International Journal of Sport, Exercise and Health Research

Systematic Review

IJSEHR 2022; 6(1): 43-54

www.sportscienceresearch.com
Received: 01-02-2022
Accepted: 19-03-2022

A Review of the Relationship between Heart Rate Monitoring, Training Load, and Injury in Field-Based Team Sport Athletes

Kevin M. Fisher[1], Lindsay Fuller[1], Judy P. Chandler[1]
[1] Department of Physical Education and Sport, Central Michigan University, Mount Pleasant, Michigan- 48859, USA

Abstract

Outdoor, field-based team sports have been a staple of American and international cultures throughout recorded history and are currently played by millions of athletes around the globe. In modern competition, it is critical for athletes and support staff such as coaches, strength and conditioning specialists, and medical personnel to cooperate to optimize competitive readiness and performance. Important variables that can enhance or reduce physiological adaptations related to these areas include the relationship between the prescribed training workload and potential injuries. Therefore, it is important to understand and modify these aspects to fit the unique needs of individual athletes and specific teams. Recent advancements in technology now allow aspects of performance to be monitored in real time via methods that are reliable, cost effective, and noninvasive. The purpose of this literature review is to summarize and elucidate the available information on the potential relationship between heart rate monitoring and training load and how it may be used to prevent, predict, or detect an injury among athletes who participate in field-based sports. Overall, results indicate that while such technology has been used to describe and prescribe training workload, little research has been done to monitor the relationship between these variables and proclivity for or recovery from injury. Future longitudinal studies that encapsulate and address the highly dynamic nature and relationship of these variables are needed to better understand how they interact. Such an understanding may allow personnel such as coaches and staff to better support athletes on and off the field.

Keywords: Heart Rate Monitoring, Sport Injury, Training Load, Team Sports.

INTRODUCTION

Field-based team sports and competitions have been an integral part of diverse societies and cultures for generations and are currently played worldwide by a multitude of participants including amateurs, high school and collegiate athletes, semiprofessional athletes, and experienced professionals. Due to the popularity of field-based sports, it is important to study athlete physiology during performance so practitioners such as coaches, strength and conditioning specialists, and medical personnel can understand what players are experiencing to prevent injury and maximize training benefits. One method of tracking physiological demand and workload that is safe, non-invasive, and accurate is heart rate monitoring.

A person's maximum heart rate can be estimated by taking 220 and subtracting the individual's age. However, this equation has been shown to have considerable variability between performers, with a range of +/- 12 beats per minute (bpm) [1]. According to Nes, Janszky, Wisloff, Stoylen, and Karlsen [2]. a more accurate equation is [211 – (.64 × age)]. The intensity of a practice can be defined as *training load*, which is how hard the athlete worked during the training session and how much time the athlete will need to fully recover before resuming training [3,4]. By identifying the length of time athletes are working, as well as the intensity of the training session, heart rate data can then be used to assess how long the athlete will need to recover before another training session.

Using heart rate monitors during practice sessions and games may not only help prevent injuries but could also prevent or identify adverse conditions such as overtraining syndrome (OTS), which occurs when physical demands offset the time needed for the body to recuperate in between bouts of exercise and work, such as practice and/or games [5]. The lack of adequate rest periods between hard training sessions causes OTS, characterized by fatigue and underperformance [6]. It can be challenging to determine when an athlete has been overworked, as many will simply push through the pain in an attempt to improve. OTS can be spotted by various biological markers, such as increased cortisol levels, decreased levels of

***Corresponding author:**
Dr. Kevin M. Fisher
Associate Professor, Department of Physical Education and Sport, Central Michigan University, Mount Pleasant, Michigan- 48859, USA
Email: kevin.fisher@cmich.edu

luteinizing hormone, and decreased levels of estrogen or testosterone, but identifying these markers can be quite expensive and invasive due to the need for blood samples [7]. Although blood testing would be ideal to detect overtraining, heart rate would allow coaches to monitor an important physiology variable in real time. This would enable coaches to better periodize their practice structures, giving athletes rest when they need it and increasing the training load when athletes are healthy and able to work.

Research concerning the training load of athletes, their heart rate responses, and correlation to injury in field-based sports is lacking. There remains a consensus as to whether heart rate monitors can detect wellness, recovery, and overtraining due to the relatively small number of studies that have used heart rate to detect injury [8,9]. Another limitation of previous research in this area is that the relationship between heart rate and training load has generally been assessed under standardized exercise conditions, like submaximal testing, rather than while the sport is being played. According to Hopkins [10]. training has a substantial effect on overtraining and injury, yet there are few studies that use validated measures of training quantification to reduce injuries. Therefore, the purpose of this literature review is to summarize and elucidate the available information on the potential relationship between heart rate monitoring and training load and how it may be used to prevent, predict, or detect an injury among athletes who participate in field-based sports.

METHODOLOGY

A review of the literature was conducted to find published studies that have examined the relationship between heart rate and training load of athletes during field-based sports to determine if the data collected was being used to monitor risk of injury. The search engines used to perform this search included PubMed, SPORTDiscus, and Eric Pro Quest. Searches were performed using the key words “heart rate monitors”, “team sport”, “injury”, “training load”, “soccer”, “field hockey”, “Australian rules football”, “rugby”, “lacrosse”, “field-based sport”, and “sport”. Literature was also found using links to related articles, bibliographies of articles reviewed, and the Polar research website. Searches were not limited by year of publication, study design, sex of participants, or age of participants, and all levels of play were examined. Articles were selected for this review if they were written in English and met the following criteria: (1) the study was done with athletes involved in a field-based sport, (2) heart rate monitoring technology was used, and (3) training load was measured.

Literature Review

This literature review addresses training load, injury, and how monitoring heart rate response through modern technologies during field-based sports practices and games could allow for improved periodized practice structure and ultimately lower the risk of injury for players. For the purpose of this review, field-based sport was defined as any sport taking place outside on artificial turf, grass, or dirt, which often features high-intensity bouts of exercise in which there is little rest between periods of work, and the limiting factors of physical performance were maximum heart rate and time spent above the target heart rate zone during practices and games. Examples of sports that met the criteria included field hockey, soccer, rugby, Australian rules football, and lacrosse.

A study by Viveiros *et al* [11]. identified the importance of monitoring training load, stating that to promote the expected adaptations, the athlete should receive appropriate stimuli; thus, modification of the training loads is a critical variable for the success of the training process. If training load is not understood, athletes can be challenged too little, resulting in suboptimal adaptations, or athletes can be pushed beyond their physical limits, resulting in adverse effects, such as OTS. The main stressor in OTS is stress through training combined with inadequate rest, but additional stressors (e.g., social, academic, financial) also contribute to reduced athletic performance [12,13]. Symptoms of OTS can also include muscle and joint stiffness or soreness, longer recovery time, weight loss or gain, depression, lack of appetite, exhaustion, loss of motivation, and sleep disturbances [5,14].

Due to the dynamic, unpredictable nature of sport, athletes are inherently at risk for injury when they choose to participate, but with proper training and safety precautions, the risk, severity, and frequency of injury can be mitigated. To understand and quantify the injuries that happen within any field sport season, injury must be defined and measurable. Many definitions of injury encompass the need to seek medical treatment. One example would be calling injury an impairment due to overuse, or a single traumatic event which happened during practice or a game in which the player was sent to be evaluated by the athletic trainer or other medical personnel and lost time from practice or a game [15]. There are also multiple classifications of injury, dependent on the amount of practice and/or playing time the athlete misses. One study of elite rugby players classified injury by the following categories based on practice and match time lost [16].

1. Transient - no training or matches missed
2. Minor – up to seven days missed practice, one match missed
3. Moderate – eight to twenty-eight days missed, two to four matches missed
4. Major – more than twenty-nine days missed, five or more matches missed

Agel *et al* [17]. created ratios to predict the likelihood of an injury based on the number of hours an athlete is participating in their sport. The ratios were created by dividing the incidence of injuries occurred during practice by the number of athletic exposures (an AE was defined as one hour of practice) and multiplied by one thousand so injury rates could be measured based per one thousand athletic exposures.

Heart rate monitoring has become one of the most common ways to track physical activity and exercise accurately and reliably [18-20]. To assess the validity of heart rate monitors, several models have been field tested against each other. Schonfelder, Hinterseher, Peter, and Spitzenpfeil [21]. performed a field test with four brands of heart rate monitors in which they were compared with each other and an electrocardiogram (ECG); the authors suggested Polar heart rate monitors had a clear design, user-friendly features, and high quality while also noting that the company had more developed software and higher quality receivers compared to other heart rate monitors.

Factors such as athlete sex or the timing of the season may cause an individual to be more predisposed to injuries. It has been found that sports involving sudden, explosive change of direction movements (e.g., “jumping and cutting”) result in higher knee injury rates for females, by as much as a four to six-fold increase, than their male counterparts [22]. Another study suggested that females do indeed have higher rates of injury in college, which will likely continue into their professional career [23]. In a study that monitored injury in collegiate female basketball players, there was a jump in injury rate between week 2 (end of preseason) and week 3 (first official practice) which could be attributed to an increase in training load [5]. This data indicated that the coach was trying to prepare the players for the beginning of the season but may have pushed too hard too quickly and overloaded the players, causing injury. Overall, injury appeared to be correlated with training load.

Other research suggests that high rates of preseason injury could be due to an emphasis on strength and conditioning instead of sport-specific skill training. Agel and Schisel [17]. compared injury rates in 15 sports teams from 1988 to 2003. All teams demonstrated higher injury rates during the preseason, with 11/15 teams having at least double the injuries during preseason than in season or postseason. This evidence suggests that perhaps less time should be spent on increasing strength during preseason workouts, and more time should be spent on sport-specific skill building drills that will gradually prepare athletes for common inseason movements. High levels of muscle soreness and fatigue after weight training and conditioning workouts may detract from skilled performance during practices and contribute to injury occurrences.

It is imperative for athletes to report their injuries so they can receive professional treatment. Failing to report existing injuries can cause further strain and amplify an injury. It is important for athletes to be educated about how to detect an injury, understanding that pain may not be the only symptom of an injury. Overuse injuries, which constitute over 25% of the injuries among collegiate female athletes, develop over time with a slow progression of symptoms, often causing the athlete to be unaware of the injury [24]. Overuse injuries are difficult to diagnose due to inconsistent patterns of symptoms and severity, as well as being a result of ongoing trauma to the affected area rather than a single traumatic event. Since overuse injuries are so difficult to diagnose and report, affected athletes are at an increased risk for developing a severe injury that could greatly affect practice and game time. Unfortunately, because players do not want to sacrifice playing time, or because they simply are unaware of their injuries, they may not report them to the athletic trainers or coaching staff. Athletes may attempt to privately treat themselves or continue to play until the pain is unbearable or they experience a more significant injury.

If injuries go unnoticed and are underreported, it is challenging to determine how the injury originated. Meeuwisse and Love [25]. provided suggestions to make injury reporting less confusing and more accurate while also attempting to help players understand why reporting is critical, such as a universal definition of injury, the benefits of collecting injury data immediately, and error acknowledgement to decrease the chance of over- or under-reporting. Differing definitions that may be used across studies can make it hard to compare results. Rather than relying solely on an athlete to report an injury, monitoring their physiological responses to exercise may prove to be a useful tool in preventing and diagnosing injuries while also ensuring the athlete is ready to return to competition.

Various methods have been used to monitor athletes' physiological responses to exercise, many of which have involved blood testing to identify biological markers related to OTS. However, overtraining may be detected by changes in the autonomic nervous system, which would manifest as changes in heart rate [8-26]. While some studies have found that resting heart rate is increased when an athlete has been overtrained and is one of the first markers of OTS, other studies have concluded that resting sympathetic activity is not altered by overload [27,28]. Thus, more research is needed to determine if an increased resting heart rate before practice is a reliable indicator of overtraining. Esposito *et al* [29]. assessed the validity of heart rate as an indicator of aerobic demand during soccer. The researchers found the physiological demands of soccer can be accurately estimated from heart rate measurements taken on the field, as they used a HR-VO2 regression line to estimate VO2 from the heart rate data obtained. To ensure accuracy, a laboratory test was performed that measured heart rate and VO2 via expired gases from a breath-by-breath automated portable gas analysis system. The findings of this study support the contention that heart rate monitoring is an accurate and reliable assessment in monitoring athlete training load. Montgomery *et al* [30]. found a correlation coefficient of 0.91 between heart rate and energy expenditure during exercise after adjustments for age, gender, body mass, and fitness.

In recent years, many individuals, including athletes and nonathletes, are now utilizing wearable devices in the form of wristwatches that track aspects of health and fitness such as heart rate variability during rest and stress, exercise outcomes (e.g., daily steps taken, running distance, or calories burned), and sleep patterns [31,32]. In a study by Dooley, Golasceqski, and Bartholomew [33]. the validity of HR measurements of three devices: Apple Watch, Fitbit Charge HR, and Garmin Forerunner 225, were compared against criterion devices: a HR chest strap and a metabolic cart. Results indicated mean absolute error percentages that ranged from 1.14-6.7% for the Apple product, 2.38-16.99% for the FitBit, and 7.87-24.38% for the Garmin. While several heart rate monitors on the market have been tested for accuracy in quantifying heart rate, there are factors that can affect the relationship of heart rate and training load. Some of these include hydration status, exercise duration, medication, altitude, state of training, environmental conditions, and time of day [34,35]. If heart rate is used as a marker of exercise intensity, it is more accurate if the aforementioned factors influencing heart rate and training load are controlled. These studies suggest heart rate monitors are a viable way to measure the internal work of the athlete, as heart rate has a generally linear relationship to oxygen consumption (VO2), and heart rate monitors are easy to use, inexpensive, noninvasive, and versatile [30,36]. As Konarski, Matuszynski, and Strzelczyk [37]. noted, it is important for athletes to be comfortable and unimpeded by monitoring devices while training or performing so they can compete at optimal levels while also providing the most accurate data possible.

In any one practice or game, some players may find the training load quite high while other players find it too low, and thus will experience little benefit from the session. To overcome these discrepancies with training as a team, heart rate monitors are a relatively simple device that can measure and monitor individual players responses to training and could allow the coaches to better tailor practices based on position played and individual fitness levels [38]. Alexandre *et al* [34]. found evidence to support this idea in their study monitoring the physiological responses of soccer players, noting that heart rate response to exercise vary by playing position: midfielders had the highest training load, followed by forwards and fullbacks. Lythe and Kilding [39]. and Dellaserra, Dao, and Ransdell18 also noted that position-specific conditioning would be beneficial, if not required, for athletes to be fully prepared for the physical demands of the respective sport due to the variance in physical outputs between different positions. Alexiou and Coutts [38]. found that training sessions performed in a group often reduce the chances that players are receiving training that is specifically tailored enough, and thus highly conditioned athletes are not receiving enough of a training stimulus, while athletes that are not as conditioned may be risking overtraining. Monitoring heart rate during exercise bouts allows coaches to better control the likelihood of positive adaptation during the training process and qualify the type of exercise the athlete has performed [37]. There are also many desirable benefits to using heart rate monitors during training, such as exploratory learning about various exercise intensities, controlling target behavior, rectifying behaviors, motivation, and logging support [19].

A device called "integrated technology" (IT) uses Global Positioning System (GPS) data, accelerometry, and heart rate measurement to capture energy costs and movement patterns of the athletes throughout practices and games [18]. Most studies that have been conducted to measure its accuracy and validity have been conducted with sports teams who play outside for the GPS function to work properly. While several studies have used IT to analyze physiological data and assess players on an individual basis to monitor fatigue and performance, there is limited research with IT to assess if measuring these variables and the determined training load can help prevent or detect injury.

Overall, there has been little research done to monitor the internal workload of field hockey athletes. As Lythe and Kilding [39]. stated, previous studies have provided a basic understanding of the physical demands of the sport, yet there are still gaps in the literature. The authors found that heart rate response during a match provided a valid and useful measure of the physiological strain imposed upon the athlete. Athletes were found to have worked above 70% of their predicted heart rate maximum for 90% of the match, above 85% for 60 % of the match, and above 95% for 4% of the match. Similarly, in soccer, Alexandre *et al* [34]. concluded that heart rate can be used to monitor the internal training load of the athletes with good validity. Such information is useful for coaches to analyze and understand so athletes can be properly trained to function at their best during such high training loads.

Although heart rate monitoring has become a popular objective measure of training load, a potentially complementary subjective measure involves asking an athlete to provide a rating of perceived exertion (RPE) at various points throughout the session. This method is based on the idea that athletes can monitor the physiological stress on their own bodies and adjust their training load accordingly based on their perceived effort [35-40]. Aamot, Forbord, Karlsen, and Stoylen [41]. found that using an RPE scale alone resulted in subjects working at a lower intensity while monitoring HR instead of RPE allowed participants to work at higher workloads. Thus, RPE may be based on the performer's mindset and may not be physiologically accurate, making heart rate monitoring the better choice when monitoring training load of athletes during exercise.

RESULTS

This literature review yielded 365 articles. Of the articles found, 329 failed to meet the inclusion criteria (Figure 1) and were excluded from final analysis. The remaining studies included two Australian Rules football studies, six rugby studies, and 26 soccer studies. All studies are summarized in Tables 1, 2, and 3, and separated by sport to increase efficiency of review. For each study, the author(s), year published, sample size, participant sex, country of origin, level of athlete, training load measurement, type of heart rate monitor, and study purpose were included.

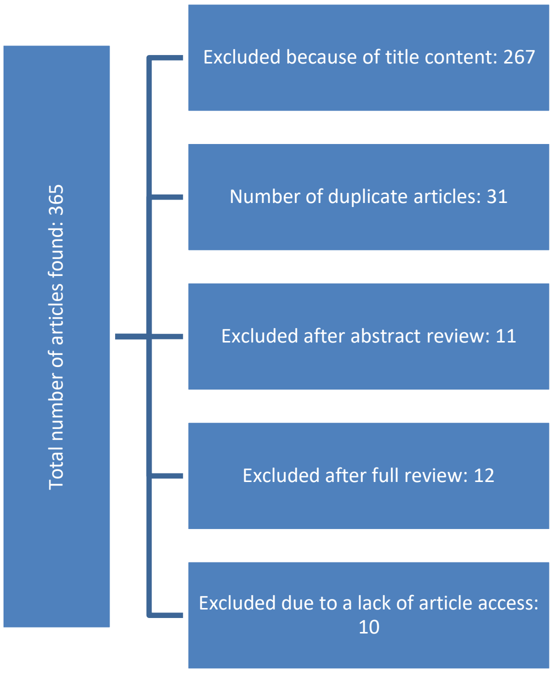

Figure 1: Diagram of the research process

Table 1: Summary of Australian rules football studies

Authors	Year published	Field-Based Sport	Sample Size	Sex	Country	Level of Athletes	Training Load Measurement	Heart Rate Monitor	Study Purpose
Buchheit *et al.*	2013	Australian Rules Football	18	Not Specified	Qatar	Not Specified	Total training session duration (min) × sRPE	Polar Team 2	To examine the usefulness of a few physiological and perceptual measures to observe fitness, fatigue, and running performance.
Scott *et al.*	2013	Australian Rules Football	21 Part A, 10 Part B	Male	Australia	Not Specified	TRIMP - Banister and Edwards, CR10, CR100 RPE	Polar Team 2	To examine and compare the criterion validity and test-retest reliability of the CR10 and CR100 RPE scales for team sport athletes that undertake high-intensity intermittent exercise.

Table 2: Summary of rugby studies

Authors	Year published	Field-Based Sport	Sample Size	Sex	Country	Level of Athletes	Training Load Measurement	Heart Rate Monitor	Study Purpose
Coutts *et al*.	2002	Rugby	17	Not Specified	Australia	Semi-Professional	Time spent in heart rate zones	Polar Vantage NV	To examine heart rate, blood lactate concentration, and estimated energy expenditure during a competitive rugby league match.
Cunniffe *et al*.	2009	Rugby	2	Not Specified	Not Specified	Elite	Time spent in heart rate zones	Polar (model not specified)	To gather information on rugby union forward and back play at the elite level and demonstrate the potential use of GPS technology in assessment of the games' physiological demands.
Higham *et al*.	2013	Rugby	42	Male	Australia/New Zealand	Not Specified	Cumulative time in 5 heart rate zones	Polar (model not specified)	To quantify the positional group-specific activity profile and physiological demands of different types of rugby sevens training and compare them with the demands of competition.
Kempton *et al*.	2015	Rugby	18	Not Specified	Australia	Not Specified	TD: TRIMP, HSR: TRIMP	Polar (model not specified)	1.) Examine the relationship between external demands and internal response during rugby league match play. 2.) Describe temporal changes in metabolic power-derived variables during rugby league match play. 3.) Examine the influence of contextual factors on physical performance variables during rugby league match play.
Lovell *et al*.	2013	Rugby	32	Not Specified	Not Specified	Professional	sRPE, Banister's TRIMP	Polar (model not specified)	To examine the validity of sRPE for monitoring training intensity in rugby league.
Waldron *et al*.	2011	Rugby	12	Male	England	Elite	sRPE, Edwards summated heart rate	Polar (model not specified)	To provide a profile of movement and physiological demands of elite rugby league, and also compare positional groups on one team.

Table 3: Summary of soccer studies

Authors	Year published	Field-Based Sport	Sample Size (included in final analysis)	Sex	Country	Level of Athletes	Training Load Measurement (Internal)	Heart Rate Monitor	Study Purpose
Aguiar *et al*.	2013	Soccer	10	Male	Portugal	Professional	Global RPE	Polar Team Sports System	To identify the acute physiological responses and activity profiles of football small-sided games formats.
Akubat *et al*.	2012	Soccer	9	NS	England	Professional	sRPE, Banister's TRIMP, iTRIMP, and modified Stagno's team TRIMP	Polar Team System	To compare the relationships between session-RPE, Banister's TRIMP, a modified version of Stagno's

									Team TRIMP, and iTRIMP, to changes in parameters of aerobic fitness in professional youth soccer players.
Akubat *et al*.	2014	Soccer	10	NS	England	Amateur	iTRIMP	Polar Team System	To see if information such as HR and distance that is regularly collected at the elite level can potentially be used to assess fitness in soccer.
Alexiou *et al*.	2008	Soccer	15	Female	Not Specified	Elite	Banister's TRIMP, Edwards' TRIMP, Lactate Threshold	Polar (Model unspecified)	To compare the sRPE method for quantifying internal training load (TL) with various HR-based TL quantification methods in a variety of training modes with women soccer players.
Aslan *et al*.	2012	Soccer	47	NS	Turkey	Junior League	RPE	Polar S610i	To determine metabolic responses, movement patterns and distance covered at running speeds corresponding to fixed blood lactate concentrations in young soccer players during match play.
Brink *et al*.	2010	Soccer	18	NS	Not Specified	Elite	TL_d, TL_{rpe}	Polar (Model unspecified)	To monitor training load, recovery, and performance of young soccer players for a full season to develop training guidelines to enhance performance.
Casamichana *et al*.	2013	Soccer	28	Male	Spain	Semiprofessional	Edward, sRPE	Polar Team System	To examine the relationships of common indicators of internal TL with objective measures of the external TL in soccer.
Casamichana *et al*.	2013	Soccer	10	Male	Spain	Semiprofessional	Player Load Formula	Polar Team Sport System	To examine the physical and physiological demands in 3 different duration formats: a continuous format, a long duration intermittent format, and a traditional intermittent format.
Casamichana *et al*.	2014	Soccer	12	Male	Not Specified	Semiprofessional	Relation to HR Max	Polar Team Sport System	To examine the effect of exercise duration and the number of touches allowed during possession on time-motion characteristics and the physiological responses of soccer players un the 6 vs.

									6 small-sided games (SSGs) lasting 12 minutes.
Castagna *et al*.	2011	Soccer	14	NS	Italy	Professional	Blood lactate, HR	Polar Team System	To examine the training intensity distribution as quantified using the HR in professional outfield soccer players during the early phase of the competitive season. Also to establish the efficacy of the quantification of TL using HR in soccer players, the relation between time spent in different intensity zones and aerobic fitness was measured.
Castellano *et al*.	2013	Soccer	14	Male	Not Specified	Semiprofessional	Player Load Formula	Polar Team Sport System	To determine whether changing the game format vs. regulation goals and goalkeepers vs. small goals but no goalkeepers and the number of players per side influences the physical and physiological response of players while maintaining constant all other variables in professional players.
Dellal *et al*.	2011	Soccer	20	NS	Africa	Elite	RPE	Polar S-810	To examine the effects of changes in the number of ball contacts allowed per individual possession on the physiological, technical, and physical demands within small-sided games in elite soccer.
Eniseler	2005	Soccer	10	Male	Turkey	Professional	Heart Rate and Blood Lactate	Polar Vantage NV	1: To estimate the training intensity on elite soccer players during a soccer match as well as various soccer training sessions by using HR values. 2: To estimate the actual exercise intensity by examining the relationship between heart rate values that were measured during the soccer activities and 2- and 4- mM lactate threshold levels that were determined during an incremental shuttle run test.
Impellizzeri *et al*.	2006	Soccer	29	NS	Not Specified	Junior	sRPE, Intensity zones (%HR Max)	Polar Vantage NV	To compare the effects of specific vs. generic aerobic

									interval training on physical fitness and objective measures of match performance in soccer.
Little *et al*.	2007	Soccer	28	NS	England	Professional	RPE	Polar (Model unspecified)	To monitor physiological responses of professional soccer players during several soccer training games (21) using HR and RPE.
Los Arcos *et al*.	2014	Soccer	14	Male	Spain	U-14	Fosters 0-10 scale, OPE (Overall perceived exertion), MPE (muscular perceived exertion)	Polar Team Sport System	To examine the variability and reproducibility of 2 popular youth soccer BD proposing or not opposition in soccer and its effect on the exercise intensity.
Mallo *et al*.	2008	Soccer	10	Male	Not Specified	Elite	Percentage of HR max	Polar Accurex Plus	To examine the kinematical, physiological and technical load imposed on soccer players during three typical small-sided 3-a-side training games carried out in an artificial grass 33x20 m surface.
Malone *et al*.	2014	Soccer	30	NS	England	Elite	RPE, sRPE	Acentas (Model unspecified)	To quantify the TL employed by an elite professional soccer team across an annual season including both the pre-season and in-season phases using current applied monitoring methods.
Manzi *et al*.	2013	Soccer	18	NS	Italy	Professional	$TRIMP_i$	Polar Team System	To examine the relationship between internal load and generic and specific variables of aerobic fitness in the male premiership soccer players using a fully individualized TL approach.
Owen *et al*.	2011	Soccer	15	Male	Scotland	Professional	Heart Rate Zones	Polar Team System	To examine the difference in HR responses and technical skills placed upon elite players when exposed to 2 SSG's differing in the number of players and playing area.
Radziminski *et al*.	2010	Soccer	19	NS	Poland	Professional	Anaerobic threshold	Polar (Model unspecified)	To lay out an incremental running test to determine anaerobic threshold and its usefulness as a predictability factor of the physiological load on professional soccer players

									during soccer training activities.
Randers *et al.*	2014	Soccer	86	NS	Denmark	Elite and Recreational	Player Load Formula	Polar Team 2 System	To evaluate activity profile, aerobic load, and player involvement in two game formats of recreational and elite youth football for two age groups.
Rebelo *et al.*	2012	Soccer	51	NS	Portugal	Youth	VAS-TL, Edwards' TL, and TRIMP	Polar Vantage NV and Polar Team System	To evaluate the convergent validity of a new method of training load monitoring based on VAS scores, and two standard heart rate-based methods during soccer practice and competition.
Roman - Quintana *et al.*	2013	Soccer	14	Male	Not Specified	Amateur	Player Load via GPS, heart rate zones	Polar Team Sport System	To evaluate the relation between the number of ball touches for individual possession and physical and physiological demands during large-sided soccer games.
Scott *et al.*	2013	Soccer	15	Male	Australia	Professional	sRPE, Banister's TRIMP, Edwards' TRIMP	Polar Team 2 Pro	To compare the sRPE method and 2 popular HR-based methods (Banister's TRIMP and Edwards' TRIMP) against measurements of player movements and accumulated accelerations (player load) to assess the use of GPS and accelerometer technologies in estimating external TL in professional soccer players.
Wong *et al.*	2011	Soccer	46	Male	China	U-14	RPE	Polar (Model unspecified)	1: To examine the relationship between VO2 and HR and RPE, respectively, in a group of regional-level youth soccer players. 2: To estimate VO2 and %VO2 Max by using HR and RPE together.
Wrigley *et al.*	2012	Soccer	16	NS	England	Elite	RPE, sRPE	Polar Team System	To evaluate the typical weekly training load (internal and external) of elite junior soccer players (U-14, U-16, U-18) registered at an English Premier League Academy during the in-season competitive phase.

DISCUSSION

This review of literature did not yield results that have effectively used heart rate monitoring technology to predict or detect injury with athletes who participate in field-based sports. This finding suggests that such technology could be used in more research and practical settings. If training load can be accurately monitored via practical means, there could be a decrease in the rate of injury as coaches are able to alter practices and the strength and conditioning protocols for the team to better accommodate the individual needs of their athletes. For example, after Rutgers University implemented heart rate monitors, they saw injury rates decline by approximately 70% [42]. Although the head coach believes a longitudinal study is necessary, he concluded that the technology has provided "indisputable improvements" for the team.

Many of the studies examined in this literature review used heart rate monitors to compare the physiological load on players during different types of game formats, such as small-sided games versus full contests. Many studies also monitored and compared internal to external training load, yet this review yielded no longitudinal study which tracked a decrease in injury rate for players that performed using the heart rate monitoring technology. Although the information found within the studies in this review is valuable, the findings demonstrate a need to expand research on heart rate monitoring technology to include the evaluation of injury rates. If the technology is accurate in assessing internal training load for the athletes, all teams should see a decrease in injury rates if coaches properly utilize the data and implement more informed, personalized training sessions. These results also demonstrate that subjective methods such as RPE may be used to monitor athlete training load, but heart rate technology could be an excellent tool to develop a more uniform method of monitoring this variable so data from different sessions, teams, sports, or studies can be easily and readily compared.

Future Directions

Longitudinal studies would likely improve our understanding of the relationship between the rate and nature of injuries for teams using heart rate monitoring technology, and they may facilitate the development of training programs that are more effective, efficient, and safer in comparison with programs that do not utilize such technology. The use of heart rate monitors could allow all parties involved to better understand the internal workload of each athlete, which was previously difficult to measure due to the need for expensive and potentially invasive equipment. With advances in technology, data related to these variables is simpler for coaches to obtain, easier for analysts and researchers to understand, and minimally disruptive for athletes to provide. Since each athlete can be unique in terms of goals, fitness, and propensity for injury, it is important to have individualized training programs to increase the chances of maximal benefit from each session. Regularly examining the relationship between heart rate, workload, and injuries (e.g., rates and the nature of injury) on a regular basis is likely to provide greater insight into coaching, training, and treating athletes who participate in field-based sports.

Conflicts of interest

None declared.

Financial Support

None declared.

REFERENCES

1. ACSM's Guidelines for Exercise Testing and Prescription. 11th ed. Baltimore: Lippincott, Williams, and Wilkins. 2021.
2. Nes BM, Janszky I, Wisloff U, Stoylen A, Karlsen T. Age predicted maximal heart rate in healthy subjects: The HUNT fitness study. Scand J Med Sci Spor. 2013;23(6):697-04.
3. Polar USA. http://www.polar.com/us-en/training_with_polar/training_articles/maximize_performance/general/training_load. Accessed February 20, 2020.
4. Eniseler N. Heart rate and blood lactate concentrations as predictors of physiological load on elite soccer players during various soccer training activities. J Strength Cond Res. 2005;19(4):799-04.
5. Anderson L, Triplett-McBride T, Foster C, Doberstein S, Brice, G. Impact of training patterns on incidence of illness and injury during a women's collegiate basketball season. J Strength Cond Res. 2003;17(4):734-38.
6. Budgett R. Fatigue and underperformance in athletes: The overtraining syndrome. Br J Sports Med. 1998;32(2):107-10.
7. Johnson MB, Thiese SM. A Review of overtraining syndrome - recognizing the signs and symptoms. J Ath Train. 2002;(27):352-54.
8. Achten J, Jeukendrup AE. Heart rate monitoring: Applications and limitations. Sports Med. 2003;33(7): 517-38.
9. Buchheit M, Racinais S, Bilsborough JC, Bourdon PC, Voss SC, Hocking J, *et al*. Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. Journal of science and medicine in sport. 2013;16(6):550-5.
10. Hopkins WG. Quantification of training in competitive sports: Methods and applications. Sports Med. 1991;12(3):161-83.
11. Viveiros L, Costa EC, Moreira A, Nakamura FY, Aoki MS. Monitoramento do treinamento no judô: comparação entre a intensidade da carga planejada pelo técnico e a intensidade percebida pelo atleta. Revista Brasileira de Medicina do Esporte. 2011;17:266-9.
12. Carfagno D, Hendrix JC. Overtraining syndrome in the athlete: Current clinical practice. Curr Sports Med Rep. 2014;13(1):45-51.
13. Wyatt FB, Donaldson A, Brown E. The overtraining syndrome: A meta-analytic review. J Exerc Physiol Online. 2013;16(2):12.
14. Grove R, Main L, Sharp L. Stressors, recovery processes, and manifestations of training distress in dance. J Dance Med Sci. 2013;17(2):70-78.
15. Knapik, JJ, Bauman CL, Jones BH, Harris JM, Vaughan L. Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. Am J Sports Med. 1991;19(1):76-81.
16. Gabbett TJ, Jenkins DG. Relationship between training load and injury in professional rugby league players. J Sci Med Sport. 2011;14(3):204-9.
17. Agel J, Schisel J. Practice injury rates in collegiate sports. Clin J Sport Med. 2013;23(1):33-38.
18. Dellaserra C, Gao Y, Ransdell L. Use of integrated technology in team sports: A review of opportunities, challenges, and future direction for athletes. J Strength Cond Res. 2014;28(2):556-73.
19. Segerstahl K, Oinas-Kukkonen H. Designing personal exercise monitoring employing multiple modes of delivery: Implications from a qualitative study on heart rate monitoring. Int J Med Inform. 2011;80(12):203-13.
20. Terbizan D, Dolezal B, Albano C. Validity of seven commercially available heart rate monitors. Meas Phys Educ Exerc Sci. 2002;6(4):243-47.
21. Schonfelder M, Hinterseher G, Peter P, Spitzenpfeil P. Scientific comparison of different online heart rate monitoring systems. Int J Telemed Appl. 2011;1-6.
22. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The Effect of neuromuscular training on the incidence of knee injury in female athletes. Am J Sports Med. 1999;27(6):699-6.
23. McCarthy MM, Voos JE, Nguyen JT, Callahan L, Hannafin JA. Injury profile in elite female basketball athletes at the Women's National Basketball Association combine. Am J Sports Med. 2013;41(3):645-51.
24. Cheng G, Covassin T, Heiden E, Nayar S, Tibbetts AS, Yang J, *et al*. Epidemiology of overuse and acute injuries among competitive collegiate athletes. J Athl Train. 2012;47(2):198-4.
25. Meeuwisse WH, Love EJ. Athletic injury reporting. Sports Medicine. 1997;4(3):184-4.
26. Bosquet L, Merkari S, Arvisais D, Aubert AE. Is heart rate a convenient tool to monitor over-reaching? A systematic review of the literature. Br J Sports Med. 2008;42:709-14.
27. Lampe, WL. Does overload exercise training alter autonomic nervous system activity and hemodynamic regulation in aerobically fit men? [thesis]. Alberta, Canada: University of Alberta: 2014.
28. Quinn E. Overtraining Syndrome and Athletes.Sportsmedicine.about.com. N.p., n.d. Web.
29. Esposito F, Impellizzeri FM, Margonato V, Vanni R, Pizzini G, Veicsteinas A, *et al*. Validity of heart rate as an indicator of aerobic demand during soccer activities in amateur soccer players. European journal of applied physiology. 2004;93(1):167-72.

30. Montgomery PG, Green DJ, Etxebarria N, Pyne DB, Saunders PU, Minahan CL *et al.* Validation of heart rate monitor-based predictions of oxygen uptake and energy expenditure. J Strength Cond Res. 2009;23(5):1489-95.
31. Hernando D, Roca S, Sancho J, Alesanco Á, Bailón R. Validation of the apple watch for heart rate variability measurements during relax and mental stress in healthy subjects. Sensors. 2018;18(8):2619.
32. Jo A, Coronel BD, Coakes CE, Mainous III AG. Is there a benefit to patients using wearable devices such as Fitbit or health apps on mobiles? A systematic review. The American journal of medicine. 2019;132(12):1394-400.
33. Dooley EE, Golascewski NM, Bartholomew JB. Estimating accuracy at exercise intensities: A comparative study of self-monitoring heart rate and physical activity wearable devices. J Med Internet R. 2017;5(3).
34. Alexandre D, Da Silva CD, Hill-Haas S, Wong DP, Natali AJ, De Lima JR, *et al*. Heart rate monitoring in soccer: interest and limits during competitive match play and training, practical application. The Journal of Strength & Conditioning Research. 2012 Oct 1;26(10):2890-06.
35. Borresen J, Lambert MI. The quantification of training load, the training response and the effect on performance. Sports Med. 2009;39(9):779-95.
36. Buchheit M. Monitoring training status with HR measures: Do all roads lead to Rome? Front Physiol. 2014;5(73):1-16.
37. Konarski J, Matuszynski M, Strzelczyk R. Different team defense tactics and heart rate during a field hockey match. Stud Phys Cult Tour. 2006;13:145-47.
38. Alexiou H, Coutts A. A comparison of methods used for quantifying internal training load in women soccer players. Int J Sports Physiol Perform. 2008;3(3):320-30.
39. Lythe J, Kilding AE. Physical demands and physiological responses during elite field hockey. Int J Sports Med. 2011;32(7): 523-28.
40. Braun-Trocchio R, Williams A, Harrison K, Warfield E, Renteria J. The effects of heart rate monitoring on ratings of perceived exertion and attention allocation in individuals of varying fitness levels. Front Sports Act Living. 2022;3:798941.
41. Aamot IL, Forbord S, Karlsen T, Stoylen, A. Does rating of perceived exertion result in target exercise intensity during interval training in cardiac rehabilitation? A study of the Borg scale versus a heart rate monitor. J Sci Med Sport. 2013;17(5):541-45.
42. Vorkunov, M. Rutgers women's soccer team uses technology to improve program and lower injury rates. http://www.nj.com/rutgers/index.ssf/2013/10/rutgers_womens_soccer_team_uses_technology_to_improve_program_and_lower_injury_rates_1.html. Updated October 6, 2013. Accessed March 2, 2020.
43. Aguiar MV, Botelho GM, Goncalves BS, Sampaio JE. Physiological responses and activity profiles of football small-sided games. J Strength Cond Res. 2013;27(5):1287-94.
44. Akubat I, Barrett S, Abt G. Integrating the internal and external training load in soccer. Int J Sports Physiol Perform. 2014;9(3):457-62.
45. Akubat I, Patel E, Barrett S, Abt G. Methods of monitoring the training and match load and their relationship to changes in fitness in professional youth soccer players. J Sports Sciences. 2012;30(14):1473-80.
46. Aslan A, Acikada C, Guvenc A, Goren H, Hazir T, Ozkara A, *et al*. Metabolic demands of match performance in young soccer players. J Sports Sci Med. 2012;11(1):170-79.
47. Brink MS, Nederhof E, Visscher C, Schmikli SL, Lemmink KA. Monitoring load, recovery, and performance in young elite soccer players. J Strength Cond Res. 2010;24(3):597-03.
48. Casamichana D, Castellano J, Dellal A. Influence of different training regimes on physical and physiological demands during small-sided soccer games: Continuous vs. intermittent format. J Strength Cond Res. 2013;27(3):690-97.
49. Casamichana D, Castellano J, Calleja-Gonzalez J, San Roman J, Castagna C. Relationship between indicators of training load in soccer players. J Strength Cond Res. 2013;27(2):369-74.
50. Casamichana D, Suarez-Arrones L, Castellano J, San Roman-Quintana J. Effect of number of touches and exercise duration on the kinematic profile and heart rate response during small-sided games in soccer. J Hum Kin. 2014;41:113-23.
51. Castagna C, Impellizzeri FM, Chaouachi A, Bordon C, Manzi V. Effect of training intensity distribution on aerobic fitness variables in elite soccer players: A case study. J Strength Cond Res. 2011;25(1):66-71.
52. Castellano J, Casamichana D, Dellal A. Influence of game format and number of players on heart rate responses and physical demands in small-sided soccer games. J Strength Cond Res. 2013;27(5):1295-03.
53. Coutts A, Reaburn, P, Abt G. Heart rate, blood lactate concentration and estimated energy expenditure in a semi-professional rugby league team during a match: A case study. J Sports Sci. 2003;21(2);97-03.
54. Cunniffe B, Proctor W, Baker JS, Davies B. An evaluation of the physiological demands of elite rugby union using Global Positioning System tracking software. J Strength Cond Res. 2009;23(4):1195-03.
55. Dellal A, Chamari K, Owen AL, Wong DP, Lago-Penas C, Hill-Haas S, *et al*. Influence of technical instructions on the physiological and physical demands of small-sided soccer games. European Journal of Sport Science. 2011 Sep 1;11(5):341-6.
56. Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, *et al*. A new approach to monitoring exercise training. The Journal of Strength & Conditioning Research. 2001 Feb 1;15(1):109-15.
57. Higham DG, Pyne DB, Anson JM, Hopkins WG, Eddy A. Comparison of activity profiles and physiological demands between international rugby sevens matches and training. The Journal of Strength & Conditioning Research. 2016;30(5):1287-94.
58. Impellizzeri FM, Marcora SM, Castagna C, Reilly T, Sassi A, Iaia FM, *et al*. Physiological and performance effects of generic versus specific aerobic training in soccer players. International journal of sports medicine. 2006 Jun;27(06):483-92.
59. Kempton T, Sirotic AC, Coutts AJ. An integrated analysis of match-related fatigue in professional rugby league. J Sports Sci. 2015;33(1):39-47.
60. Little T, Williams AG. Measures of exercise intensity during soccer training drills with professional soccer players. J Strength Cond Res. 2007;21(2):367-71.
61. Los Arcos A, Martínez-Santos R, Yanci J, Mendiguchia J, Méndez-Villanueva A. Negative associations between perceived training load, volume and changes in physical fitness in professional soccer players. Journal of sports science & medicine. 2015;14(2):394.
62. Lovell TW, Sirotic AC, Impellizzeri FM, Coutts AJ. Factors affecting perception of effort (session rating of perceived exertion) during rugby league training. International journal of sports physiology and performance. 2013;8(1):62-9.
63. Mallo J, Navarro E. Physical load imposed on soccer players during small-sided training games. J Sports Med Phys Fit. 2008;48(2):166-71.
64. Malone JJ, Di Michele R, Morgans R, Burgess D, Morton JP, Drust B. Seasonal training-load quantification in elite English premier league soccer players. International journal of sports physiology and performance. 2015;10(4):489-97.
65. Manzi V, Bovenzi A, Impellizzeri MF, Carminati I, Castagna C. Individual training-load and aerobic-fitness variables in premiership soccer players during the precompetitive season. The Journal of Strength & Conditioning Research. 2013;27(3):631-6.
66. Owen AL, Wong DP, McKenna M, Dellal A. Heart rate responses and technical comparison between small-vs. large-sided games in elite professional soccer. The journal of strength & conditioning research. 2011;25(8):2104-10.
67. Radzimiński Ł, Rompa P, Dargiewicz R, Ignatiuk W, Jastrzębski Z. An application of incremental running test results to train professional soccer players. Baltic Journal of Health and Physical Activity. 2010 ;2(1):66-73.
68. Randers MB, Andersen TB, Rasmussen LS, Larsen MN, Krustrup P. Effect of game format on heart rate, activity profile, and player involvement in elite and recreational youth players. Scandinavian Journal of Medicine & Science in Sports. 2014;24:17-26.
69. Rebelo A, Brito J, Seabra A, Oliveira J, Drust B, Krustrup P, *et al*. A new tool to measure training load in soccer training and match play. International journal of sports medicine. 2012;33(04):297-4.
70. San Román-Quintana J, Casamichana D, Castellano J, Calleja-González J, Jukić I, Ostojić S. The influence of ball-touches number on physical and physiological demands of large-sided games. Kinesiology. 2013;45(2):171-8.
71. Scott BR, Lockie RG, Knight TJ, Clark AC, de Jonge XA. A comparison of methods to quantify the in-season training load of professional soccer players. International journal of sports physiology and performance. 2013;8(2):195-2.
72. Scott TJ, Black CR, Quinn J, Coutts AJ. Validity and reliability of the session-RPE method for quantifying training in Australian football: a comparison of the CR10 and CR100 scales. The Journal of Strength & Conditioning Research. 2013;27(1):270-6.
73. Waldron M, Twist C, Highton J, Worsfold P, Daniels M. Movement and physiological match demands of elite rugby league using portable global positioning systems. Journal of Sports Sciences. 2011;29(11):1223-30.
74. Wong DP, Carling C, Chaouachi A, Dellal A, Castagna C, Chamari K, *et al*. Estimation of oxygen uptake from heart rate and ratings of perceived exertion in young soccer players. The Journal of Strength & Conditioning Research. 2011 Jul 1;25(7):1983-8.

75. Wrigley R, Drust B, Stratton G, Scott M, Gregson W. Quantification of the typical weekly in-season training load in elite junior soccer players. Journal of sports sciences. 2012 Nov 1;30(15):1573-80.