports (and in indoor or covered locations)

Table 2. Most common wearables currently implemented at interviewee facilities.

Devices	Commentary	Sports
Catapult	Cannot track quick change of directions	Football, soccer, baseball
Zephyr	Inconsistent	Football, soccer
First Beat	Good UI and output	Hockey, soccer
Polar	Good UI and inconsistent	All Olympic sports
Kinexon	Accurate indoors	Basketball
Whoop	Intrusive	All Olympic sports
Vert	Mixed results	Volleyball, basketball
Fatigue science	Replacing other systems	All Olympic sports
Strive Tech	Built into own clothing	Football
Zebra	Proprietary algorithms	Football
Garmin	Cost effective	Cross-country
Athos	New tech & (pre- or post-injury) rehabilitation	Football

due to interferences from building materials and other devices causing signal interference. Too much bluetooth noise from fans within stadiums often leads to malfunctions and frustration. Interviewees question how a single metric or algorithm can accurately take in all the variables of human performance and create an accurate, meaningful output (e.g. load). Often, this leaves training staff with more questions than answers. In addition, 47.5% (n = 39/82) of all interviewees currently using wearables (34.5%; n = 39/113 of all participants) spoke of limited access to wearable vendors for the purposes of scientific conversations about the relationship of the data to performance, further fuelling frustration, and resulting in the rationale to hire sport scientists to search for meaning in the data. One simple solution that institutions have begun to employ is to simply stop using data-producing devices all together.

Lessons learned. Unfortunately, technology isn't perfect. Organizations looking to use wearables and other technology need to be prepared that it won't always work and have a plan for what to do when it does not work. Once data collection for athletes occurs, patience and analysis will need to be combined in order to get something meaningful. Systems provide models of work and activity from the raw data, and there isn't always a clear meaning of what that data means for individual players. Manufacturing variances can and will make devices "different" from each other. Interviewees recommend that players are always assigned to the same devices (e.g. player #30 always wears device #xyz123). Repeatability is key with technology. When it comes to data analysis, all interviewees with five or more years of experience using wearables (42.4%; n = 48/113) explained that they often look at longitudinal data instead of acute data points (daily and weekly), when making decisions.

The organizational environment

Ecosystem. The process of these interviews led to the identification of the athlete ecosystem. This ecosystem consists of family and friends, S&CCs, ATs, sport coaches, medical professionals, administration, NCAA, insurance companies, agents, players' associations, and professional leagues. Often decisions and opinions of wearable technology expressed by different components of the ecosystem impact whether wearable devices are used, and how the data are shared.

Athletes' opinions range from full acceptance to outright refusal to wear the device because of reasons such as uncomfortable straps and the device's appearance. For example, one S&CC from the Division I collegiate basketball reported:

> Players are comfortable wearing devices and [this] has become the culture.

whereas a football S&CC stated that their athletes refuse to wear technology:

> ... because they are inconvenient, uncomfortable, look funny, or [for] simply no good reason other than entitlement.

Athletes are also concerned about how coaches will use the data to determine playing time. Another concern athletes have is how management may use the data from the device to modify their contracts and change the athlete's current worth or playing time. An AT at a Power Five conference university stated her awareness that:

> [Athletes] are worried that they are being tracked [and] that the coach will know when they are slacking.

In addition, athletes have often blamed poor performance on the requirement to wear athletic wearable technology as reported by another S&CC basketball coach:

> Some athletes won't wear them [because] they blame the device on their poor performance [during play].

As reported by 48.8% of interviewees actively working with wearables (n = 40/82), lower level NCAA athletes (Division II and III), female athletes, and international athletes were reported by the interviewees to be more open to the use of wearables compared to the elite NCAA male athletes. The 40 participants included in this assessment currently work or have worked with these three athlete populations and could speak to the implementation of wearable technology. For example, statements like the following were common:

> Basketball players from lower level schools treat wearables [better] versus Power Five [conference athlete] prima donnas [because they are] excited to use wearable and see it as a competitive advantage.

> Female soccer and volleyball players are accustomed to wearing devices [via] sports training bras.

> International athletes are up to two times easier to comply due to mindset of training methodologies.

However, the interest of the athletes can change if the organizational culture openly adopts and encourages proper device usage

Professional athletes spend considerable money on developing their own training and recovery strategies. According to 73% of the interviewees with current professional organization affiliations (n = 8/11), the athlete will have their personal coach or trainer that may or may not fit within the defined protocols of the team's S&CCs and ATs. This has caused some interesting situations for professional organizations such as the NFL and NBA. As one NFL S&CC stated:

> I get very limited time with these [athletes] and may have to spend half of that time convincing them that their training [consultant] is more interested in social media "likes" than their performance.

Lessons learned. The ecosystem is extremely complex and just one or a few individuals within that ecosystem can shift the direction of the mindset of the athlete. For the athlete to use and train with technology, there must be complete trust that the coaches, administration, ownership, trainers, and the entire ecosystem are there to help make the athlete better... not for the ecosystem's agenda but for the athlete.

Establish a purpose. Establishing a rationale for using wearables has been reported as a critical step in deciding to purchase wearables and other sports training technology. During the interviews, the research team learned of the "three musts of wearables:" (a) know what performance data you want measured, (b) how accurate and usable is the technology, and (c) what does the data mean.

> [The] three musts of wearables – What is measured, Accuracy and Use, Data interpretation.

> Wearable devices are used like training wheels for lowerclassmen to give them a reminder of what [an] appropriate workload looks like from a physiological versus distance perspective.

> Load was the critical decision factor for purchase but what set Polar apart from other price comparable devices was the visuals of the Polar output.

> Teams aren't ready to use a data scientist because they are still trying to figure out how use this new massive amount of data in the first place. Incorporating use of data is new, the benefit of the data is new, and the role someone needs to play to analyse the data while still fitting in the athletic culture is all new.

Wearables and other sports training technologies have a tremendous amount of data output. The accuracy, the amount, and how the data are visually represented are major concerns for practitioners.

Lessons learned. Developing an ecosystem plan for wearables and other sports training technologies can save time, frustration, and money. For example, the amount of time managing wearable technology inventory and personal compliance can be greater than the meaningfulness of the data. Teams have opted to shelve wearable technology due to excess time spent with no new knowledge. Based on the S&CCs and ATs experience, their assessment of the athlete was, in many cases, quicker and more precise than the data from the wearable.

Organizational structure. The decision to use wearables and other sports training technology differs depending on the organizational structure, budget, and strategy of the team. Based on data taken from the interviews, there exists a spectrum of team organizational models anchored by autocratic and group consensus. The USA team model could be considered autocratic, where the head sports coach has the final say about an athlete's playing and training activities. Thus, the question of coach "buy-in" or not is critical in the use of wearables and other sports training technologies. Of all the practitioners, regardless of currently wearable use, 21.2% (n = 24/113) reported that there appears to be an "over-trust" of data by the head sports coach in athlete management. NCAA Division I football and men's basketball largely represented in this insight.

Counter to the USA viewpoint was labeled the International team model of shared team decision making. The International team approach consists of all influential coaches and trainers involved with athlete practice and training at the beginning of the game week. The interviews revealed that as many as 30 coaches and trainers may be involved in the group training decision process.

> There is a gap in [the] USA approach compared to the European team approach. For example [a] European [team] utilizes sports scientists, strength coaches, athletic trainers, skill and sport coaches . . . [this group] meets prior to the week's practice to discuss player return to play, training, performance, and [to] make decisions as a group on individual player activity.

Lessons learned. On the field or court, success cannot be directly linked to how the team operates on the team organizational structure spectrum (from autocracy to a shared decision-making model). However, trust and respect for the athletes from each of the coaches and trainers involved in making team-based decisions are critical components for successful organizations. For teams where there exists a lack of professional trust and respect, the athletes and support staff may endure internal stressors because the team's performance won't be perceived to be optimized.

Brand development and recruiting. As wearables and other sports training technologies evolve, the rationale to use technology varies from developing differentiation of the institutional brand during the recruiting process, to injury mitigation, performance tracking, rehabilitation, and pre-rehabilitation (rehab and prehab) validation that enables players to return to training, practice, and play. Further pressure for teams to use wearables has been experienced from high school recruits who currently use technology during training either at home from parental purchases or local training center amenities.

> "Everyone" is trying to bring in and hire data analysts for the purposes of interpreting all this wearable and human performance data as well as to impress on the recruiting trail.

> Student-athletes coming in are expecting wearables because their parents bought them for the kids in high school.

> The difference between pulling in a big-time recruit and not getting them committed is now actually being affected by the amount of technology available and the expertise to use it.

> Most people in other [collegiate and professional] programs and [the] NFL only have the wearables because others have it but [they] don't use the data for anything. Just something that people must show that they are progressive.

Failure of the institution to showcase the latest training technology may impact the recruit's decision of where to attend. Beyond just the appearance of using wearables, new recruits are interested in how the data will be used to prepare and develop their skills for the professional level of competition.

Lessons learned. If a team buys technology for the purpose of brand development and recruiting, this doesn't mean the training staff should hurry to implement changes in programming because of the numbers shown in the data. Seven of the interviewees (6.2%; n = 7/113) reported using wearables for 10 or more years, and they all corroborated that teams may need to wait up to as many as five or six years to fully understand what the data truly mean. For example, a consultant S&CC for professional organizations stated:

> Some professional teams take over four years to really get acclimated to making good decisions that are proactive and not reactive.

Thus, being on the leading edge of sport science is viewed as a positive to the potential athlete while true sport science and finding significant meaning in the data can be applied once deemed appropriate. Thirteen of the interviewees (11.5%; n = 13/113) had recently implemented wearables and mentioned the unrealistic expectations on the part of the head coach or administration. One S&CC for an NCAA Division I football program tried to explain to his team that he . . .

> . . . [preferred] to collect data for a minimum of a year and use a previous year's worth [of data] to then begin making decisions and recommendations to the coach for the upcoming season.

The coaching staff wanted the wearable data to provide training practice guidance within weeks of making the purchase. There can be a lot of pressure to make immediate use of and justification for an expensive technology purchase. An NCAA Division I basketball coach confirmed that he was . . .

> . . . worried that the pressure from [the] coaching staff could force me to try to infer information from the data before there is anything to learn.

Realistically, however, wearables and data are a "long game" approach that is only successful when considered one part of long-term planning. Just as changing a coaching staff year after year can prove unproductive,[23] so too can changing wearable technology year in and out for the latest and greatest solution.

Sports science department. Overall, a consensus appeared through the interviews that there is not enough time in the day to manage the data captured by the wearables and still properly train the athletes.

> The culture is just now getting use to unlimited data; [we] need to wait until data is understood then define the scientist role.

This has led to the hiring of data analysts or sport scientists. However, disputes between the athletic training staff and data analysts have emerged as a result of inefficient organizational culture support, and from the analyst's lack of the contextual understanding of the sport they are applying data-driven decisions toward.

> Biggest disconnect is that the data analyst doesn't have sports context but requires the guidance from someone who understands not just the sport but the sport culture and hierarchy.

> Data analysts (the scientists) and the athletic staff . . . these two groups aren't getting along because they do not or cannot speak the same language.

> [I've] seen where so often the data scientist and strength staff are in "furious agreement" but don't realize they may be saying the same thing . . . yet leading the coach down different, incorrect paths. Bringing in data scientists too soon before their positions were clearly defined is a big issue I see.

For clarification, furious agreement is a term often used when two or more people agree to the same general principle or course of action but their desire to be correct deafens them to the fact that everyone is essentially proposing or stating the same thing.

> The data scientists and the athletic trainers are not seeing eye to eye and are making power plays to hire people.

Instead of understanding and developing meaning behind the numbers, the numbers become the decisive guidelines for management and head sport coaches to make decisions regarding players.

> [The] player's associations [are] concerned that management will use data against the athlete, but often there are other metrics that tell the coaches and management something isn't right.

> Technology is still being purchased at a ridiculous rate; however, the intent and use of that data is getting skewed and used for "evil" purposes.

When hiring a data analyst isn't possible due to budget constraints, the S&CCs or ATs are now becoming the sports scientist therefore increasing and straining the time demand of the staff. With the amount of data being generated, if the wearables and sports training technologies aren't providing easy-to-interpret and meaningful recommendations, the technology has been shelved. Resourcefulness of the S&CCs and ATs has led to the development of personalized spreadsheet systems to manage and utilize the data.

> [We] developed [a] system to create "baseline" for players based on three different tech systems and assessments . . . [our system] incorporates "mental conditioning" two × per week, using Zephyr, force plates, FitLight Trainer, and Quick Board.

Due to the complexity of human physiology and athletic performance, there is often more data available than time to analyze it. In addition, the usefulness and correlation between various data points hasn't been clearly identified. This leaves many questions unanswered about the effectiveness of wearables and sports training technology. Further, analysis of the data by practitioners often leads to the discovery of inaccurate data or inconsistent algorithms.

The goal of any organization should be the development of a cohesive data management plan and a contextual understanding between all the coaches, trainers, and analysts. Coordination and sharing of technology between sports teams at the same institution have shown to be cost effective as the data management techniques are then also shared.

Lessons learned. Sport science departments are being created either with additional analysts or sport scientists. Hiring a data analyst can be effective if—and only if—the data analyst will work closely with the S&CCs and ATs in "interpretation" of the data. Devices and technology are relatively new, and their applications are still under evaluation. Currently the National Strength and Conditioning Association (NSCA) is considering developing a "Sports Scientist" certification which may help relationships between S&CCs, ATs, and data analysts. However, depending on the budget, the burden of data analysis may further fall to the S&CCs or ATs. The inclusion and automation of devices and data are highly desired from the interviewees. Depending on budget and capabilities, it is advisable for more budget-constrained organizations and institutions to reach out to academic departments for assistance in managing and assessing data.

> [We are] beginning to use academic departments . . . to help with data management and sport science.

> [We] created a mutually beneficial relationship with academic departments in order to have wearable data validated and, in some cases, analysed for the coaches.

> Creating and training a staff of researchers to aid in technology selection decision making [via] validation and increased levels of understanding of what existing data trends show. Academic departments that partner with athletics are becoming a significant influencer of technology solution implementations and money spending by athletic departments.

The athlete

Compliance. One criticality of wearables and sports training technology is player compliance. Whether the athlete doesn't want to "look bad" or states that "it's interfering with my performance," the acceptance to wear devices was noted by practitioners to be very mixed. When the athlete is personally motivated to improve, compliance is often high. However, if the athlete doesn't believe technology will help or if there is minimal reinforcement, culturally, of the importance of technology, then compliance will usually be low.

> Players are reluctant to wear devices due to poor comfort and performance. [The device] must not interfere with daily routine. [Device] materials must be breathable and high quality.

Depending on the institutional culture, "buy in or not" from the athlete parallels the attitude of the sport coaches and teammates. As stated in section "The organizational environment" for interviewees currently using wearable technology, 48.7% ($n = 40/82$) interviewees agreed that female athletes, lower division institution athletes, and international athletes as well as younger athletes are more apt to comply. Higher device acceptance from women is partly due to the supports used to hold the devices are sports bras. Lower division programs are often grateful for the advantage that they will likely have over conference competition. International athletes tend to be more compliant for several reasons including either no expectations or biases toward the use of technology or an increased understanding of technology depending on the sport they play and their country of origin. For younger athletes, they will often mirror adoption practices of the upperclassmen. If more senior athletes are compliant, younger athletes often will be as well.

Another aspect of hardware compliance is defined by the sport being played and location of the device relative to impact areas. Falling onto a hard-plastic device isn't acceptable, and wearing wrist devices while shooting a basketball, hitting a volleyball, or while holding a racquet have been met with some resistance.

Lessons learned. Creating a sense of normalcy is critical for compliance. In addition, the more the devices are invisible, out of sight, and out of mind, then the higher compliance will become for team culture. Having a management plan for who is maintaining, housing, distributing, and collecting the devices after practice makes for an easier implementation. Frequent and regularly scheduled communications with the manufacturers responsible for the maintenance of the devices and repair is critical for frustration minimization.

Gamification. Gamification—taking typical elements of games and competitions and applying them to other areas of activity—has seen a recent resurgence in the industrial sector as a means to increase employee productivity and output.[24] Technology allows the concept of gamification to be introduced into an athletic training environment. A potential benefit from wearables and other training technologies is how coaches are using the data to challenge and create a competitive environment within the team. For example, an NCAA Division I S&CC for football explained that he uses leader boards in the weight room to display various load and performance metrics. He uses these boards as motivation for competition outside of standard achievements such as starting and playing time.

He has noted increases in performance measurements such as jumping when two or more of the student athletes' baseline their performance on force plates at the same time versus when jump data are collected one athlete at a time. Creating games within games allows athletes to use the data to compete with other teammates (i.e. who is the fastest, quickest, strongest, most hydrated, had the best sleep, had the overall highest load output, etc.) thereby leading to greater amounts of work and higher training intensities. Regardless of technology type, 58.4% (n = 66/113) of all interviewees reported using some form of gamification strategy and, with it, increased levels of engagement in otherwise non-competitive assessments. Using wearables to establish gamification creates greater levels of team member-induced competition thereby allowing S&CCs and ATs to measure athletic performance in real-time outside of game situations.

Lessons learned. As with compliance, motivating athletes can be a challenge. However, using technology to create competition between positional athletes can be very effective to create higher levels of output. In addition, the specificity of gamification training may offer the opportunity to improve positional skills that can transfer into game scenarios.

The analyst or sports scientist

Baselining. One of the uses of technology is to understand the athlete's current health and athletic performance level. Understanding each athlete's current state allows for the development of an individualized training program. In addition, this would help S&CCs and ATs understand the athlete's level of fatigue, potential risk of injury, and current playing readiness state. The idea of developing a "resilient, balanced, and durable athlete" is a key attribute in determining an accurate baseline. With the limited amount of time S&CCs spend with athletes, using technology to create positional and athletic baseline parameters is desired and generally captured prior to the season. Furthermore, ATs would now have a very clear understanding on whether the athlete is "ready to return" from an injury, comparing current numbers to pre-injury baseline numbers.

> [We want to know where] players are at from a mechanical load (run step and yardage based on individual baselines for yardage amounts) and physiological loads (cramping). Coaches use this baseline to sub players in for others who are getting too much volume of work . . . all [of this is] based on individual baseline loads.

Lessons learned. Using technology to know an individual athlete's current performance status, both cognitively and physically, can help S&CCs know how hard to push an athlete to reach new ability levels. Knowing pre- and post-injury baselines would help ATs to determine how effectively the athlete is reacting to rehab treatment allowing for identifications of "return tos" which creates a safe and trusting relationship between the organization and the athlete (see subsection "Return Tos" for more information).

> Baselines are created for players for improved "return to play" after an injury, [we are] not trying to rehab [the injured leg] to the non-injured leg.

Internal loads. Internal loads are the factors and reactions of how the internal body responds to stressors. One of the parameters involved in developing the resilient athlete is to identify their cognitive and physiological capabilities. Currently, assessing heart rate through wearables is one main factor in determining internal load. However, this currently requires an athlete to wear a chest strap or wrist wearable to gather physiological information. Depending on the sport being played, these devices often "get in the way" and are not worn if given the option. In addition to heart rate, identifying rate of perceived exertion (RPE) can help coaches and trainers generate the amount of work the athlete perceives they are doing. Even though RPE isn't captured via a wearable device, this data can be used in conjunction with wearable data to help establish a player-readiness state.

> [For us] physiological load [is] . . . heart rate response for demands of competition . . . level of readiness for next day including a self-evaluation questionnaire . . . yesterday's RPE; you know, how hard you thought the day was . . . [all of these metrics] marr[ied] up [with] what load says versus what the athlete thinks. How you think you feel is more in line with how you may actually perform; [this is] better info than some data from wearables.

Lessons learned. Internal loads can be taken as the physiological and psychological responses to training, practice, and games from functions such as energy systems, hydration, and maximal oxygen uptake, to the likes of rate of perceived exertion and cognitive processing. However, 43.8% of the interviewees with five or more years of experience with wearables (n = 21/48) expressed concern in the separation of internal and external load assessment as each must be carefully weighed. As the human body is an integrated complex system, changes in one system can have diverse effects on other systems.

External loads. External loads are all the various environmental factors impacting the athlete. These include the biomechanical aspects of the sport, impulse forces, training, and kinetics of movement. An NCAA Division I basketball S&CC described external load as:

> Run distance, run distance at high velocity, intensity of run, jumps, cutting ... like to the rim. This is the [external] load [measurements] I need and what I would like [captured] in a wearable.

Other S&CCs described similar data needs for external load measurement:

> [I] really wish that [wearables could tell me] ground reaction forces on the foot and intensity of the moves (runs, jumps, landing and rebounding, etc.).

> We would like a heat map at the bottom of the foot ... toe walkers lead to bad dorsiflexion ... someone sprints on their heels.

> Our [head coach] would like to be able to quantify [load] by gait. Some bad gaits are caused by the shoes being worn. [More] importantly, [we] would like someone to help prove certain shoe styles lead to bad gait [cycles].

As most sports are played on a surface, ground contact is important to understand the external loads on the athlete. The development of the durable athlete is the ability to find gaps between functional assessments and athletic performance. Currently, there is not a consensus on what assessments are most applicable to gauge the volume of external loads an athlete can handle. Technology has promoted a measure of the total work and total distance to be used to assess external loads. However, due to positional demands, the data of total work and distance does not offer a complete picture of the stressors placed on the athlete. Many of the interviewees (53.1%; $n = 60/113$) who support open, outdoor sports such as football, soccer, track and field, etc. have suggested that acceleration intensities are a better indicator for external loads compared to total work and distance.

Lessons learned. External loads are generally considered as the output from the athlete, such as accelerations, decelerations, agility, weight training, athlete-to-athlete contact, ground reaction forces, and many other biomechanical and kinetic factors. However, internal loads can influence the athlete's ability to handle and produce external loads. Depending on the sport team's culture and approach, integration of systems appears to produce better athletic results than isolation of training loads.

Injury mitigation. Initially, the purpose of this investigation was to discover how wearable technology is used to "prevent injuries." However, this concept proved to be unattainable. The human body is far too complex to consistently predict a non-contact injury. Instead, learning to apply a holistic approach to athlete development appears to offer an opportunity to reduce or mitigate (not prevent) injuries. A holistic or integrated approach brings in the multiple stress factors that can positively or negatively affect an athlete. An example of this is the inclusion of lifestyle, mental stress, sleep, and nutrition (fuel), integrated with the internal and external training and conditioning loads, of practice and games placed upon the athlete.

> Hydration, nutrition, and sleep are [the] most critical elements; mobility comes next due to decrease caused by age with professional athletes and limitations not commonly found at the college level since players turn over more frequently on average.

Other noted injury mitigation factors include cognitive and physiological fatigue which are tied to the amount of rest and recovery, shoe and other uniform design, asymmetrical muscular loads, and skeletal alignments.

> Fatigue issues are somewhat invisible, but fatigue may lead to injury.

> Improper technique will lead to injury and slows down return to play. Shoes have a major influence on injuries, originating from the foot and ankle, leading to knee and lower back problems.

> Single leg stability, balance testing, jump testing all provides a movement signature. All athletes do this [at the beginning] when they come into the program. [We] use this to make immediate adjustments for high needs people that are low in either of the load, explode or drive.

> Correcting asymmetries is what I spend most of my day doing typically at the lower body level. I follow the teachings and research of Carmelo Bosco who used jump assessments to understand where the legs were weak and overcompensating versus over trained and at risk.

Shoes and shoe manufacturers were very specifically targeted as primary issue points for athletic injuries. Every university visited had at least one S&CC or AT mention their concerns with the current athletic shoe landscape.

> Improper shoe size and design are major factor in foot and ankle issues due to improper fit and materials restricting mobility.

> Shoes are a huge issue; they are no longer healthy to wear. [We] must place shoe orders now without being able to look at shoes until they get in.

> Clothing corporations seem to care more about marketing a new shoe versus the health and safety of the athlete. Mesh material is not working. But strength and conditioning coaches and trainers are having a difficult time proving to their sponsors that shoes are a problem. Shoes models [and] styles aren't out long enough to collect longer term data to correlate injuries back to shoe type.

These areas have all been reported as identifiers of potential occurrence to an injury. RPE's and simply asking an athlete how they feel have been shown to be an effective mitigator of establishing training and practice intensities.

Lessons learned. Wearable technology data are not a guarantee for the prevention of non-contact injury occurrences. Even though wearables are often presented as injury prevention solutions, the goal for using wearables should be the development of a "resilient athlete;" an athlete who can handle a wide range of stressors. This includes the capability of the athlete to overcome and adapt to the mental and physical stressors involved during games. Based on wearable output, reports, and recommendations from data analysts about how a coach should conduct practice, there is a growing tendency to "pull back" training and practice to lower levels; however, the athlete then must acutely adjust his or her power output for game situations. This has been represented by interviewees as a slippery slope. The current acute to chronic ratio formula is being evaluated and criticized. Current opinions are that the evidence of this ratio isn't as clear as has been reported.

Return Tos. "Return Tos" are identified as return to Sprinting, Agility, Practice, Play, Performance, and Continuing Performing.

> "Return to Play" protocols are different than traditional strength & conditioning protocols.

> [We have a] need for return to play metrics before and after injury... [Physical therapy] settings [are] not always relevant compared to sport activity. [The athlete] could be cleared to play but field performance isn't the same as before... is [the] athlete ready or not?

After an injured athlete has healed, the ATs and S&CCs will generally assess movement patterns based on the "Return To" criteria. This allows for the athlete to regain their athletic ability after the injury without the worry of reinjury during the process. Athletes are generally not allowed to move onto the next "Return To" until they can adequately work at 100% of their current level. However, depending on the athlete's skill level...

> ...not being at 100% doesn't mean the athlete is not game ready.

Comparisons between injured and non-injured limbs have generally been their recorded movement baseline. However, athletes know how to compensate and can often fool the system. Unfortunately, this can lead to re-injury. Certain therapy protocols have been suggested as insufficient when it comes to determine an athlete's sport readiness status due to lack of sport movement intensity comparisons. Thus, knowing the individual's baseline data prior to injury is a critical factor in determining the appropriate athlete's "Return To" status.

Lessons learned. This topic was one of the more complex situations and engaging discussions regarding the athlete. Organizations should have a common goal of establishing a trusting relationship where the athlete's health is the highest priority. This may be at odds at times with the sport coaches who recognize that elite athletes can sometimes play at a quality level without being 100% injury free; instead organizations should establish individualized baselines prior to injury based on the "Return To" levels of athletic recovery. The use of dynamic testing and force plate analysis do offer an improved status assessment over non-dynamic functional testing and often beyond the current capability of available wearable technology.

Quantifying performance. Athletic performance is a combination of sport skill, athleticism, cognitive processing, and other difficult-to-measure factors. The goal for training has been expressed to improve an athlete's ability that can be transferred to the field or court to win games.

> Training should not just focus on the injured segment; ensure that training is improving the entire integrative human machine.

However, there appears to be discrepancies in protocol approaches that often contradict each other.

> FMS [or Functional Movement Screen]...[we] use [it] but no sport specific demands are considered.

> FMS [is] too generic, we use it [but] we need baseline and measurable data.

> FMS does not accurately measure athletic ability.

Establishing a data management protocol to quantify the effectiveness of the training program has been one recommendation and priority even if not automated.

> You are guessing if you are not measuring...

> ...was stated repeatedly in interviews.

Lessons learned. The development of an elite athlete means different things for different positions and sports. Measuring training protocols for performance should not isolate muscle specific movement patterns but encourage the athlete to experience a wide variety of stressors and at different angles. For example, velocity-based training (VBT) versus basic muscular strength training, depending on the demands and needs of the position, the use of technology may help to determine which protocol is most effective.

> Explosive jumping power, lateral movement, "game of quickness," how quickly you can get off the ground just as important as [jump] height.

> Touching the ground extremely briefly and still getting back up to maximum height; change of direction drills are great predictors [and] major indicator of athletic success and performance.

> Functional tests must be "performance based" [for] the athlete's sport.

Conclusion

Based on all unstructured interviews, the categorical findings discussed in this review highlight the current status and opinions of wearables and sports technology. This conclusion section summarizes the perspective of the research team on the landscape of technology and data as well as a few guidelines for their application in sports.

First, understanding how the organization views athlete data should be discussed and prioritized. If the sports coach is not on board and the team culture is that of an autocratic organization, building a true sport science program may be difficult. Next, all the parties involved in making athlete performance, prehab, and rehab decisions need to be identified and routinely engaged especially in technology purchasing decisions. These individuals must collectively discuss individual and team health as well as performance status. One interviewee emphasized that "ego's need to be left outside the room" during these critical discussions. Next, if the organization wants to build out a sports science department, there must be a plan that includes all the participants involved in the data collection, management, and decision-making process. This includes any data analysts, sports scientists, S&CCs, ATs, nutritionists, and sports coaches. Organize (a) what data are important and to whom, (b) performance, health, or rehab data, (c) how the data will be collected, (d) the type of equipment the data will be collected on, and (e) how the data will be shared, stored, and managed. Most importantly, all stakeholders in this process need to know why data are being collected, and what data are currently available versus data that is still needed. Additionally, S&CCs and ATs should work openly and directly with technology vendors and consider academic departments as a resource. If vendors are not willing to stand by their product at all hours of the day and support issues, then they may not be worth the cost or frustration.

Finally—but still evolving—develop a budget or plan on how to secure funding for purchasing and maintaining equipment and software. Be aware of storage space, sharing of technology between teams and athletes to improve return on investment, and recognize initially that no technology is perfect; none of it works all the time.

Limitations

This study presented several limitations due to the nature of the variance in the unstructured interview methods. The challenging reality is that the S&CC and AT community at elite levels of competition are very time restricted, very protective of their sensitive environment that revolves around athlete health information, and they are very limited to whom they are willing to disclose their opinions. These concerns had to be accommodated as the researchers believed that compiling these opinions was a more valuable contribution than ensuring every interview was conducted in the same way and thereby limiting the number of participants. This compromise in data collection comes at a cost, however, as minimal quantitative results can be shown. Also, there were limitations given the region in which all interviews occurred. Only S&CCs, ATs, and similar personnel were interviewed from organizations and institutions within the USA. European, and Australian regions are well known for their advancement in athletic technology and data usage. Future studies should include representation from these advanced sports regions as well.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the National Science Foundation (NSF) under Grant 1844451.

ORCID iD

Reuben Burch https://orcid.org/0000-0003-2944-1945

References

1. Hynes G, O'Grady M and O'Hare G. Towards accessible technologies for coaching. *Int J Sports Sci Coach* 2013; 8: 105–114.
2. Luczak T, Saucier D, Burch VR, et al. Closing the wearable gap: mobile systems for kinematic signal monitoring of the foot and ankle. *Electronics* 2018; 7: 117.
3. Creasey S. Wearable technology will up the game for sports data analytics. *Computer Weekly*, www.computerweekly.com/feature/Wearable-technology-will-up-the-game-for-sports-data-analytics (2014, accessed 27 October 2016).
4. McMahan D. Wearable devices give athletes a personal performance boost. iQ.intel.com., https://iq.intel.com/wearable-devices-give-athletes-a-personal-performance-boost/ (2015, accessed 27 October 2016).
5. Steinbach P. Tracking technology revolutionizes athlete training. AthleticBusiness.com., www.athleticbusiness.com/equipment/tracking-technology-revolutionizes-athlete-training.html (2013, accessed 27 Oct 2016).
6. Mayhew S. Professional sports teams and athletes driving wearable technology. BiometricUpdate.com., www.biometricupdate.com/201410/professional-sports-teams-and-athletes-driving-wearable-technology (2014, accessed 27 October 2016).
7. Sheldon R. Trend alert: wearable devices are about to take off. TechTarget.com., http://searchmobilecomputing.techtarget.com/feature/Trend-alert-Wearable-devices-are-about-to-take-off (2013, accessed 27 October 2016).
8. Lamkin P. Wearable tech market to be worth $34 billion By 2020. Forbes.com., www.forbes.com/sites/paullamkin/2016/02/17/wearable-tech-market-to-be-worth-34-billion-by-2020/%7B#%7D6afc17033fe3 (2016, accessed 27 October 2016).
9. Newswire PR. The wearable technology ecosystem: 2016 – 2030 – opportunities, challenges, strategies, industry verticals and forecasts, www.prnewswire.com/news-releases/the-wearable-technology-ecosystem-2016–2030–opportunities-challenges-strategies-industry-verticals-and-forecasts-300309592.html (2016, accessed 3 November 2016).
10. Ohio University. How wearable tech is transforming a coach's decision-making. Ohio.edu., http://onlinemasters.ohio.edu/how-wearable-tech-is-transforming-a-coachs-decision-making/ (2016, accessed 4 November 2016).
11. ABI-Research. Wearable sports and fitness devices will hit 90 million shipments in 2017. *ABI Research*, www.abiresearch.com/press/wearable-sports-and-fitness-devices-will-hit-90-mi/ (2012, cited 1 Feb 2018).
12. Tiwari R. Smart sports and fitness wearables market to hit $14.9 billion by 2021. *PR Newswire*, www.prnewswire.com/news-releases/smart-sports-and-fitness-wearables-market-to-hit-149-billion-by-2021-528461241.html (2015, accessed 1 Feb 2018).
13. Hanuska A, Chandramohan B, Bellamy L, et al. Smart clothing market analysis. *Technical Report*. 2016.
14. Valovich McLeod TC, Decoster LC, Loud KJ, et al. National Athletic Trainers' Association position statement: prevention of pediatric overuse injuries. *J Athl Train* 2011; 46: 206–220.
15. Brice SM, Hurley M and Phillips EJ. Use of inertial measurement units for measuring torso and pelvis orientation, and shoulder–pelvis separation angle in the discus throw. *Int J Sport Sci Coach* 2018; 13: 985–992.
16. Griffin JA, McLellan CP, Presland J, et al. Quantifying the movement patterns of international women's rugby sevens preparation training camp sessions. *Int J Sport Sci Coach* 2017; 12: 677–684.
17. Tee JC, Lambert MI and Coopoo Y. GPS comparison of training activities and game demands of professional rugby union. *Int J Sport Sci Coach* 2016; 11: 200–211.
18. Burch VRF. Technology arms race: a story about wearables, athletics, and trust. *Nexus: A Magazine*, NSPARC at Mississippi State University, May 2019, pp.2–7.
19. Martin D, Swanton A, Bradley J, et al. The use, integration and perceived value of performance analysis to professional and amateur Irish coaches. *Int J Sport Sci Coach* 2018; 13: 520–532.
20. National Science Foundation. *NSF I-Corps* [Internet]. https://www.nsf.gov/news/special_reports/i-corps/
21. Donohoo J. Learning how to learn: Cornell notes as an example. *J Adolesc Adult Lit* 2010; 54: 224–227.
22. Teddlie C and Tashakkori A. *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences*. Thousand Oaks, CA: Sage, 2009.
23. Shipherd AM, Wakefield JC, Stokowski S, et al. The influence of coach turnover on student-athletes' affective states and team dynamics: an exploratory study in collegiate sports. *Int J Sport Sci Coach* 2019; 14: 97–106.
24. Hitch J. Gaming the factory: can data make manufacturing fun again? *Ind Week* 2018; 267: 17–21.