BRIEF REVIEW

Use of Integrated Technology in Team Sports: A Review of Opportunities, Challenges, and Future Directions for Athletes

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Abstract

Dellaserra, CL, Gao, Y, and Ransdell, L. Use of integrated technology in team sports: A review of opportunities, challenges, and future directions for athletes. *J Strength Cond Res* 28(2): 556–573, 2014—Integrated technology (IT), which includes accelerometers, global positioning systems (GPSs), and heart rate monitors, has been used frequently in public health. More recently, IT data have been used in sports settings to assess training and performance demands. However, the impact of IT in sports settings is yet to be evaluated, particularly in field-based team sports. This narrative-qualitative review provides an overview of the emerging impact of IT in sports settings. Twenty electronic databases (e.g., Medline, SPORTdiscus, and ScienceDirect), print publications (e.g., Signal Processing Magazine and Catapult Innovations news releases), and internet resources were searched using different combinations of keywords as follows: *accelerometers*, *heart rate monitors*, *GPS*, *sport training*, *and field-based sports* for relevant articles published from 1990 to the present. A total of 114 publications were identified, and 39 that examined a field-based team sport using a form of IT were analyzed. The articles chosen for analysis examined a field-based team sport using a form of IT. The uses of IT can be divided into 4 categories: (a) quantifying movement patterns ($n = 22$), (b) assessing the differences between demands of training and competition ($n = 12$), (c) measuring physiological and metabolic responses ($n = 16$), and (d) determining a valid definition for velocity and a sprint effort ($n = 8$). Most studies used elite adult male athletes as participants and analyzed the sports of Australian Rules football, field hockey, cricket, and soccer, with sample sizes between 5 and 20 participants. The limitations of IT in a sports setting include scalability issues, cost, and the inability to receive signals within indoor environments. Integrated technology can contribute to significant improvements in the preparation, training, and recovery aspects of field-based team sports. Future research should focus on using IT with female athlete populations and developing resources to use IT indoors to further enhance individual and team performances.

Key Words accelerometers, GPS, training, field-based sports

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Introduction

During the past decade, time-motion analysis systems, such as video recording, hand notation, and computer digitizing, have been used to objectively assess human locomotion for determining physiological measures. Also, these systems have been used to improve sport performance. Unfortunately, many logistical issues exist including questionable validity, a labor-extensive nature for collecting such data (e.g., up to 8 hours produces digitized data that often compare poorly with those of other methods), and a requirement of manual hand-notation techniques (11,24,31,56,71). Another concern is the failure of these systems to provide real-time information in the context of human locomotion (35,76). For example, athlete position, movement displacement, velocity, and acceleration of their movements, which are considered vital quantitative information for athletes and teams, are often not examined (30).

One solution may reside in the use of global positioning systems (GPSs) and accelerometer technology, 2 instruments often used in the sport and physical activity realm. The development of GPS in 1990 has enabled the collection of real-time data on human locomotion to examine sport performance in a more convenient, efficient, and precise manner. Global positioning system studies have evolved from assessing steady-state movements for examining energy expenditure to assessing human locomotion within the context of sports (50). Currently, 2 types of GPS networks exist, differential and nondifferential. Differential GPS was primarily used in earlier studies to obtain speed, position, and distance measurements of orienteering athletes (47,48). Nondifferential GPS units have several advantages over differential

GPS, which include a decreased cost, lighter and smaller design, and a simplified data analysis procedure (79). However, nondifferential GPSs have provided inconclusive results on speed and displacement measures, and further research is needed to validate the use of nondifferential GPSs in biomechanical and sports studies (1).

GPS units are often combined with accelerometers to determine the objective recordings of physical activities conducted during different times of the day (28,64,72,81). Accelerometers or devices that measure the physical activity in 3 planes have previously been used to examine physical activity levels as they correspond to public health (17,41,59). Accelerometers use "cut points" to classify individuals from "low activity" to "high activity" levels, and they evaluate daily activities of living from data recordings of linear movement on several axes (83). The most common types of accelerometers are peizoresistive, piezoelectric, and differential capacitive. Differential capacitive accelerometers are used most widely in sports and physical activity settings because of their ability to classify posture and movement, estimate energy expenditure, and analyze gait and balance control (83). The ActiGraph series (e.g., GITM. GT3X and ActivPAL) accelerometers seem to be used very often in sports and physical activities studies to measure activity and step counts, energy expenditure, and gait analysis. The validity and the reliability of these accelerometers have been previously established through studies demonstrating significantly higher correlations between ActiGraph monitors and study replication compared with StepWatch, AMP 331, activPAL, and other commonly used accelerometers (21,53).

The combination of GPS, accelerometer, and heart rate technology, which is called "integrated technology (IT)" in this study, allows for a greater understanding of the energy cost and specificity of movement patterns in controlled situations. Integrated technology was first developed in 2003 with the SPI-10, and recent models include the MinimaxX OptimEye, SPI-Pro, and SPI Elite (3,15,37,45). The MinimaxX series, the most commonly used IT models in training and research, have examined numerous sports, including Australian Rules football, soccer, cricket, field hockey, and team sport simulations (7,13,42,66,70). To date, the MinimaxX series has been used in 14 studies that examine field-based team sports and >190 professional sport teams and organization training sessions (3,14,15). The OptimEye, the most commonly used model in research, monitors >20 measurements during match play, training, and injury prevention, including impact load, directional movement, and activity identification with its integration of accelerometry and gyroscopes (15). Moreover, MinimaxX technology has a reliability variation lower than the 5% acceptable level across multiple sports, which is significantly lower compared with that of other models, such as SPI-10 and SPI-Pro (7,42,66,69). Most studies using IT have targeted physical activity among the general population (e.g., adults, children, and senior citizens) (13,17,21,28,32,41). However, during the last 5 years, research has expanded to include amateur and elite athletic populations.

The recent use of IT in sport settings presents the capability to overcome limitations of time-motion analysis systems (3). These sport-specific units can measure various locomotor categories (e.g., sprinting and jogging) distance traveled, and length and distance of sprints performed by athletes in specific sports (30). The use of IT has been examined in team-based field sports, including soccer (67), field hockey (52), Australian Rules football (82), rugby (38), and cricket (65). Although this method of study is still emerging, the use of IT in team sports settings has been deemed reliable and valid, and it requires minimal human involvement during data collection because of its noninvasive nature, and leads to rapid data collection and analysis compared with that in video-based analysis (43,80).

According to Aughey (3), validation of IT for team sport applications did not occur until 2009–2010, meaning this analysis strategy requires further research and examination to address some of the aforementioned issues and limitations. Research using IT in team sports settings has only been conducted in outdoor settings because GPS units are unable to track movement patterns indoors (3). Because of this issue, the use of IT has been presently limited to field-based team sports (5,13,27). Therefore, until advancements in research enable GPS to be used indoors, field-based team sports will be the primary participant demographic, as IT productivity and accuracy are cited as the highest when examining this demographic (3). Previous studies have applied IT to determine the speed, position, and distance of athletes during match play (48,74); more recent studies have used IT to interpret physiological data, such as heart rates and magnitude and frequency of contact (34,52). Current research uses match play analysis, where IT assesses players on an individual basis through player movement, fatigue measurements, postgame analysis, and performance comparisons (2,5,23,51).

Recent studies using IT for match play analysis include a study by Dwyer and Gabbett (30), which examined the sprint patterns in male and female soccer and field hockey players and Australian Rules football players. They found that athletes playing Australian Rules football spent a greater amount of time running and sprinting compared with that in the other field sports. Additionally, researchers reported that velocity ranges tended to be larger between men's and women's sports, as opposed to comparisons between numerous field sport teams. Finally, the most interesting conclusion was that sprinting within these field sports consisted of short accelerations of 1- to 2-second duration covering distances between 1.8 and 3.2 m. Such results are important because they provide specific insights into the distances covered in low- and high-intensity activities, sprinting velocities achieved during training and competition, and differences between sports and respective playing positions or levels of competition. These findings have implications for physical and tactical

Table 1. Study characteristics and overview.*

Author† (year)	Purpose	Sample size	Gender	Sport/activity	IT used
Spencer et al. (2004)	Analyze movement patterns and RSA during field hockey matches	14	Male	Field hockey	Labview 4.0 software
Spencer et al. (2005)	Analyze movement patterns and RSA over several matches	14	Male	Field hockey	Labview 4.0 software
Burgess et al. (2006)	Profile movement demands, speed, and sprint categories in soccer	45	Male	Soccer	Trak performance software
Hartwig et al. (2006)	Compare rugby training and game demands	34	Male	Rugby	Trak performance software
Impellizeri et al. (2006)	Compare general vs. specific soccer interval training on fitness and performance	29	Male	Soccer	Video editing software (not specified)
Di Salvo et al. (2007)	Determine soccer movement patterns and velocity patterns	300	Male	Soccer	Amisco pro software
Pino et al. (2007)	Analyze soccer match and position demands	6	Male	Soccer	FRWD f500 GPS
Gabbett et al. (2008)	Compare training and competition movement patterns and RSA	13	Female	Soccer	Integrated software (not specified)
MacLeod et al. (2008)	Assess player movement demands in field hockey	9	Male and female	Field hockey	SPI Elite
Castagna et al. (2009)	Examine effects of endurance training on soccer performance	21	Male	Soccer	SPI Elite
Cunniffe et al. (2009)	Evaluate physiological demands of elite rugby	2	Male	Rugby	SPI Elite
Duffield et al. (2009)	Examine core temperature and performance during sprinting	10	Male	Australian rules football	SPI Elite, SPI-10
Petersen et al. (2009)	Determine validity and reliability of cricket movement IT measures	1	Male	Cricket	SPI-10
Aughey (2010)	Examine soccer player work rate	18	Male	Soccer	MinimaxX
Aughey et al. (2010)	Determine validity of real-time vs. postgame IT data	12	Male	Australian rules football	MinimaxX
Barbero-Alverez et al. (2010)	Determine validity and reliability of IT speed and sprinting measures	35	Male and Female	Soccer, physical education	SPI Elite
Coutts et al. (2010)	Assess validity and reliability of quantifying high-intensity, intermittent exercise with IT units	2	Male	Moderately trained	SPI Elite, SPI-10, WiSPI
Coutts et al. (2010)	Examine influence of match demands and increased physical activity on performance	16	Male	Australian rules football	SPI-10
Duffield et al. (2010)	Compare IT and VICON accuracy and reliability	1	Male	Moderately trained	MinimaxX
Gabbett (2010)	Analyze elite field hockey training and competition	14	Female	Field hockey	MinimaxX
Gabbett et al. (2010)	Determine collision impact and injury during rugby training	30	Male	Rugby	MinimaxX
Gray et al. (2010)	Examine validity and reliability of IT distance measures in field-based sports	1	Male	Linear and nonlinear movements	WiSPI
Jennings et al. (2010)	Use IT to measure distance during team sport movements	20	Male	Australian rules football	MinimaxX

McLellan et al. (2010)	Determine movement patterns and pre, during, and post creatine kinase levels	17	Male	Rugby	SPI-Pro
Minett et al. (2010)	Examine effects of supplementation on rugby match performance and recovery	12	Male	Rugby	SPI Elite, SPI-10
Montgomery et al. (2010)	Characterize physical and physiological responses during basketball training and games	11	Male	Basketball	MinimaxX
Osgnach et al. (2010)	Analyze energy cost and metabolic power during soccer matches	399	Male	Soccer	SICS software
Petersen et al. (2010)	Quantify and compare movement patterns of cricket games	42	Male	Cricket	MinimaxX
Portas et al. (2010)	Examine validity and reliability of IT linear, multidirectional, and soccer movements measures	1	Male	Soccer, team sport movements	MinimaxX
Wisbey et al. (2010)	Quantify AFL season game movement demands	179	Male	Australian rules football	SPI Elite, SPI-10
Aughey (2011b)	Compare running demands of regular and final AFL matches	8	Male	Australian rules football	MinimaxX
Dogramaci et al. (2011)	Assess validity and reliability of IT measures of player movement patterns	10	Male	Team sport movements	SPI Elite
Hartwig et al. (2011)	Compare match and practice demands of youth rugby players	118	Male	Rugby	SPI-10
Macutkiewicz et al. (2011)	Evaluate activity profiles of field hockey players during matches	25	Female	Field hockey	SPI Elite
Mooney et al. (2011)	Determine relationship between physical capacity and match performance	9	Male	Australian rules football	MinimaxX
Dwyer et al. (2012)	Propose velocity ranges and sprinting definition	25	Male and female	Soccer, field hockey, Australian rules football	MinimaxX, SPI Elite
Gabbett et al. (2012)	Determine rugby training and competition physical demands	30	Male	Rugby	MinimaxX
Johnston et al. (2012)	Examine validity and reliability of IT team movement demands measures	14	Male	Team sport movements	MinimaxX

*AFL = Australian Football League; RSA = repeated sprint ability; IT = integrated technology.
†Authors listed in the table are the primary authors of each respective study.

TABLE 2. Brief results and analysis of studies.*

Author† (year)	Category	Variables measured	Validity evidence studied/cited	Reliability evidence studied/cited	Limitations	Future directions‡
Spencer et al. (2004)	Quantifying movement demands	• Distance • Time • Speed	n/a	n/a	• Repeated-sprint activities errors indicate that IT need further development to assess sprinting <21 s	• Account for the bias and errors work toward creating a universal sprinting definition
Spencer et al. (2005)	Quantifying movement demands, velocity, and sprinting definition	• Time • Speed • Other frequency	n/a	n/a	• IT unit error significantly increased when assessing repeated-sprint bouts	• Use IT to determine how sprinting activity is affected in the long term in elite field hockey competition
Burgess et al. (2006)	Quantifying movement demands, velocity, and sprinting definition	• Distance • Speed	n/a	n/a	• Bias of 1 game per player may have affected the results • Trak Performance validity and reliability not stated	• Account for the bias and errors and interpret them to decrease IT unit subjectivity
Hartwig et al. (2006)	Quantifying movement demands	• Distance • Speed • Other-intensity	n/a	n/a	• A more homogeneous sample is needed for validity • Frequency of soccer-specific movements unknown	• Explore training efficiency and specificity of training outcomes and performance goals
Impellizeri et al. (2006)	Training vs. match play requirements, metabolic & physiological demands, velocity and sprint effort definition	• Distance • Speed • Other-intensity	1.0–5.0% CI (cited)	1.0–4.3% TE	• Results based on theoretical numbers from software	• Incorporate wearable IT units to further validate these results
Di Salvo et al. (2007)	Quantifying movement demands, velocity, and sprint effort definition	• Distance • Speed	n/a	n/a	• Validity and reliability of software programs not stated	• Determine how position and work rate can effect developing individualized training programs
Pino et al. (2007)	Quantifying movement demands	• Distance • Speed • Other-intensity	n/a	n/a	• Small sample size may not be generalizable • Validity and reliability of IT not stated	• Aim to assess more subjects to further validate the results, particularly velocity recordings

Gabbett et al. (2008)	Training vs. match play requirements, velocity, and sprint effort definition	• Distance • Time • Speed	≥0.76 R	0.6–4.6% TE	• Small sample size may not be generalizable • Validity and reliability of IT not stated	• Use more advanced IT to validate measures and results
MacLeod et al. (2008)	Quantifying movement demands	• Distance • Speed	0.99 R	0.8–1.9% TE	• IT is less reliable when measuring frequent changes in movement patterns	• Increase the sample size to determine the validity and reliability of results
Castagna et al. (2009)	Training vs. match play requirements	• Distance • Speed • Other-intensity	n/a	n/a	• Validity and reliability of integrated software not stated	• Examine the relationship between fitness testing and match play performance
Cunniffe et al. (2009)	Quantifying movement demands, metabolic and physiological demands	• Distance • Speed • Other-intensity, impact load	0.8–1.2% CI (cited)	1.0–4.8% TE (cited)	• Small sample size may not be generalizable • Descriptive nature of statistical analysis only	• Use IT to determine position-specific training programs with appropriate exercise load
Duffield et al. (2009)	Metabolic and physiological demands	• Distance • Speed • Other-temperature	0.99 R (cited)	5.5% TE (cited)	• Results may be because of changes in the game environment and player interchanges instead of IT recordings	• Examine pacing strategies to help determine player internal heat load
Petersen et al. (2009)	Quantifying movement demands	• Distance • Other-locomotion patterns	0.4–3.8% CI	0.3–2.9% CI	• Sample size significantly reduces the validity and reliability • High variability of *SEE* on sprinting measures	• Use an increased sample size and more advanced IT to validate results
Aughey (2010)	Metabolic and physiological demands	• Distance • Speed	−0.40 to −0.53 R (cited)	1.7–61% CI (cited)	• Validity and reliability of IT units not stated • IT measures of acceleration less valid and reliable	• Use IT to aid in developing rotational strategies and recovery plans
Aughey et al. (2010)	Training vs. match play requirements	• Distance • Speed	6.4–19.6% CV	5.0% TE (cited)	• Real-time data errors makes IT questionable to use for making decisions on player performance	• Determine an upper velocity limit for athletes with IT
Barbero-Alverez et al. (2010)	Velocity and sprint effort definition	• Speed • Other-intensity	0.87–0.94 R	1.7–36.2% CV	• IT may not be a reliable measure of repeated-sprinting performance.	• Further assess the relationship between fitness testing and match performance

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Buchheit et al. (2010)	Training vs. match play requirements, metabolic and physiological demands	• Distance • Speed	0.97 R (cited)	1.7–5.0% CV (cited)	• Population of youth players not generalizable to majority of field-based team sport population	• Examine the IT ability to assess repeated-sprinting performance
Coutts et al. (2010)	Quantifying movement demands	• Distance • Speed	4.6–32.4% CI	−4.1 to 5.2% CV	• IT may not be reliable for measuring high-intensity activities • Sample size not generalizable	• Determine the IT ability to examine peak speaks during high-intensity, intermittent exercise
Coutts et al. (2010)	Metabolic and physiological demands	• Distance • Speed	−0.40 to (−0.53) R	<5.0 CV	• Technical skill efficiency and the tactical approach of players could not be controlled	• Examine the relationship between position, skill proficiency, physical activity, and team success
Duffield et al. (2010)	Quantifying movement demands	• Distance • Speed	0.10–0.70 R	4–25% CV	• Results not be generalizable for field-based team sport population • IT failed to capture all velocity and frequent changes data	• Use the player load equation to increase the accuracy of IT distance and speed measurements
Gabbett (2010)	Training vs. match play requirements, metabolic and physiological demands	• Distance • Time • Speed	≥0.76 R (cited)	0.6–4.6% TE (cited)	• Validity and reliability of IT units not stated	• Assess how modifications in training group size and drills may simulate the demands of competition better
Gabbett et al. (2010)	Metabolic and physiological demands	• Distance • Speed • Other-physical collisions	9.0–32.4% CI (cited)	3.6–77.2% CV (cited)	• IT units areunable to differentiate between collisions that occur in attack and defense	• Validate IT under a wide range of collision events (e.g., hit-ups, support runs, tackles effected)
Gray et al. (2010)	Quantifying movement demands	• Distance • Speed	0.8–2.8% Bias	2.6–2.8% CV	• Sample size not generalizable • IT distance measures variable as movement intensity increases	• Research how to overcome IT limitations in measuring nonlinear, intense movements
Jennings et al. (2010)	Quantifying movement demands	• Distance • Speed	9.0–32.4% CI	3.6–77.2% CV	• Level of IT between-unit variation was inconsistent at higher velocities (striding, sprinting)	• Have participants wear the same IT unit to prevent between-unit variation
McLellan et al. (2010)	Quantifying movement demands, metabolic and physiological demands	• Distance • Speed • Other-biochemical	0.4–3.8% CI (cited)	0.3–2.9% CI (cited)	• Validity and reliability of data questionable as only 1 match was assessed	• Further examine the relationship between movement patterns endocrine responses

Minett et al. (2010)	Metabolic and physiological demands	• Distance • Speed • Other-biochemical, recovery	−0.40 to −0.53 R (cited)	<5.0% TE (cited)	• Nature of rugby play and uncontrollable game conditions may have created a masking effect	• Assess intensity levels and work load information necessary on supplementation value in other sports
Montgomery et al. (2010)	Training vs. match play requirements, metabolic and physiological demands	• Other-physical demand, intensity	0.60 R (cited)	0.54–0.81% CV	• Validity and reliability of IT units not stated • GPS component of IT cannot be used indoors	• Research how to develop IT usable within-indoor settings to expand the current research
Osgnach et al. (2010)	Metabolic and physiological demands	• Distance • Speed • Other-power	1.9–2.9% CI (cited)	8.9% CV (cited)	• Software cannot provide same data as comprehensive and wearable IT units	• Examine the relationship between high intensity and actual metabolic power with speed
Petersen et al. (2010)	Quantifying movement demands, training vs. match play requirements	• Distance • Speed • Other-intensity	0.4–3.8% *SEE*	0.3–2.9% CV	• IT measures of a number of sprints, mean and total sprint distance highly variable	• Study all formats and positions of cricket to increase the validity of results and reassess sprinting
Portas et al. (2010)	Quantifying movement demands	• Distance • Speed	1.30–6.88% *SEE*	2.03–7.71% TE	• Using 1 subject limits the generalizability of the results • 1-Hz devices are less effective for examining multidirectional movements	• Examine complex course movement patterns with greater hertz IT units to validate conclusions
Wisbey et al. (2010)	Quantifying movement demands, training vs. match play requirements	• Distance • Time • Speed	0.99 R (cited)	0.8–1.9% TE (cited)	• Validity and reliability of IT units not stated • Using 2 different IT units may have affected the results	• Use IT to determine the relationship between movement patterns and key game performance indicators
Aughey (2011b)	Quantifying movement demands, metabolic and physiological demands	• Distance • Speed • Other-intensity	5–10% Bias	11–16% CV	• IT units less reliable when measuring velocities from 3–5 $m \cdot s^{-1}$ • Validity and reliability of IT units not stated	• Use IT to help formulate conditioning plans to prepare athletes for long competitive seasons
Dogramaci et al. (2011)	Quantifying movement demands, velocity and sprint effort definition	• Distance • Speed	2.2–7.8% TE	2.7%–11.1% TE	• IT validity significantly decreased when measuring short-interval distances	• Research methodology to help decrease IT error during short-interval activities

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Hartwig et al. (2011)	Training vs. match play requirements, metabolic and physiological demands	• Distance • Time • Speed	0.99 R (cited)	5.5% TE (cited)	• Using different time-motion devices can increase error • IT units were not used during match play because of rules	• Observe velocity ranges during match play and based upon position for additional sports
Macutkiewicz et al. (2011)	Quantifying movement demands	• Distance • Speed • Other-intensity	0.99 R (cited)	0.8–1.9% TE (cited)	• Validity and reliability of IT units not stated • Field hockey substitution rules may have affected results	• Continue to assess physiological profiles of female athletes, because research is limited
Mooney et al. (2011)	Training vs. match play requirements, metabolic & physiological demands	• Distance • Speed • Other-performance	−6.2 to 4.6% Bias (cited)	3.6–11.9% CV (cited)	• IT unit validity and reliability not stated • Small sample size is not generalizable	• Assess the relationship between recovery tests and match performance
Dwyer et al. (2012)	Velocity and sprint effort definition	• Distance • Time • Speed	0.99 R (cited)	1.08% TE (cited)	• Choice of 5% as the acceleration threshold was arbitrarily chosen by the researchers	• Include high-intensity, short-duration sprint efforts to aid in training athletes' acceleration
Gabbett et al. (2012)	Training vs. match play requirements, metabolic and physiological demands	• Distance • Time • Speed • Other-collisions	9.0–32.4% CI (cited)	3.6–77.2% CV (cited)	• Results from 1 team difficult to generalize to professional rugby	• Investigate if modifications are needed to prepare rugby players for competition
Johnston et al. (2012)	Quantifying movement demands	• Distance • Time • Speed • Other-player load	5–10% TE	5–10% TE	• IT is significantly less reliable when measuring velocities>20 km^{-1}	• Increase the duration of the task when examining higher velocity ranges

*CI = confidence interval; CV = coefficient of variation.
†Authors listed in the table are the primary authors of each respective study.
‡Future directions are suggestions proposed by studies included in the data analysis, not the opinions of the authors of the article.

training of field sports, and they provide future recommendations for strength and conditioning coaches to meet the specific demands of their respective sport and player position.

With the recent emergence of IT, the impact of IT in sport settings is yet to be evaluated, particularly in field-based team sports. Investigating this impact can lead to significant insights into using IT within the field, and potentially describe how IT can be used in the future. To fully understand the impact IT has made on the sporting realm, a systematic review of current application trends of IT within field-based team sport settings will examine the impact of IT on the field. Evaluating the limitations of using IT will determine future research directions regarding IT applications and where the field may be headed in the upcoming years.

Methods

Data Sources

Electronic databases were searched from 1990 to present, for published articles that used IT in a field-based team sport setting, starting from the development of GPS. The following databases were searched: Medline, SPORTdiscus, ScienceDirect, Ovid, Elsevier B.V., ArticleFirst, Academic Search Complete, and ProQuest. Print publications (e.g., Signal Processing Magazine and Catapult Innovations news releases). Internet resources were also searched for publications. Key words included accelerometers, GPS, heart rate monitors, sport training, and field-based based sports. Also, bibliographies of identified articles were searched for relevant studies.

Criteria

Research articles considered for inclusion were published in English in peer-reviewed journals and quantified specific uses of IT with respect to the population being studied. Each publication selected for analysis examined a field-based team sport using a form of IT. Articles were excluded from analysis because of (a) non–sport-related population samples, (b) duplication of data, (c) quantitative data not collected, and (d) dependent variables that were not collected using IT. A total of 114 publications were identified, and 39 were used for analysis. The articles chosen for analysis examined a field-based team sport using a form of IT.

Data Extraction

Studies that met the inclusion criteria were categorized based on the following: (a) subjects and purpose of study, (b) category of IT, (c) variables measured, (d) methodology, and (e) results. Specifically, articles that determined the basic patterns of movement to improve athlete conditioning and performances, deal with rule changes, and increase task efficiency were categorized together. Articles that compared physical and movement patterns during training and compared those with patterns exhibited during match play demands were categorized together. Articles that determined how physiological and metabolic demands of athletes affected performance outcomes were categorized together. Articles that defined and examined velocity and sprinting efforts enhanced were categorized together. Articles that met >1 of the above descriptions were placed in all applicable categories.

Results/Discussion

Twenty-three of 39 studies used professional-level male athlete participants in field-based outdoor sports, such as Australian Rules Football, field hockey, cricket, soccer, rugby, and orienteering. Sample sizes were between 1 and 300 participants based on the nature of the study (individual vs. team, year-round, or weekly data extraction), with an average of 5–20 participants per study. The average age of the participants was 24.3 ± 4 years. The most commonly used models of IT for data analysis included the MinimaxX OptimEye, SPI Elite, and SPI-10. Table 1 presents an overview and characteristics of studies reviewed for this article and is classified by the category and year of publication. Each study is listed with the first author's name, purpose of study, sample size, gender, sport activity examined, and IT device used.

Table 2 provides brief results and analysis of each study and is classified by the first author's name, category of IT examined, variables measured, validity and reliability evidence studied or cited, limitations, and future directions. Analysis of the literature revealed that the uses of IT were categorized into 4 main areas: (a) quantifying movement demands ($n = 22$), (b) assessing differences between demands of training and competition ($n = 12$), (c) measuring physiological and metabolic responses ($n = 16$), and (d) determining a valid definition for velocity and sprint efforts ($n = 8$).

Category 1: Quantifying Movement Demands

Studies within this category ($n = 22$) determined the basic patterns of movement to improve athlete conditioning and performances, examined error levels when using IT in different activity scenarios, and determined the validity and the reliability of using IT. Several studies ($n = 13$) used IT to examine the movement of players during competition, because coaches and sport physiologists often seek information about the basic patterns of movement to use tactical strategies or to improve fitness and conditioning during practice. For example, Wisbey et al. (82) reported that Australian Football League (AFL) athletes covered 3.4% more distance, and demonstrated a 23% increase in running and a 14% increase in intensity levels during a 5-year period. Aughey (4) compared regular season and finals matches of the AFL and noted an 11% increase in the total distance, a 9% increase in high-intensity running, and a 97% increase in the number of maximal accelerations during final matches. Such detailed results on the movement patterns of AFL athletes provide coaches with additional information about how to properly design conditioning, preparation, and recovery programs.

A common finding across the studies in this category ($n = 15$) was that IT errors resulted from increased velocity ($n = 7$), repetitive motion (e.g., sprinting, shuffling, and jogging) particularly within confined spaces ($n = 4$), short-interval exercise ($n = 5$), and high-intensity activities ($n = 6$). In AFL and cricket studies, the standard error of estimate (*SEE*) was between 10 and 40%, indicating that IT units require further validation when measuring sprints and change of direction activities, especially because results tend to be highly variable (4,66). This notion of the difficulty in measuring faster speeds with accuracy is evident when examining tennis movement patterns in confined spaces, where IT underestimated the peak and mean speed by 10–30% (27). Jennings et al. (42) reported a similar conclusion when assessing Australian Rules football player strides and movement patterns. The greatest percentage of difference was between IT monitoring during short-interval activities and changes in direction. These results suggest that the devices may fail to capture all relevant data during movements performed at high velocities and with frequent changes in the direction.

Johnston et al. (43) examined movement demands of team sport simulation circuits and cited the need to exercise caution when using IT to observe high-speed velocities, because IT error level increased as the velocity of exercise increased. In fact, the IT was found to be significantly unreliable at velocities $>20\ \text{km}\cdot\text{h}^{-1}$, indicating that there may be a velocity threshold where the IT is less accurate for measuring the speed. However, when the duration of a task increased, the IT error decreased. Many studies in this category have indicated significant decreases in standard error with the increased duration of measurements, which held true for all current models of IT (18,27,51,68). When the velocity of a moving object is decreased or the movement patterns are more linear, the IT has more time to capture and process the data. Quick and sudden changes in the direction make it much more difficult for the IT to read changes in positional coordinates. By focusing on linear, endurance-based activities, researchers are able to collect more accurate long-term data.

Petersen et al. (66) reported an IT standard of error between 0.5 and 2.1% among MinimaxX, SPI-Pro, and SPI-10 units when measuring low-intensity endurance activities during cricket-specific training drills. These results validated the claims of previous studies that IT reported the lowest standard errors when measuring low-intensity endurance movements compared with an average *SEE* of 2%. Coutts and Duffield (18) reported a 5.3% *SEE* with SPI-10, SPI Elite, and WiSPI units when measuring high-intensity running and total distance, with increased errors occurring during very–high intensity running. The IT unit error detection, which varies from 1 to 10 Hz (79), is based on the hertz power, defined as the magnitude of frequency measured per second. The IT units will detect satellite signals at different rates and units with a higher frequency are statistically more reliable (3,79). Studies have indicated that despite variability among IT Hz power, error can be reduced by two-thirds if the task duration is increased (3,37,42). Integrated technology units have acceptable levels of accuracy and reliability for lower intensity, long duration movements but may not be reliable for measuring higher intensity activities. Further improvements are required to validate IT for accurately measuring high-intensity and variable movement tasks, and practitioners and researchers will have to account for the variability and error of such tasks to confidently quantify the tasks in question.

Category 2: Assessing Differences Between Training and Competition Demands

Studies within this category ($n = 12$) compared training and competition demands by assessing the physiological outputs of athletes ($n = 10$), measuring real-time quantitative measurement of player movement patterns ($n = 8$), and using fitness testing to predict athletic performances ($n = 3$). Comparing training and competition demands helps determine if modifications in training are needed so that training could adequately match competition demands. Gabbett et al. (33) studied women's field hockey training and competition and concluded that athletes spent more time in low-intensity activity during training sessions compared with the time spent in moderate and high-intensity activities during competition. The training sessions did not reflect the physiological demands of competition, indicating that modifications may be needed in training group size and drill complexity to simulate the competition demands better. These results are comparable with those of a study conducted on adolescent rugby players, where it was concluded that they covered greater distances and spent more time jogging, striding, and sprinting in match play compared with that while training (39). Integrated technology can then quantify the above velocity ranges to provide physiological information to compare training and competition demands. The studies above have significant implications on the field, for having specific quantitative information on training, and competition differences can aid in developing game-specific training sessions and drills that simulate the physical demands the athletes experience in games. A word of caution is advisable in regard to always using practice to simulate game play–this is best done in conjunction with a full periodization plan that incorporates rest and recovery periods with intense training and competition.

Another aspect often analyzed was the comparison of player position relative to training and competition. There are significantly different physiological demands imposed on athletes based on their respective position, and this applies to multiple sports (2,18,52,82). For example, Petersen et al. (65) quantified and compared cricket movement patterns during training sessions and competition. Fast bowlers sprinted twice as often, covered 3 times the distance, and had a small work-recovery ratio compared with that of other positions.

In comparison, the wicketkeeper rarely sprinted during the match, and covered on average 7 less kilometers compared to sprinting of fast bowlers. These results suggest that positional differences may require specific conditioning programs to be fully prepared for the physical demands of the respective sport. Wisbey et al. (82) also noted differences between the player positions in Australian Rules football. Nomadic players covered 3.5% more distance, had a 17% higher exertion index, and spent 23% more time running compared with that of forwards and defenders. This information is vital for coaches, because understanding the differences between positions can determine the relationship between movement demands and key game indicators, such as decision making, skill execution, possessions, tackling, and scoring.

A third trend found in the literature was the relationship between fitness testing and athletic performance. Mooney et al. (62) determined that there was a strong relationship between the Yo-Yo IR2 fitness test and the match performance of AFL players, where the playing experience and position affected fitness test scores and ball disposals during matches. Differences were also noted in a study that examined male soccer players (22). Players who performed small-side game training compared with general running training spent 29.4 seconds more in aerobic training and had higher $\dot{V}O_2$max levels during training. These results indicated that soccer-specific training was a more effective method of aerobic training compared with general running and provides the soccer athletes an advantage heading into a match. Such results can reveal if player experience and position can affect fitness and match performance, and may reveal whether preseason and inseason conditioning programs need to be altered to provide proper preparation and recovery practices to benefit individual and team performance.

Understanding the differences between positional requirements and training protocols can further refine the training and recovery process, because modifying the design and complexity of training programs will better simulate the demands of competition. Then, in turn, there is a significantly greater transfer of skills from training to competition. Future studies should aim at assessing individual player differences at various positions, because basing training protocols on the skill sets of individual players can enable coaches and trainers to develop athletes not only by their positional requirements but also by their unique skill sets; this in turn can bring out the full potential of the athletes.

Category 3: Measuring Physiological and Metabolic Demands

Studies within this category ($n = 16$) measured physiological and metabolic demands to assess muscle damage and hormonal responses ($n = 4$), determine effective fitness and recovery protocols ($n = 3$), and determine fatigue levels among athletes ($n = 10$). Analysis of the literature revealed that the IT is used to examine muscle damage and hormonal response during activity, to formulate proper recovery protocols and to determine mechanism of fatigue during match play (2,20,26,60,63). For example, McLellan et al. (57) measured creatine kinase (CK), a biomarker for muscle damage, and hormone levels of testosterone and cortisol combined with IT movement data to assess muscle damage and determine the necessary time period for full muscle recovery. They concluded that CK and cortisol levels peaked at 24 hours postmatch and that a period of at least 5 days was required to achieve full recovery from muscle damage. Another study investigated the effects of Re-Activate:01, a multinutrient supplement that contains ingredients aimed to increase muscular strength (e.g., adenosine triphosphate), energy level (e.g., folic acid), metabolism function (e.g., black pepper extract), muscle recovery (e.g., L-histidine and citruline malate), alertness (e.g., lysine HCl), and electrolyte levels (e.g., sodium bicarbonate), on performance based on the IT movement data (60). The authors observed the same peak in CK and hormone levels postmatch as noted in the previous study. Supplementation increased very–high intensity mean speed during the first half and moderate-intensity mean speed during the second half, indicating that supplementation may aid in the recovery process. These studies can be highly beneficial to athletes and coaches, for quantitative information on the time frame needed for optimal muscle recovery can ensure that athletes are fully rested and prepared for future match play.

Analysis of physiological and metabolic demands also revealed information about formulating proper fitness and recovery methods, because failure to do so may cause athletes to have potential performance decrements and injuries. Buchheit et al. (9) observed the effects of spa treatment (sauna, cold water immersion, and jacuzzi) on match play performance. They determined that using the IT to measure high-intensity running was an effective way to link performance with the effects of various spa treatments on male soccer players. They concluded that spa treatments provided effective recovery for muscle damage caused by high-intensity running. Gabbett et al. (34) investigated the physical demands of professional rugby matches compared with training activities used in preparation for competition. Match play had more moderate and heavy collisions, skill activities, and high-intensity efforts compared with training sessions. These results suggest that the physical demands of training sessions did not fully prepare athletes for the demands of match play, and may increase the recovery time needed for muscle damage and fatigue. Such studies have significant implications for preparation and recovery programs, because determining the most effective prematch and postmatch protocols can decrease the time needed for athletes to recover from muscle damage and ensure that fatigue does not arise in future performances because of a lack of recovery time.

Using the IT to measure fatigue was found to be inconclusive, because studies noted mixed results as to whether the IT can properly quantify fatigue. It is unclear whether such results are generalizable to multiple sports because most studies examined AFL players (2,4,19). Currently, there are no fatigue studies on cricket, field hockey, and soccer, sports often used as the subject population for IT-based studies. For example, Aughey (2) examined male soccer player work rates with IT units and found indications of fatigue during high-intensity running and maximal accelerations. However, the use of distance (meters) per minute of match time failed to determine evidence of fatigue when the average distance covered by the athletes was on the lower side. This discrepancy exists because when the total distance covered is on the lower side, averages may not easily demonstrate significant changes in the distance per minute to indicate fatigue. This discrepancy also demonstrates the importance of avoiding sport comparisons of fatigue, for using total distance measures may lead to false assumptions. Examination of Petersen et al.'s (65) data on male cricket athletes would reveal greater distance measures from the IT compared with that in a similar study conducted on Australian Rules football players (19). Without a full examination of the average per minute data, researchers would fail to recognize that fatigue is more evident in the Australian Rules football players because of a higher average distance per minute covered. If such errors in data analysis are to be avoided, a universal protocol and definition of fatigue through IT must be determined and quantified.

Category 4: Determining a Valid Definition for Velocity and Sprint Efforts

The fourth and final category of studies ($n = 8$) examined the justification for a valid definition of velocity ($n = 3$), determined the need to categorize sprinting efforts ($n = 4$), and assessed the difficulty of analyzing repeated-sprint efforts ($n = 4$). Previous literature examining velocity ranges has reported variable median velocity ranges for walking, jogging, and sprinting, creating confusion as to where to set values (10,22,25,30). Recently, Duffield et al. (26) classified mean velocity values as low-intensity ($<$7.0 $km \cdot h^{-1}$), moderate-intensity (7.0–14.4 $km \cdot h^{-1}$), high-intensity ($>$14.5 $km \cdot h^{-1}$), and very–high intensity ($>$20 $km \cdot h^{-1}$) running when examining the core temperature and match performance of AFL players. However, Impellizeri et al. (40) classified mean velocity into different thresholds, using jogging (7.6 $km \cdot h^{-1}$), low-speed running (10.2 $km \cdot h^{-1}$), moderate-speed running (13.9 $km \cdot h^{-1}$), high-speed running (17.1 $km \cdot h^{-1}$), and running sprint (26.7 $km \cdot h^{-1}$). These studies demonstrate that the lack of a universal definition leads to confusion as to where to set velocity threshold levels, for these discrepancies can lead to false conclusions being made based on where the velocity threshold is set. Using averages also cannot account for data points that may lie between the means, negatively affecting the validity and reliability of IT data.

The literature on defining sprint efforts revealed that the IT usually characterizes sprint efforts as movements $>$6–7 $m \cdot s^{-1}$, with Krustrup et al. (44) first defining sprinting as a velocity of $>$6.7 $m \cdot s^{-1}$. Other sprint definitions have been proposed, such as reaching 6.7 $m \cdot s^{-1}$ and lasting $>$2 seconds, or using 3 different threshold velocities to characterize sprinting (10,40). However, these definitions are problematic because the majority of field-based sports may begin short-duration, maximal efforts at lower velocities (1–2 seconds), failing to reach the defined criteria of a sprint effort (30,35,77). Inconsistencies in speeds that meet the criteria of a sprint demonstrate the need for a more concrete definition of sprinting. For example, Dwyer and Gabbett (30) collected data from male and female soccer and field hockey athletes, and male AFL players to propose standard velocity ranges and a definition of sprinting. The researchers concluded that 40% of their sprinting data would not fit the definition of traditional sprint because of its short-duration, low-velocity nature. Creation of a standardized definition and a broader range of velocity measures would account for data similar to those identified by Dwyer and Gabbett (30), and could provide athletes and coaches with vital information on how to train for high-acceleration movements and provide additional information on field-based sport physiology.

A third trend found in the literature was that discrepancies in quantifying velocity ranges and sprinting increased the difficulty of assessing repeated-sprint ability (RSA). The RSA, defined as short-duration sprints (1–2 seconds) interspersed with brief recovery periods, are difficult to quantify because these sprints do not meet the traditional criteria for sprinting (36). Earlier studies failed to establish the validity and the reliability of using the IT to assess the RSA (29,75,76). However, Barbero-Alvarez et al. (6) validated the use of the IT to assess speed and RSA during small-sided soccer training matches. The IT was able to assess the RSA over 30 m but not for 15 m, suggesting that the IT may not be suitable for assessing the RSA over shorter distances. Gabbett and Mulvey (35) reached a similar conclusion, because the majority of women soccer players performed primarily short-duration (1–2 seconds), maximal sprinting efforts that failed to reach the RSA criterion of a minimum of 3 sprints with a recovery period $<$21 seconds between the sprints. Because of such inconsistencies, there is currently limited research on assessing the RSA using the IT; however, IT was recently piloted against a laser, and its errors of measuring instantaneous velocity were comparable with the criterion of the laser (3). With the large number of short-duration, high-acceleration movements that occur in field sports, it is vital that researchers continue to explore the RSA to provide athletes with additional information to enhance their performances and insight into advancing to higher levels of competition.

Limitations

Although IT has significantly advanced over the past decade, there are several limitations derived from the literature that pose difficulties for collecting reliable and valid data (3,54).

Limitations include scalability issues using ≥2 time-motion analysis devices, inconvenience for athletes to wear, and the effect of environmental conditions. Scalability issues often arise when using ≥2 time-motion analysis devices (e.g., the GPS network and an accelerometer) because of cost and participant inconvenience. The IT is primarily used for studying velocity and distance measurements, and to assess muscle damage, energy cost, and other physiological and biophysical adaptations that occur during match play, other devices are required. The IT alone is incapable of assessing physiological and biophysical measures. GPS is also incapable of measuring vertical jumps, because movement can only be monitored horizontally without satellite degradation; although accelerometers measure movements in several planes, this technology does not assess specific movements like the GPS does. The average cost of IT alone varies between $500 and 2,000 USDs, and adding additional technology can be very costly for researchers (15).

From the perspective of the subject, wearing multiple devices can be bothersome or uncomfortable, and can become distracting to athletes trying to focus on a game or practice while having to remember to comply with all directions on using the devices (54). Although research has noted that GPSports and Catapult Innovations have created IT devices that are compact and durable to withstand athletic competitions (3,10,19) the feasibility of using them during training and important matches is still questionable as many organizations (e.g., Guiness Premiership Rugby League, FIFA (Federation Internationale de Football Association), and US Tennis Association) refuse to allow their usage (8,20,31,63,71). Oftentimes, the device must be attached with special clothing such as a vest, which adds to the discomfort of the athlete and requires proper fitting to prevent errors in device readings (14). Also, the use of multiple devices may decrease the validity and reliability of the resulting data, because all devices must be calibrated and timed precisely in tangent, otherwise large discrepancies in data can occur (3,39,42).

Another limitation of IT is the potential effect of the environment on the desired measurement capacities. Environmental conditions that can affect the signal accuracy of the IT include the following: (a) being indoors, (b) atmospheric conditions such as clouds, (c) local obstructions such as tall buildings, or (d) being in a highly populated area (3,16,45,58). Before reaching the IT, the satellite signals can become influenced by such conditions, leading to an error in the calculated distance from the satellite and consequently produces errors and missing data in speed and position measurements (54).

The main issue plaguing the use of sport-based IT during match play is the inability to use IT indoors. No study to date has analyzed indoor-based team sports using the technology. Integrated technology requires towers and satellites for signal transmission, and having the barrier of a closed building prevents the IT from reading accurate data (49). Indoor settings cause degradations in signals with obstacles such as furniture, moving people, roofs, floors, and walls (73). These degradations lead to decreased recording of signals, inability to detect multipath locomotion, and increased near-far effects where reception of a stronger signal makes it impossible to detect weaker signals.

Future Directions

Analyzing physical fitness testing, assessing biophysical measures during training, and developing further usability of the IT are the focal points of future research. The correlations between physical fitness testing and match performance have been highlighted in many recent studies (9,60,62,63). Examining physical fitness testing enables the use of field tests to predict performances, provides strength and conditioning coaches with information on how to train their respective athletes, and provides comparisons for in-match performances. For example, Castagna et al. (12) examined the effects of intermittent endurance fitness on match performance in young male soccer players using IT to assess the effectiveness of plyometrics, sprinting training drills, and short or long interval running training. The endurance fitness measures used in the study positively affected match play performance in young male soccer players. Such studies can allow strength and conditioning coaches to hone in on the technical skills and fitness demands addressed during fitness testing and training to facilitate improved performance.

Another future direction of the field may involve biophysical measurements, such as the effects of supplements on performance, core temperature responses, indirect calorimetry, and hormone responses. These measures are vital when assessing changes in prematch and postmatch play, as preparation and recovery are 2 phases of training that can make or break the success of athletes. One area that is often an issue in high-intensity sports is blunt force trauma, which can cause microtears in skeletal muscle and postgame muscle soreness. McClellan et al. (57) addressed this issue by examining CK levels in the skeletal muscles and hormone responses of rugby players prematch, during, and postmatch play. The results suggested at least 5 days of modified activity were required to achieve optimal recovery from postcompetition muscle damage, providing insights into the physical demands of rugby. Examination of blunt force trauma and postmatch muscle damage through hormone responses in conjunction with IT movement data can enable sport scientists and coaches to further establish recovery programs to ensure that athletes are fully rested before future match play.

A solution to developing further usability of IT may reside in developing wearable clothing with built-in technology. In 2004, Japanese scientists developed the jogging support system, which combines GPS, heart rate monitoring, and accelerometry directly into clothing items worn (55). Elgethun et al. (32) also incorporated GPS technology into children's clothing to provide tracking and assessment of various physical activities, and concluded that GPS technology integrated into clothing provides the direct quantification of time-location activity patterns. Future development of wearable technology could enhance time, activity, and location of team sport studies, and provide valuable insights into the nature of physical activity among children and other populations.

An additional future direction involves enhancing the usability of IT. As mentioned above, IT devices are currently only usable outdoors, and development of advanced technology such as indoor cell phone GPS product SiRiFstar V can allow for necessary improvements in data collection to enable studies to be conducted within indoor settings. Another possible development for indoor IT use resides in creating indoor "satellites" or GPS towers inside stadiums or arenas that function in the same manner as those in outdoor settings (3). Because of the severe signal degradation that occurs while indoors, the development of advanced IT capabilities is an area in need of further examination. Data collection can also be enhanced through advanced mathematical equations, such as Player Load. Player Load, a modified vector magnitude calculated from accelerometer data, describes the differences in the relationship between distance and load, and can provide researchers with evidence to compare training drills (7,8,61). Player Load is highly correlated with the total distance measured by GPS networks, and creation of a standardized regression equation can provide increased accuracy on measuring data on total distance. This equation can be further applied to measure player load during match play analysis, and practitioners can use this information if a standardized reporting method is developed to enable them to give coaches and athletes feedback on individual and team performances. Increased accuracy in data may also lead to a better quantification of changes in the direction of movement, fatigue, and gait, which was difficult during early research (45,78).

Functionality of IT can be enhanced through increased battery power, minimization of the product size, and improved memory storage. Because some sporting events can exceed the average sport-based IT battery life of 4 hours, an increase in the battery life is needed (3). Decreasing IT device size can also be beneficial, because athletes wearing bulky technology during training and/or competition can limit their performance or endanger others. With a decrease in device size it is likely governing bodies will allow athletes to wear IT during elite competition (3). Increased memory storage within IT can enable researchers to perform extended studies determining the long-term effects of the variables in question, and it enables the study of trends and patterns in the physiological changes of the athletes. Memory storage can also improve upon limiting the amount of incomplete or lost data during match play analysis, which is a current problem in field-based sports (2,24,79). Field-based competition studies cannot be repeated unlike in laboratory settings; therefore, any discrepancies in data can prove to be catastrophic.

Practical Applications

In conclusion, the development of IT has made a significant impact on the sporting realm. Integration technology provides coaches, physiologists, and athletes with real-time information on individual and team performances; in turn, this has led to significant improvements in the preparation, training, and recovery programs for field-based sport teams. Coaches can use IT to identify basic movement patterns to formulate tactical strategies based on player position, develop sport-specific training programs, and detect differences over extended periods of time. With an average reported reliability variation of 5–10% and low interunit variability across multiple studies, IT demonstrates significant accuracy in measuring field-based team sport exercise tasks. The ability of IT to provide real-time, noninvasive, and rapid data collection on measurements, such as impact load, directional movement, and activity identification offers an advantage over other time-motion analysis systems. Being small and lightweight in design, having memory storage of >4 hours of data, and measuring multiple athletes at once, IT serves as a cost-effective analysis method for training, match play, and injury prevention. Although IT has proven to accurately identify low-intensity, long duration, and linear movements, coaches should exercise caution when using IT to measure high-intensity and speed, frequent change of direction, and confined space movements because of its decreased validity and reliability. Coaches can also use IT data to compare training and competition demands to determine if modifications are needed in training and conditioning. The IT can assess if current training methodology adequately matches the demands placed on athletes during competition and determine whether player position and fitness levels impact training and match play demands.

A third use of IT involves physiological and metabolic demands, because IT data combined with biophysical markers (e.g., CK and testosterone) allow coaches to assess muscle damage and determine the necessary time period for full muscle recovery from match play. From this information, coaches have the ability to formulate improved recovery methods and determine which methods may be the most effective for the athletes. However, coaches should understand that the lack of a universal definition on velocity and repeated-sprint efforts can lead to a confusion on data analysis and where the velocity threshold should be set. Although measuring RSA can provide coaches information on high-intensity activities during competition, coaches must keep in mind using previous velocity threshold recommendations to assess RSA may lead to false conclusions based on where the threshold is set. Current IT research is aimed at investigating 4 main areas of study, where the strengths and weaknesses of IT are revealed through the validity and reliability of using IT to examine the 4 study areas. Fully understanding the current limitations and future directions of IT can enable coaches to understand the issues and topics of concern that need to be addressed to facilitate a lasting, significant influence of IT on team-based sport performance.

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