The role of motion analysis in elite soccer

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Abstract

The optimal physical preparation of elite soccer (association football) players has become an indispensable part of the professional game especially due to the increased physical demands of match-play. The monitoring of players' work-rate profiles during competition is now feasible through computer-aided motion analysis. Traditional methods of motion analysis were extremely labour intensive and were largely restricted to university-based research projects. Recent technological developments have meant that sophisticated systems, capable of quickly recording and processing the data of all players' physical contributions throughout an entire match, are now being used in elite club environments. In recognition of the important role motion analysis now plays as a tool for measuring the physical performance of soccer players, this review critically appraises various motion analysis methods currently employed in elite soccer and explores research conducted using these methods. This review therefore aims to increase the awareness of both practitioners and researchers of the various motion analysis systems available, identify practical implications of the established body of knowledge, while highlighting areas that require further exploration.

Key terms: fatigue, global positioning systems, match analysis, positional role

Introduction

A significant body of research into the host of factors contributing towards optimal performance in sport has emerged over the past two decades.[1] This increased research activity has been particularly evident in soccer (association football), where the importance of scientific research and applied work has become increasingly accepted in the professional game.[2] Over this period, comprehensive reviews have been published on the physiology,[3,4] psychology,[1,5] biomechanics[6] and interdisciplinary[7] aspects of soccer. This growing acceptance of sports science is unsurprising considering the performance-enhancing role that it can offer elite soccer coaches continually searching for a competitive edge against rival teams.[8]

Among the traditional sport science disciplines, exercise physiology has arguably had the greatest impact upon practices within professional soccer. The optimisation of physical fitness is now an integral facet of player and team preparation. Physiological demands of contemporary professional soccer implicate an increased work-rate, a higher frequency of competition, and as a consequence, players are obliged to work harder than in previous decades.[9,10] The monitoring of players' work-rate profiles during competition was originally achieved using manual video-based motion analysis techniques such as that developed by Reilly and Thomas.[11] The employment of such methods elicited essential scientific observations but the perceived complexity and consumption of time required for coding, analysing and interpreting the output formed barriers to their adoption by performance analysts.[12] The original techniques were also extremely time-consuming and restricted to the analysis of a single player and therefore were limited to university based research projects.

Over the past decade, technological advances have included the introduction of increasingly sophisticated motion analysis systems that have begun to be utilised in elite soccer. These systems enable the simultaneous analysis of all players to be completed in a relatively short period of time, and provide a valuable pool of data that can inform and influence the daily practices of coaches. The utilisation of these advanced approaches furthers our understanding of position-specific work-rate profiles of soccer players and their fitness requirements, the intensities of discrete activities during match play and the occurrence of a reduced work-rate among players.[13,14] Moreover, these contemporary methods employed by elite clubs can be used to make objective decisions for structuring the conditioning elements of training and subsequent match preparation.

In recognition of the important role that motion analysis now plays as a tool for measuring the physical performance of soccer players, we begin by critically appraising the various methods of motion analysis available to researchers and practitioners in soccer. Throughout, we highlight that many of the latest computerised systems now are not only logistically practical, but also offer a greater breadth of analysis when compared to the more traditional labour-intensive methods. However, many of these systems still require scientific validation to ensure that data derived from these methods are both accurate and reliable. A presentation and critical appraisal of various validation protocols used for assessing contemporary motion analysis technologies are provided in an attempt to prompt further research into this area of investigation. Also considered are various issues concerning the interpretation of the data obtained through techniques of motion-analysis. In the remainder of this review, motion analysis research into work-rate profiles within competitive games, exercise patterns, positional demands, fatigue and other uses, is considered. Collectively this review should serve to increase awareness of practitioners and researchers concerning the various motion analysis systems and the body of accumulated knowledge acquired through using this approach, whilst identifying areas that require further exploration.

1. Contemporary techniques for work-rate analysis

1.1 Individual player analysis

Motion analysis has been applied for over 30 years to the study of work-rates in professional soccer, since the classical study of Reilly and Thomas[11]. Research studies undertaken in the last 5 years by Scandinavian and Italian researchers[15-19] on top-level soccer have incorporated similar approaches to that employed over a decade earlier by Bangsbo and co-workers[20].This original method involved the positioning of video cameras near the side of the pitch, at the level of the midfield line, at a height of approximately 15 m and at a distance of 30-40 m from the touchline. Each camera was used to film a separate player. After the game, the subjects were video-taped for reference purposes whilst performing specific activities from walking to sprinting in order to provide calibration values. The video tapes were played back on a television monitor and coded for various match activities. The duration of each activity was recorded, total time summed and frequency of activity calculated according to separate time blocks. The distance covered at each activity within each time block was the product of mean velocity and total time spent in the activity. The total distance covered during a match was calculated as the sum of the distances covered during each individual type of locomotor activity.

The main technological advancement evident in subsequent studies has been the employment of better quality cameras and more advanced input coding methods as a result of contemporary computer software. To this end, Bloomfield et al.[21] used the “PlayerCam” facility (Sky Sports Interactive Service, British Sky Broadcasting Group, UK) to provide high-quality close-up video footage focusing on a single player’s movements and actions. The footage was digitised and synchronised for manual coding using the Noldus Observer Pro behavioural analysis system[22] which in turn automatically calculated the time spent in the defined movement activities.

These particular video-based methods used for manually measuring work-rates have generally demonstrated in the studies that have been reported to use them, high levels of reliability, objectivity and validity.[8] For example, a previous report that employed these methods, stated that no systematic differences were reported in a test–retest analysis of a match and the mean intra-individual difference in total distance covered was less than 0.2 km (coefficient of variation, CV= 1%).[15] Nevertheless, human error is possible in entering data inaccurately due to the subjective nature of human movement recognition, variable observer reaction to events being performed by the player under scrutiny and different interpretations of performance indicators relating to work-rate and movement by different observers.[23] In addition, the methods previously described are restricted to the filming and analysis of a single player per camera. Video-based motion analysis may also be subject to errors due to changes in gait during game movements,[24] and provides only low spatial and temporal resolutions.[25] Furthermore, these techniques do not allow real-time analysis and are extremely labour-intensive in terms of the capture and analysis of data. In this respect, the detailed manual methodology used by Bloomfield et al.[26] to code manually and determine the physical demands of English Premier League football was described by the authors as extremely time consuming and laborious. This criticism applied even for the collection of data from only 5 min of match footage due to the frequent changes of movement type, direction and/or intensity. A total of 1,563 ‘purposeful movement’ passages were observed for 55 players during 15-min periods of Premier League soccer which involved 23,487 changes in movement, direction, perceived intensity or individual soccer-specific events (e.g. pass, dribble, shoot). Players performed a mean of 28.4±4.3 passages of purposeful movement for each 15-min period of the match at a mean duration of 13.1±3.2 s. These figures equate to a mean of 15.03 changes in activity for each passage at a rate of 0.87 per second. No significant differences were found between the amount of purposeful movement passages by match period or playing position although strikers had a significantly shorter mean duration and frequency of passages >15 s. Due to the level of detail in this manual based time-motion analysis, the application and use of such methods of motion analysis are generally restricted to academic research projects as the intense competitive schedules of elite soccer clubs require data to be available usually within 24-36 hours post-match. The difficulties encountered in manually coding movements may lead some researchers to analyse a single selected period of action per player per game. Attempts can then be made to extrapolate the data from these periods to a projection for the entire match. However, incomplete recordings are limited in their ability to provide detailed individual work-rates as the work-rate pattern is highly variable throughout a game and is therefore not so easily predictable.[27]

As technology has advanced, time-motion analysis has begun to incorporate electronic devices, mathematical modelling procedures for automatic tracking, sophisticated computer processes and satellite tracking. An overview of contemporary systems used to analyse workload in soccer can be seen in Table I.

Many contemporary approaches are based essentially on an original method designed by Ohashi et al.[28] which employed the calculation of players' position and speed through trigonometric techniques. For example, the motion characteristics of elite Japanese soccer players have been recently measured throughout a game's entirety using a triangular surveying method.[29] This method entailed recording the player's movement as angular changes, which were measured by two potentiometers linked to cameras mounted outside and overlooking the field of play. Coordinates for the player were calculated using the angular data from the cameras and were monitored every 0.5 seconds. The distance between two consecutive coordinates was calculated continuously to obtain the total distance covered. The major limitation of this particular methodology was that it did not allow simultaneous analyses of more than one player.[8] Limiting the analysis of the activity profile to one player per game does not allow comparisons to be drawn between the concomitant work-rate profiles of team-mates or those of opposing players and can limit full understanding of the tactical importance of work-rate.[27]

A further technological advancement in this field has been the development of the software “Trakperformance” which provides a means of mechanically following a single player using a conventional computer pen and commercially available drawing tablet on a scaled version of the specific playing field.[24,30] This method is an improvement from the classical cartographic approach previously used by Japanese researchers where movements of soccer players were traced onto a scaled map of the pitch presented on paper sheets.[31] The Trakperformance system functions by using ground markings around the pitch which are employed as reference points for tracking the players. The miniaturised playing field is calibrated so that a given movement of the mouse or mouse-pen corresponds to the linear distance travelled by the player. This computerised system has demonstrated acceptable levels of accuracy and intra- and inter- observer reliability. For example, an error measurement level of 5% for player distances has been presented and a test of inter-observer reliability between three separate observers reported a Pearson’s correlation of $r = 0.98$ for total distance travelled.[30] A further advantage is that movements can also be tracked in real-time (although operator skill does need to be very high and a sustained training period is needed for familiarisation with the technique) and cost is significantly reduced in comparison to other commercially available tracking systems. Finally, the portability of this system means it can be readily employed to analyse work-rates of players within training contexts.

1.2 Multiple player analysis

Few systems have the ability to analyse all the players in a team throughout a whole match, tracking each player both on and off the ball.[32] The AMISCO Pro system developed in the late 1990s by Sport-Universal Process in collaboration with the French Football Federation was the first system to achieve the simultaneous analysis of the work-rate of every player in a team throughout the entirety of a match.[33] This system measures the movements on video, of every player, the referee and ball by sampling activity up to twenty-five times a second during the whole game.[8,34] This process leads to the collection of around 4.5 million data-points for position on the pitch as well as over 2000 ball touches per match. Along with the ProZone® system,[35,36] its chief commercial European competitor, these pioneer multi-player video tracking systems based on state-of-the-art computer and video technology are currently the most comprehensive and widely used commercial tracking systems in professional European soccer. These systems provide a detailed analysis of each player's work-rates over the entire match, and create a two-dimensional animated reconstruction of player movements together with an interactive graphical representation of all playing actions such as passes and duels.[37]

Video-based multi-player tracking systems such as AMISCO Pro and ProZone generally require the permanent installation of several cameras fixed in optimally calculated positions to cover the entire surface of play (Figure 1). This lay-out ensures that every player is captured on video, whatever the position and the moment in time. The number, position, orientation, zoom and field of vision of the cameras depend on factors such as the dimensions of the pitch and the structure of the stadium. The stadium and pitch are calibrated in terms of height, length and width and transformed into a two-dimensional model to allow player positions (x, y coordinates) to be calculated from the camera sources. Complex trigonometry, propriety mathematical algorithms, image-object transformation methods for obtaining 2-D or 3-D space coordinates such as Direct Linear Transformation (DLT)[38] from video footage of soccer play, as well as various image processing and filtering techniques, can be used to identify each player's location on the pitch. The individual's movements can then be tracked on the video by computer software through either manual operation or automatic tracking processes, at every single moment of the game. The technology is facilitated by supportive information such as shirt colour, optical character recognition of shirt numbers and prediction of running patterns to help maintain accurate player identification and tracking. During set-play actions such as corners or free- kicks, play can become compressed so such supportive information may be required to help maintain accuracy in tracking individual players. For a further description of the workings of video-based player tracking, see Di Salvo et al.[35] and Barros et al.[25]

Despite being largely computer automated, these pioneer tracking systems still require some manual input as well as continual verification by an operator to make sure that players are correctly tracked by the computer program. Automatic tracking may not be possible due to changes in light quality as well as occlusions due to a crowd of players gathering in a small zone at one time. In this case, it becomes necessary for an operator to correct these mistakes manually. Nevertheless, the Dvideo system designed at the University of Campinus, Brazil, is reported to have a 95% automatic tracking rate.[25] However, this system used a lower number of digital film images per second (7.5 hertz) compared to other video tracking systems such as AMISCO Pro in order to reduce the amount of data to be processed. This footage would lower its capacity to measure in detail, changes in running speed and direction. Work has also shown when determining the positions of soccer player from digital video footage that a low frequency images per second (2 Hz for example) may lead to a higher rate of error when calculating distances covered.[39] A recent DLT-based video-tracking system used to analyse the work-rates of professional Japanese players reportedly requires the utilisation of a single digital camcorder, making it more cost effective in comparison to multi-camera systems.[40] However, it also employs a limited number of image frames per second (2Hz) and requires manual frame-by-frame analysis of play. Furthermore, no information is available on the time required to analyse physical performance using this system and its reliability has not been investigated. Most of these video tracking systems used to date in elite soccer do not provide real-time analysis, the results generally being available within 24-36 hours of the final whistle. This time lag, however, seems acceptable for the many top-level clubs who have adopted these systems over the last decade.

The most recent commercial video-based automatic tracking systems such as DatatraX[41] and the TRACAB Image Tracking System[42] now provide real-time analysis albeit using similar tracking methodologies based on multi-camera and image processing techniques. According to commercial information available from the supplier,[42] the TRACAB system exploits enhanced techniques for video image processing and by using mathematical algorithms designed for object tracking and guiding missiles in the military industry. Similarly, DatatraX uses pixel recognition to track the players automatically and voice recognition to code the match specific events. Three manual operators are required to manage the process, two people to correct tracking mistakes in real-time for each team and one to perform the voice recognition coding procedure. The main benefit of both systems is that they provide coaches with a high level of instantly available detail concerning match performance, allowing informed decisions to be made during the match that may influence the eventual outcome. Although both companies claim to have high levels of accuracy for their systems, the validity and reliability have again yet to be scientifically established.

A major advantage of both the manual and automatic video-based tracking systems is that they do not require players to carry any electronic transmitting device. Carrying such material is strictly forbidden by various governing bodies of soccer. Their major disadvantage, however, resides in the high costs and the necessity of installing multiple cameras and a computerised network with at least one dedicated operator to organise the data collection and further operators to perform the analysis.[35] This apparent lack of portability means that teams can only employ these systems for matches in their home stadium.

However, the DatatraX system can apparently still be operated at away venues using two portable cameras from the stadium gantry and some mathematical corrections for errors created when players are further away from the camera lens. In addition, the introduction of reciprocal contractual agreements has led to clubs being able to access work-rate data when playing in opposition stadia which also equipped with their same service providers system.

Electronic transmitting devices have previously been described as the future of the computerised analysis of sport and are taking match analysis one step further in terms of data processing speed and accuracy.[8] These wireless and telemetric communication systems allow remote real-time data acquisition and record movements and positions of every player and the ball up to several hundreds times per second. A small lightweight microchip transmitter is worn in clothing or in a strap around the chest of each player. The identification signal of the transmitter is registered in a fraction of a second by several antennae positioned around and outside the playing field. The reception time of the signal source to the recipient is synchronised and as a result the position is determined. These data are relayed to a central computer and immediately processed for immediate analysis. The LPM Soccer 3D® system developed by INMOTIO in collaboration with PSV Eindhoven Football Club provides positional measurements over a 100 times per second leading to the production of highly detailed and previously unavailable information on player accelerations, decelerations and changes in direction.[43] This system also combines physical data with physiological measurements through heart-rate monitoring (built into the transmitter) as well as synchronised video footage to provide a comprehensive picture of the daily, weekly and monthly workloads experienced in training. Constraints of such systems include potential electronic interference, strength of the electronic signals from players due to the size of playing surfaces and the energy source to accomplish this signal transfer.[24] Furthermore, no investigation has yet attempted to determine scientifically the reliability of these electronic measuring systems.

Global Positioning Technology (GPS) has also begun to impact on the analysis of performance in elite soccer. As with electronic transmitting devices, its use is restricted to measuring player efforts during training sessions or friendly matches although it is now permitted in competition for other codes of professional football such as Australian Rules Football. The technology of GPS requires a receiver to be worn by each athlete which draws on signals sent from at least four earth orbiting satellites to determine positional information and calculate movement speeds, distances and pathways as well as altitude.[44] The latest SPI Elite GPS receiver designed by GPSports has been adopted by several teams competing in the English Premier Football League and is provided with propriety software for simultaneous analysis of data from all players.[45] Similarly, in Spain a company known as Real Track Football has also made commercial GPS systems specifically available for soccer teams.[46] It is possible to purchase kits with over 11 trackers in a set, with potential applications to training contexts and to the other football codes.

Although automatic tracking devices have established methods of providing data on work-rate characteristics such as total distance run and time spent in various categories of movement, the latest systems are advancing the analysis of sports performance through a superior level of co-ordinated biofeedback to accompany the traditional physical feedback. In this respect, the SPI Elite GPS is capable of monitoring heart rate and recording information on the frequency and intensity of impacts such as tackles and collisions by means of a built in tri-axis accelerometer which also depicts three direction types (forwards, sideways and backwards). The accuracy and reliability of GPS receivers are relatively high as results of a test of accuracy showed a 4.8% error rate in measuring total distance covered and a test of intra-tester reliability reported a technical error of measurement (TEM) of 5.5%.[24] These

TEM values can therefore be taken into consideration when interpreting the raw data. Recent technological developments have also led to increased miniaturisation and increased portability.[47] An alternative device known as the Biotrainer is also being produced by Citech Holdings Pty Ltd.[48] This system is described as a disposable patch, similar to a band-aid, worn by the athlete which provides GPS tracking data both indoor and outdoor as well as reportedly supplying real-time biofeedback on nine physiological outputs such as heart rate, body temperature and hydration level. Nevertheless, GPS receivers are still subject to problems of accuracy as the magnitude of error depends on land configuration and the number of available satellite connections. Furthermore, in previous systems, data were usually collected at one measurement per second which was insufficient in frequency for measuring detailed variations in speed and direction. However, the latest GPS receivers[45] are now reportedly capable of logging data at frequencies of 50 measurements per second. Although this development has potential to provide much more precise data and could be very useful in speed and agility assessments, the volume is therefore 50 times larger and creates potential problems in unit size, storage capacity and battery life. This new facility may also require extra manual work in data interpretation which could ultimately delay any feedback. It therefore becomes the challenge for developers and researchers to investigate the optimal measurement frequency to provide appropriate data. Although, the price of individual GPS units means they are now more within the reach of the non-elite player, purchasing enough receivers to cover the needs of every member of a squad of players may still be beyond all but the wealthiest of clubs.

2. Main issues in contemporary motion analysis technologies

2.1 Validity, Objectivity and Reliability

The methodologies employed to collect motion-analysis data must meet the requirements for scientific criteria for quality control.[8] These specifications include reliability, objectivity and validity. There is a need for a detailed analysis of the errors associated with the analytical procedures used by the systems.[27] To date, many of the contemporary commercial motion-analysis systems already discussed in the present review have not undergone satisfactorily quality control checks. Other than manufacturers' statements, very little scientific evidence exists to verify validity claims.[24] The lack of a single validation test protocol considered the 'gold standard' for testing the validity, reliability and objectivity of motion analysis data collection methodologies, may be one reason for this low number of validation studies. Any validation protocol itself must also have undergone quality control testing and be easily transferable across the range of systems currently used in elite soccer. However, there are various issues that can play a part in preventing researchers from designing and undertaking validation projects. For example, researchers may face logistical problems such as gaining access to test systems using the playing facilities within soccer stadia. The current laws of the game also prohibit players from wearing electronic equipment for measuring the reliability of movement measurements within competition conditions.

If human input for data collection is still required when using a contemporary system, inter-observer and intra-observer reliability testing of the same competitive match(es) must be undertaken to assess measurement error. When automatic data collection processes such as tracking movement on video or via a GPS are employed, it is important to test the intra-reliability of the system itself by analysing the same match several times. It is also necessary to check the reliability of data by examining within-subject (player) error across a number of games, which has rarely been achieved in the literature.[27] Similarly, to ensure full validation of a system, comparison of the measurements obtained using contemporary analysis software and equipment should be made with those obtained from already established methods. There are also statistical considerations to be taken into account when examining the reliability of a system. The statistical procedures used to compare reliability measurements and the amount of disagreement between measurements deemed to be acceptable must be suitably defined at the outset of the study. In addition, the statistical test selected should aim to show agreement between observer measurements rather than differences. For more detailed information on reliability checks in match analysis, see review by Drust et al.[27]

A validation procedure of a commercial match analysis system was designed by Di Salvo et al.[35] to compare data on running speeds of soccer players obtained via video-based tracking against those obtained from timing gates measurements. The subjects were asked to perform a series of short runs at different determined speeds over several marked courses. Correlation coefficients and absolute reliability coefficients between velocity measurements over runs of 50 and 60 metres obtained from both systems were high (r=0.999; total error 0.05, limits of agreement 0.12) indicating that the system can be confidently used to provide an accurate recording of running speed during soccer play. However, as this type of semi-automatic tracking system requires manual input, it would have been beneficial to have compared the reliability of data obtained from the runs by distinguishing between human and automatic tracking of the subjects' movement. Similarly, an intra- and inter-observer reliability study comparing the data from the whole duration of several matches played under real competitive conditions is necessary to gain an idea of the overall reliability of the system output. Validation protocols of video-based tracking systems which use marked courses or zones to evaluate running speed and distance, should ensure the inclusion of all the different types of running actions previously identified by means of motion analyses. For example, as well as running in a straight line, moving in backwards and sideways directions, turning, shuffling and jumping actions and dribbling should be carried out by test subjects. Similarly, adding and removing players to the area analysed are advisable to ensure analysis conditions are close to those observed in real competition. Validation procedures should also be carried out under different climatic conditions (such as variations in light) as environmental variables can affect the quality of the video recordings used for computer tracking. [8]

It is important to assess the reliability of data for each individual class of movement intensity. In a previous study, data obtained from manual coding using a computer interface of the time spent in high-intensity running by English Premier League players (during the same match) were compared between two different observers.[49] There was a relatively low level of inter-observer reliability between measurements and a significant systematic bias between observers for the percentage time spent performing high- intensity activity ($t59 = 2.7$, $P < 0.01$) with one observer recording much higher values than the other observer. The validation of a motion-analysis system employing photogrammetric techniques to obtain the x- and y-positional coordinates from digital video images of soccer games has recently been achieved.[50] The test subjects were instructed to run at paced speeds over follow pre-established trajectories with defined distances and the measurements were subsequently compared to the distances obtained by means of the photogrammetric method. Results showed an error in distance measurement of less than 1.5% for each of the movement categories. In the same study, the accuracy of the system to determine general position and distance of targets was also determined. For this process, 40 markers were randomly distributed over a football pitch and the pitch was filmed from the main stand. The position of these markers was determined using a pre-calibrated 50-m measuring tape and later obtained through digitization of the frames. A low root mean square error for reconstruction of the coordinates in the x- and y-axis was obtained (0.23 and 0.17 m respectively). Similarly, the authors reported an error of less than 2% for reconstructing the distance between two individual coordinates. Whilst the accuracy of this system in determining distances covered by players over set running courses seems sufficient, it would also have been pertinent to compare results from whole competitive games against hand-based motion-analysis methods[11,20] which have previously demonstrated high levels of reliability and validity (coefficients >0.9). This validation requirement should apply even if the measurement error in novel experimental technology may be less than that for a reference method such as that used by Reilly and Thomas[11].

In a recent comparison of global positioning and manual computer-based tracking systems for measuring player movement distance during Australian Rules Football games,[24] a range of ways was used to determine the validity and reliability of these methods for measuring distance covered. Validity checks for both systems were undertaken by comparing the data obtained by each system for distance covered by players running over a pre-determined marked circuit against the distance calculated by a calibrated trundle-wheel pedometer. Intra-tester reliability of the distance calculated by both systems was also assessed over a range of running courses. Inter-tester reliability of distance covered from the tracking system was assessed by comparing data obtained in both competition and over a marked course. A comparison of the two tracking technologies for measuring movement distances was performed when data were collected simultaneously. Players wearing a GPS receiver ran around circuits of different lengths and geographic layout whilst two observers simultaneously tracked their movements. A calibrated trundle-wheel pedometer was then used to verify the actual track distance following the completion of the circuit. Both the GPS and the tracking system were found to overestimate the true distances (on average less than 7%) travelled by players. The authors considered that these relatively small overestimations combined with an acceptable level of relative technical error of measurement both within and between trackers should not prevent the use of either of these technologies to monitor player movements. However, this particular manual tracking system relies on the subjective skills of observation and visual judgement on the part of the tracker. An omission was therefore the lack of testing of the reliability of data for the individual classes of movement and notably for movements at high-intensities which tend to be overestimated.[49]

2.2 Interpretation of Results

Ultimately, contemporary measurement systems are based upon gathering data concerning the events in a match and the physical efforts of the players. In terms of the latter, the workload of the players is based around data collected on speed, distance and time and complied to form an assessment of physical exertion. However, the distance covered by players has been an area which has been adversely affected by methodological differences. This includes a lack of standardised approaches and a need for a more rigorous analysis of data. Furthermore, it is important to recognise that physiological evaluation is limited due to the fact that the method makes the general assumption that energy is expended only when the player travels to a new location on the pitch, with sprinting usually classified as the most exertive motion. This is an important issue as this provides an underestimation of total energy expenditure of the players as several high intensity movements are performed in soccer match-play without obvious changes of location on the pitch, for example a vertical jump, competing for possession or a high-speed shuffle. Furthermore, many contemporary systems assume players only travel in a forward direction and therefore do not provide detailed information on backward, sideways or other unorthodox movements which have been reported as more physiologically demanding than movements performed forwards at the same velocity.[8,9] To this end, other parameters such as agility (acceleration, deceleration, changing direction), physical contact, and 'on-the-ball' activity also contribute to physiological energy expenditure, and critically, the sequence in which these activities happen. Considering the dynamic nature of movements in soccer, this lack of information restricts a truly valid and thorough assessment of a player's expenditure in match-play. However, if the file containing the raw positional data can be accessed as in the case of contemporary GPS receivers for team sports[45], then algorithmic filtering may be employed to obtain these missing data.

Some major limitations exist with systems that centre on measuring distance covered through measurement of time spent in motion at different speeds. To this end, there is an inconsistency in the agreement of what speed thresholds to be used in soccer with, for example, values for sprints set at speeds of >30 km/h[15], >23 km/h[35] and >24 km/h[51] having been reported. These discrepancies in the definition of speed thresholds make it difficult to compare work-rate data between different studies. However, the very latest software used to analyse work-rate data allows end-users to define their own speed thresholds permitting a more objective means of analysing and comparing the physical efforts of players according to different intensities of movement.[34]

One of the main concerns with motion analysis data is the stringency of the speed thresholds used to categorise the motion types. Essentially, results are created by objective measurement systems by acknowledging the frequency of the occasions that a player enters a certain threshold and then the time that player spends within that threshold and subsequently calculating distance covered. However, if a player were to perform a single effort at speeds on the boundary of a particular threshold, it is quite possible that the data reveals that multiple efforts have been performed if the boundaries have been crossed. For example, if a threshold for 'sprinting speed' was set at efforts >24 km/h and a 1Hz (second-by-second) raw output over 7-s reads 22-23-24-26-23-25-23, it is interpreted that this player sprinted on two occasions when realistically (subjectively) it could and perhaps should be only interpreted as once. Furthermore, it should also be noted that the interpretation here is that the player 'sprinted' for a certain duration, although this only accounts for the time spent >24 km/h. This result is easily misinterpreted as it fails to account for the speeds below >24 km/h that account for the acceleration phase of this ‘sprint’. Instead, the interpretation should be that the player achieved speeds >24 km/h for a certain duration. This fact therefore applies to all motion category thresholds used to evaluate performance as it will also affect total frequencies and mean durations of each motion type. One way of combating this error is to filter or smooth the data using mathematical algorithms to make inferences on the data. For example, this may also be used to illustrate differences between rapid or gradual accelerations or decelerations by determining how quickly a player has moved through different threshold zones. However, this use of multiple equations within a data set requires further validation of the system.

Similarly, although differences have been identified in total distance covered in various levels of performance, with higher levels of performance corresponding with higher distances[15], caution must also be taken when assessing a player’s match performance based on the total distance covered. In this respect, players may be inefficient with their movement and in essence ‘waste energy’ by performing unnecessary movements which may actually be detrimental to the team tactic but result in a large distance covered which may therefore be open to misinterpretation. Alternatively, a player may remain in low-intensity motion for a significant percentage of a match through being highly efficient in the movement selection. This would produce a below average total distance covered, number of sprints, workload and work-rate yet this player may have had the highest impact on the team’s performance. In turn, an opposing player who is responsible for marking this type of player may also appear to have done less workload than normal.

Finally, the overall reporting of results is usually provided macroscopically and in isolation. Traditionally, values for total overall distance, as well as total, frequency and mean distance, time and/or percentage time spent in each motion type are reported.[9] This huge amount of data for each match can be a challenge in itself for professional soccer staff to make true assessments of match performance, monitor workloads and plan appropriate physical fitness regimes. In this respect, a recent programmed exercise protocol for netball based on mean 'bursts' of high intensity activity and 'recoveries' of low to moderate intensity based on time-motion analysis proved to be ineffective in enhancing match-play specific physical fitness.[52] To this end, a full range of 'bursts' and 'recoveries' are sought to design physical conditioning programmes that are specific to soccer match-play. Consequently, ratio scales should be used to present data based on levels of intensity.[53]

The holistic approach of reporting work-rate data ignores the interaction between and within motions, movements and playing activities. Therefore, it is also important to perform temporal pattern detection to identify patterns within the data. In this respect, the detection of patterns that are not identifiable through simple observation has great benefit not only in soccer match-play variables but also in establishing the specific physical performance demands.[54] A temporal pattern (T-Pattern) is essentially a combination of events where the events occur in the same order with the consecutive time distances between consecutive pattern components remaining relatively invariant with respect to an expectation assuming, as a null hypothesis, that each component is independently and randomly distributed over time. The method of T-patterning has already been employed to establish playing patterns in soccer by identifying complex intra- and inter-individual patterns for both individuals and teams using the detected behavioural patterns in combination with elementary statistics.[55] Figure 1 displays a player's movement pattern which identifies a varied range of motions. This particular pattern begins with the player shuffling backwards and then sprinting forwards and slowing down in which he shuffles at high intensity. From this point he skips sideways left at low intensity, turns left and jogs forward at low intensity, gradually increasing pace into a run and changing direction by moving diagonally left to complete the complex pattern. Preliminary investigation of pattern complexity between player positions suggests that a higher number of different patterns and pattern occurrences are detected for defenders than forwards and midfielders.[54] The same also seems to apply for length of patterns. These findings, and their significance, need further examination, although they could be very useful for creating specific training programmes according to individual positional requirements.

3. Contemporary motion analysis research

3.1 Analysis of data on overall work-rate

There is a growing interest amongst practitioners within elite soccer in the work-rate characteristics of soccer players using the data obtained from the various techniques and technologies described in the previous section. Generally, the overall work-rate in field sports can be expressed as distance covered in a game, given that this measure determines the energy expenditure irrespective of the speed of movement and the individual contribution towards the total team effort.[9] This activity can then be broken down into discrete actions for each player across the whole game for classification according to intensity, duration and frequency. Although caution should be made when comparing the results of various studies due to the differing methodologies employed to obtain data, contemporary outfield male elite soccer players cover on average 9-12 km per match,[15,25,56,57] whilst some players may attain distances of around 14 km (see Table II).[35,58] Observers of elite female soccer players have generally reported lower results than elite male players in terms of overall distance covered (8.7-12km) but a similar level of physiological strain.[16,19,59-61]

From a coaching perspective, it may be of value to compare the overall distance run by individual players with that of team mates or opposition players to ascertain relative exertion rates. However, this distance may not be a fair reflection of a player’s performance as playing style, team formation, technical actions and tactical role also influence overall work-rate. For example, Rienzi et al.[62] presented evidence that the distance covered by South American players was about 1 km less than the output of professionals in the English Premier League.

The authors suggested that the higher sustained pace by players in the English game could explain this disparity. However, no motion analysis study has yet been conducted to compare the distances run by elite soccer players belonging to teams across a larger range of national championships.

Measuring the total distance run may also help in examining the evolution of work-rates over several seasons to determine if the physical requirements of the game are the same and if current training programmes and fitness tests are still optimal. Professionals in the English Premiership tend to cover greater distances during matches than those in the former 1st Division (pre-1992) which has had obvious consequences on contemporary fitness training programmes.[13] Data presenting the total distance run by 300 professional European midfield players have recently confirmed this upward trend.[34] Although contemporary elite players are running greater distances than in previous years, the effects of playing position on distance run is consistent across the last three decades.[9]

A pertinent coaching issue may be to look at a division of the total distance run into data for defending (opposition in possession) and attacking (own team in possession) play. This comparison may help determine whether players are working as much in a defensive role as they are in attack. At present, this factor has not been examined in the scientific literature although results are likely to be affected by the tactical role of players. For example, a ‘holding’ midfielder deployed on mainly defensive duties will no doubt cover less distances compared to other midfielders when his/her team is attacking. Another concern may be to identify if physical demands are comparable between different levels within elite soccer, for example between the various divisions in professional leagues. A comparison of professional Italian and elite Danish players showed that the former covered a significantly higher distance during games.[15]A motion analysis study of the total distance run by the same elite females competing at both national (for their clubs) and at international level (for their national team) established that these players ran significantly greater distances when competing at international level.[19] The observation highlights the need to take the level of competition, and perhaps the importance of the game, into consideration when interpreting data on motion analysis of match-play.

It is not feasible to use the total distance run to compare the overall physical contributions of players when there is a difference in the overall duration of games. For example, different categories of age in youth soccer generally play games of different time length and other types of soccer such as futsal are limited to a total of 40 minutes play. An alternative means of comparing the overall physical contributions of players is to calculate a relative measurement of performance by correcting the absolute value (total distance covered) for the match, to a minute by minute analysis of distance run. Recent studies have shown that the intensity of play in professional futsal[63] was higher compared to elite players competing in the Australian National league[30]. The futsal players covered on average 117 meters per minute compared to 111 meters per minute for the Australian players indicating that the intensity of the game of futsal is higher than that for traditional soccer games.

3.2 Categories of movements

In field sports such as soccer, movement activities are generally coded according to their intensity which is determined by the speed of actions. When evaluating performance, the frequency of each type of movement and the time spent or distance run in each movement can be analysed. The main categories generally used to analyse soccer work-rate are classed as standing, walking, jogging, cruising (striding) and sprinting. These categories have recently been extended to include other activities such as skipping and shuffling.[26] Most activities in soccer are carried out at a sub-maximal level of exertion, however, there are many other game-related activities which must be taken into account such as alterations in pace, changes in direction, execution of specific game skills and tracking opponents which will be examined later in this review. Elite players spend the majority of the total game time in the low-intensity motions of walking, jogging and standing.[13,15,34] In comparison, high-intensity efforts (cruising and sprinting) constitute around 10% of the total distance covered.[3,9] This finding compares to analysis of performance in professional futsal games where the percentage of the total distance covered spent in high intensity is almost a quarter (22.6%) and can, on occasions, exceed a third.[63] Research on females has shown that these players spend more time in lower intensity activities compared to males which may be explained by biological differences such as endurance capacity.[64]

In soccer, activities at lower levels of intensity such as jogging and walking tend to dominate work-rate profiles. However, the impact of high-intensity efforts in match-play cannot be over-emphasised and it has been suggested that this feature may be the most appropriate means of evaluating and interpreting physical performance.[16,56] Measurement of high-intensity exercise, for example, every 5 min during the course of the game, is an alternative way for coaches to evaluate overall work-rate. High-intensity exercise is a constant feature across matches[9] and games are often won or lost on successful attempts at scoring carried out at high speed.[64] The high-intensity category of work-rate includes the addition of cruising and sprinting actions which are pre-determined according to running speed. In elite soccer, players generally have to run at a high-intensity every 60 s and sprint all-out once every 4 min.[13] However, Di Salvo and co-workers[34] presented evidence that the number of sprints made per player ranges greatly (from 3-40). These authors suggested that this finding strongly depended upon individual playing position.

Because of the intermittent nature of the game, performance can be enhanced through improving players’ ability to perform high-intensity work repeatedly. The timing of anaerobic efforts, their quality (distance, duration) and the capacity to repeat these efforts, whether in possession of the ball or without, are crucial since the success of their deployment plays a critical role in the outcome of games.[8] Players in successful teams competing within the same elite league were reported to perform more high-speed running and sprinting in the most intense periods of the game and more sprinting over the whole 90 minutes compared to less successful teams.[65]

In elite soccer, the average distance and duration of sprints are short as evidence has shown that these activities are rarely more than 20 metres in length and tend to last around 4 seconds[3,34,57]. These findings imply that when a player is required to sprint, his or her acceleration capabilities may be of greater importance than their maximal running speed as the tactical demands of the game probably render it unnecessary to attain maximal speeds. Improving performance in these actions will help players in many aspects of their game, such as being first to the ball or getting away from a marker. For example, if a player tends to lose out by poor acceleration or lack of speed over a short distance, the trainer could suggest an individual speed development programme. A more detailed motion-analysis study on the characteristics of sprint patterns of players during competition could be beneficial. For example, no information is available on whether sprints commence from a variety of starting speeds such as a standing start or when jogging and, if so, does such differentiation also exist between playing positions. A recent study on elite rugby union players showed that forwards commenced these actions most frequently from a standing start (41%), whereas backs sprinted from standing (29%), walking (29%), jogging (29%), and occasionally striding (13%) starts.[66] Practitioners designing conditioning programmes would no doubt benefit from this information by ensuring that training sessions involve the actual movement patterns performed in matches. The programme can then provide sufficient overload through careful manipulations of the match demands in preparation for competition. This may involve alterations in playing time, size of pitch or number of players involved in order to increase the training intensity.

In soccer, only a small percentage of the total distance covered by players is in possession of the ball. Nevertheless, evidence from a field test of maximum oxygen consumption has shown that running with the ball significantly raises oxygen consumption and energy expenditure and should be taken into account when evaluating player efforts.[67] The vast majority of actions are “off the ball”, either in running to contest possession, support team-mates, track opposing players, execute decoy runs, counter runs by marking a player, or challenge an opponent. These actions often require frequent changes in movement activities such as accelerations and decelerations, changes of direction, turns, unorthodox movement patterns (backwards and sideways runs) and significantly contribute to additional energy expenditure.[8] The latest GPS systems are reported to enable the quantification of the stress placed upon players from accelerations, decelerations, changes of direction and impacts, permitting the individualisation and optimisation of exercise and recovery programmes[45] although this claim has yet be scientifically validated. A challenge to future researchers is to investigate and combine data on both contacts, collisions and tackles and on motion analysis categories into a single index of training and competition loading.

Two studies have recently been undertaken to investigate deceleration[68] and turning[69] movements in professional soccer. Players were shown to perform an average of 54.1 deceleration movements and 558 turning movements, during ‘purposeful movement’ passages from FA Premier League matches. The authors suggested that both these types of actions are a common and highly important part of the modern game and there is a particular need for developing specific deceleration and turning exercises in strength and conditioning training sessions. An investigation into whether the inclusion of an enforced deceleration phase on repeated sprint efforts would cause greater fatigue and slower sprint times compared to efforts undertaken without this phase may be of interest in further understanding match performance and optimising fitness training programmes.

The activity profile of players may be influenced by the style of play used by individual clubs and by regional differences. Such regional differences in performance are important as players moving between countries will probably need time to adapt both physically as well as tactically to the particular style of the different leagues. Nevertheless, there is still a lack of studies attempting to address either cultural or geographical differences in the work-rate pattern[27] especially at international level or between various professional leagues. Similarly, motion-analysis research on the work-rate performance characteristics of female and in particular younger players is still relatively limited in the literature. Results of a recent study on elite youth Brazilian players belonging to under 15, under 17 and under 20 age groups indicated significant differences in both overall work-load and individual playing positions according to player age.[70] The age of players should therefore be a relevant factor when evaluating work-rate profiles.

3.3 Determining positional demands

Understanding the work-load imposed on top-level soccer players according to their positional role during competitive matches is necessary to develop a sport specific training protocol.[34] Contemporary data[13,15,34] generally confirm the previously identified trend[11,20] that midfield players generally cover greater distances per game than defenders or forwards. Goalkeepers usually cover much lower distances (around 4 km) per match. However, individual differences in the distance covered are not just related to a division into basic traditional team positions of defenders, midfielders and attackers. For each playing position, there may be a significant variation in the physical demands depending on the tactical role and the physical capacity of the players. For example, Barros et al. [25] and Di Salvo et al.[34]

showed that in professional Brazilian and European soccer, fullbacks ran significantly further distances than central defenders. Similar results between defensive positions have also been obtained for international female soccer players.[61] These results highlight that individual differences in playing style and physical performance should be taken into account when planning training and nutritional strategies.[71]

Again, marked differences in the intensity of various running activities exist across the various playing positions. A detailed analysis of English Premier League players showed that playing position (defender, midfielder and attacker) had a significant influence on the time spent sprinting, running, shuffling, skipping and standing still. [21] Rienzi et al. [62] observed that defenders perform more backward running than strikers. Similarly, it has been reported that Premier League midfielders and strikers engaged in significantly more of the 'other' type of movements (jumping, landing, diving, sliding, slowing down, falling and getting up) compared to the other positions. [21]

Analysis of work-rate categories also suggests that training and fitness testing should be tailored specifically to positional groups (e.g., separation between central and external midfielders) rather than simply differentiating between forwards, midfielders and defenders as each positional group has its own unique physical demands. For example, a variation in the distance covered at high intensity of 1.9 km among the midfield players in the same game has been reported.[15] Variations in work-rate between players may imply that not all positions may be taxed to full capacity in every game. Findings from a study comparing 123 professional European players showed that central defenders sprinted significantly less distances than fullbacks.[34] A large-scale study on professional Spanish soccer reported a significant difference in the total distance run in sprint by wide midfielders compared to central midfielders.[72] This research again demonstrates the need for a criterion model in order to tailor training programmes and strategies to suit the particular needs of individual playing positions. Research dividing the high-intensity efforts of players for defending (opposition in possession) and attacking (own team in possession) play would be pertinent to determine whether positional role determines the physical contribution of players according to whether their team is in possession or not.

Motion analysis and its application to training must also take into account the relationship between the physical and technical demands of games. For example, match data on professional English players show that forwards tend to receive the ball more frequently when cruising and sprinting than defenders and midfielders, indicating that the ability required to implement technical skills at pace when attacking is important for this position.[73]

3.4 Use of motion-analysis in studies of fatigue

In motion-analyses of soccer, data may be split into distinct time frames to help establish if work-rate varies with time or task. According to analyses and performance measures during elite match-play, fatigue manifested as a decreased performance seems to occur at three different stages in a game: (1) after short-term intense periods in both halves; (2) in the initial phase of the second half; and (3) towards the end of the game.[56] Simple comparisons of the overall work-rate between first and second halves of matches can indicate the occurrence of fatigue although it may be more closely identified if activities during the game are broken up into 15-min or 5-min segments.[8] Minute by minute analysis of work-rate throughout a game has also been employed as a possible means of identifying a drop off in physical performance.[25]

In soccer, the evidence of a difference in the total distance covered between halves is inconsistent and a significant decrement does not necessarily occur in all players especially if players operate below their physical capacities in the first half. Therefore, a simple comparison of the overall distance run per half may not be a valid means to allow interpretation on whether or not a player has experienced fatigue. Nevertheless, Table III presents data from various studies comparing the total distance run by elite soccer players for the two halves of the game. An average difference of -3.1% in the total distance run between halves (range -9.4% to +0.8%) can be observed across all studies on elite soccer. The largest difference between the total distance run in the first half compared to the second half was reported for players participating in the Australian National Football League.[30] Professional Brazilian players have also been reported to cover significantly more distance in the first half,[25] whereas more recent data showed no significant difference in work-rates between halves for elite Spanish players and other European players participating in Spanish League and UEFA Champions League games.[34] In this latter study, the data may have been confounded as no mention was made as to the inclusion of substitutes and the effect their work-rates may have had on the results. Nevertheless, individual teams and players may pace their efforts in order to finish the game strongly. A comparison of total distance run between match halves of the winners (Barcelona) and losers (Arsenal) of the 2005-06 UEFA Champions league final showed that the Spanish players covered more distance in the second half compared to the first half (5121 m versus 5218).[74] In contrast, players belonging to the losing team who completed the whole match, covered slightly less ground in the second half (5297 m versus 5252 m) compared to the first half suggesting they may have been forced into a fatigued state. In this study, the data may have been confounded as Arsenal was forced to play with ten players for the majority of the game due to the exclusion of the goalkeeper.

A 14% slower overall speed in the second half of the game when compared with the first half has been reported in elite Australian soccer players.[30] This result was attributed to fewer observations of the low-intensity movements (9.0% less walking and 12.4% less jogging) and more stationary periods. Engagement in game events such as kicking and passing was also 11.2% less frequent in the second versus first half of games. Similarly, a recent study of work-rates in professional Italian players examined the effects of fatigue on technical performance. [75] A significant decline between the first and second half was found for both physical performance and some technical scores (involvements with the ball, short passes and successful short passes). Minute-by-minute analysis of total distances covered by Brazilian players revealed significant differences after the fifth minute of the game with highly significant differences after the eighth.[25] The authors suggested that this more detailed analysis may allow a better understanding of fatigue. However, these results should be treated with caution as it is highly unlikely that players experience fatigue so soon during a match. This reduction in performance is more likely to be linked to play settling down after the frantic first few minutes of the game where engagement is at its most intense. Indeed, a study by Rahmana et al.[76] yielded evidence that the majority of critical game incidents and the highest intensity of activities were observed in the first 15 minutes in comparison to any other period of the game.

A significant reduction in the distance run in exercise of medium-intensity[34] and high-intensity[33, 77] between halves has been reported in players competing in elite European soccer games and tournaments. In elite Scandinavian soccer players, the amount of high-intensity running was lower (35-45%) in the last 15 min than in the first 15 min of the game with more than 40% of the players having their lowest amount of intense exercise in the last 15 min.[15] This trend was confirmed in a study of elite female players where a marked decrease in the amount of high-intensity running within each half was observed and 13 out of 14 players did their least amount of high-intensity running in the last 15-min period of the first or second half.[16] Similarly, GPS-based tracking of activity patterns in professional Futsal players has shown that during the last period of the game, the number of bouts of high-intensity exercise significantly decreased.[78] However, the total distance covered or the amount of sprinting may be unaffected between playing halves in certain players[25] and the distance covered in high-intensity activities may even increase between halves[79] and in the last few minutes of the game.[8] Players carrying out fewer actions at low or moderate intensity may be ‘sparing” their efforts for the final few crucial actions as their energy levels become depleted. Some players demonstrating no decrease in performance between halves or in the final quarter of the match may have paced themselves in order to finish the game strongly. A pertinent study may be to examine whether the type of competitive match affects work-rate and any subsequent reduction in performance. For example, it would be relevant to determine whether players tend to work harder or demonstrate greater fatigue during Cup games compared to league games or when playing against teams from lower standards of play.

Another method of examining fatigue may be to concentrate on the maximal speed or duration of individual sprints to determine whether a player’s sprint performance is declining (e.g. is the player less quick?) towards the end of the match. The maximal sprint speed of an international midfield soccer player averaged every 5 min throughout the match has been reported to decrease significantly towards the end of the match.[79] However, as the data were drawn from a case study of one player, it is difficult to draw conclusions about the relationship between maximal sprinting speed and fatigue. In addition, soccer players may not always reach maximal speed during sprinting actions due to the tactical demands of the particular situations restricting the length of these runs. Work-rate analysis to determine whether there is a decrease in the capacity to accelerate rather than in maximal sprint speed towards the end of a game may be a more pertinent means of evaluating the occurrence of fatigue although no study has as yet examined this feature. Nevertheless, work-rate information indicating fatigue towards the end of the game could lead the coach to change tactics or even make a substitution to avoid the opposition exploiting this emerging physical weakness. Substituting players before the onset of fatigue towards the end of the game may restore the imbalances in work-rate. Substitute players have been shown to cover significantly more ground at high-intensity during the final 15 min than the other players already present on the pitch.[15] The very latest video-tracking systems allow coaches to analyse work-rate in real-time and make objective evidence-based decisions when attempting to identify players who may need replacing.

Evaluating fatigue during match-play may lead coaches to examine if the intensity of the following sprint is affected by the intensity of the previous sprint (e.g. if the sprint is long and at maximal speed). It may also be useful to look at the relationship between successive sprints and whether the intensity of the subsequent activities is affected e.g. if moderate intensity exercise has more of a negative impact on ensuing sprint performance than efforts at low intensity. Individual sprints often depend on the requirements of the game situation, and particularly the recovery allowed by the unpredictable nature of play. After the 5-min period during which the amount of high-intensity running peaked, performance was reduced by 12% in the following 5 min compared with the game average in elite players.[15] Further data on 4th Division Danish players have shown that performance of the third, fourth, and fifth sprints carried out after a period of intense exercise during the first half was reduced compared with before the game.[80] This finding together with the observation that sprint performance measured at the end of the first half was the same as before the match, provided direct evidence that fatigue occurs temporarily during a game.

Fatigue may be evident as a prolonged recovery during the game, for example, increased time spent in low-intensity activities. The reason for this decline in performance could be repeated pressure from the opposition on an individual player, eventually leading to an inability to respond to game demands. Rampinini et al[81] recently observed that the work-rate of a team of professional soccer players was significantly influenced by the activity profile of opponents. Fatigue during match-play may be transient, the player recovering once there is respite from the opponents. In this instance, tactical support for the player targeted is vital so that the offence from the opponents is not relentless. However, the same study[81] showed that the total distance covered and the amount of high-intensity running during matches were higher against the ‘better’ opponent teams compared to ‘lesser’ opponent teams. This finding suggests that players can increase or decrease their work-rate according to both the demands of individual matches and to the quality of the opposition.

A study of the relationship between match scoreline and work-rate in soccer showed that players performed significantly less high-intensity activity when winning than when the score was level.[82] Players also performed significantly less high-intensity activity when losing than when the score was level. The authors suggested that players on teams that are winning relax their work-rate, allowing opponents back into the game, and that players on teams that are trailing may lose the motivation to maintain a sufficient work-rate. When a team is ahead however, forward players perform significantly more exercise although this only appears to relate to the ~10min period directly after a goal has been scored and the elevated work-rate is not ultimately sustained.[83] This phenomenon merits further investigation, such as the impact of what match-time when goals are scored, actual score-line, significance of goal to score-line, as well as the impact of sendings off, specific formations and tactics on the work-rate of players.

Work-rates may vary between successive matches and different phases of the season with players periodically experiencing a possible decline in performance. Distance covered per match may vary which again suggests that players may not always be fully utilising their physical capacity.[8] Reasons may include the specific tactical role chosen by the coach for the player or the self-imposed physical demands chosen by the player. Analysis of the total distance run by top-level players has been shown to vary significantly for individual players at different stages of the season with players covering greater distances at the end of the season.[15] These discrepancies may be partly explained by changes in the physical condition of the players as the work-rate profile fluctuates in conjunction with the amount of training that is completed by teams.[27] During an intense schedule of three competitive matches in five days in the English Premier League, total distance run did not vary significantly[84] suggesting this measurement may not be always be a valid indicator of a drop-off in performance during the season.

Analysis of the physical efforts made in the various categories of movement may yield information on whether the performance of a player is decreasing across different games. A case report comparing the performance of an international French player over 5 successive weekend matches showed little variation in the distance covered within the different categories of running.[37] In top-class Danish soccer, the coefficient of variation in high-intensity running has been shown to be 9.2% between successive matches, whereas it was 24.8% between different stages of the season.[15] The seasonal variation is most likely due to alterations in fitness as the competitive schedule reaches a peak. However, few reports have included the ambient conditions under which the games analysed were played.[27] As soccer is often played across all four seasons of the year, a future study to examine the relationship between physical performance and playing conditions is recommended. Similarly, a study comparing work-rate performance between games played at varying times of the day would be pertinent.

Teams may be required to play several games within a very short time frame and there is potential for residual fatigue and incomplete recovery to affect the movement patterns of players during subsequent games. English Premiership soccer players were reported to demonstrate a significant increase in recovery time between high-intensity efforts during an intense period of three matches in five days.[84] Further work is needed to identify if performance is affected significantly between playing positions. Nevertheless, this finding indicates that motion analysis data can play an important role in the approach to training and preparation before and during intense playing schedules. A future study could be designed to look at a possible relationship between work-rate and injury occurrence. For example, a decline in high-intensity performance over several consecutive matches may suggest recuperation of a player is needed to avoid becoming susceptible to "overtraining". Similarly, players returning after injury could have their profiles scrutinised to see how they have recovered from intense periods of play or have their performance compared against a benchmark profile obtained from previous matches.

Once a susceptibility to fatigue is identified in individual players, the possible reasons for its occurrence should be explored. A fall in activity has been identified at the beginning of the second compared to the first half.[56] During the break, players tend to rest leading to a drop in muscle temperature and subsequently to reduced performance levels. Mohr and co-workers[85] presented evidence that undertaking a few minutes of low to moderate intensity exercise during the pause may help players to 'ready' themselves and to perform better physically straight after the break. As previously mentioned, fatigue can also occur as the end of a game draws near. Reduced exercise performance at the end of soccer games may be associated with lowered glycogen levels in individual muscle fibres.[71] Therefore, adequate attention to nutritional preparation (before, during and after matches) for competition is necessary. The effectiveness of nutritional interventions could be monitored using motion-analysis in match-play. Monitoring efforts during training by means of heart rate monitors may also help coaches to avoid over-exerting players before matches and lowering their energy stores. This information can now be combined with motion-analysis data from electronic transmitters worn by players to determine individual physiological work-load during training.

3.5 Other uses of motion analysis research

Physiological studies and motion-analysis research on elite soccer players have provided evidence that the total amount of work done during match-play is related to the maximal aerobic power of players which underlines the need for a high level of aerobic fitness.[17,86] This fact is especially important for certain playing positions such as midfield players who are expected to work harder than the other outfield positions. Motion-analysis studies may be employed to determine the effects of a training intervention on competition work-rate. Evidence shows that improvements in maximal oxygen uptake after an 8-week period of aerobic interval training corresponded to significant increases in the total distance covered during a match in elite junior players.[87] Players who are aerobically well trained can maintain their work-rates better towards the end of the game than those of poorer aerobic fitness.[9] Increasing maximal aerobic power may also aid recovery following successive bouts of high-intensity anaerobic efforts which produce transient fatigue.[37] Its role is paramount as the recovery during repeated-sprint bouts in soccer is often of an active nature. A six-week programme of aerobic interval training undertaken by a group of amateur senior players led to an 18% increase in high intensity activities during competition.[17]

However, there is still a limited amount of knowledge on the effects of training programmes on actual performance of players in matches at elite level. In addition, no motion analysis study in elite soccer has as yet assessed the degree to whether the physical demands of the game are adequately replicated in training. For example, it may be worthwhile determining whether players undertake comparable amounts of high-intensity exercise (e.g., number and duration of sprints) in training as in match-play.

Over recent years, researchers have attempted to examine the validity of selected field tests by establishing links with on-field physical performance. The results from such tests can help determine the physical capacity of players and whether or not they may be susceptible to experiencing fatigue during match-play. The results from a ‘repeated sprint ability’ test have been highly correlated to the total distance covered in competition when sprinting.[36] Similarly, a strong correlation has been observed between an intermittent recovery test and both total distance run and sprint performance in elite females.[16] Mohr et al.[15] assessed the relationship between physical fitness and match performance at two standards of soccer. They compared the performance of top class soccer players to moderate level players both in an intermittent recovery test and in work-rates in match play. The top players reported a superior performance in the intermittent test and carried out significantly more high-intensity running and sprinting during match-play.

These results justify the use of field and laboratory fitness testing of players and linking the fitness data to work-rate assessments. However, the majority of research has been carried on top-level Scandinavian players and further research (and on a larger scale) is needed to test these relationships in higher-level professional leagues and for differing age groups. Furthermore, although various tests have been related closely with the physiological load imposed through match-play, they still appear to lack ecological validity with respect to the motion types, directions, turns and intensities corresponding to the physical demands of the game and do not provide sufficiently adapted protocols for the individual playing positions within soccer.[21] These questions may be resolved using motion-analysis methods for determining precise locomotor activities during matches.

Motion analysis data drawn from match-play have also been employed to help design laboratory based protocols to simulate soccer specific intermittent exercise and examine factors such as the effects of training interventions (Sari-Sarraf et al., 2006),[88] nutritional strategies (Clarke et al., 2005),[89] temperature (Drust et al., 2000)[90] and fatigue on performance. In the application to fatigue, an intermittent-exercise protocol was designed to simulate the exercise intensities associated with playing a match in order to monitor the functional characteristics of lower limb muscles at half-time and at the end of the 90 minutes.[91] Results showed a progressive increase in muscle fatigue due to a decline in muscle strength as exercise continued. Findings therefore had implications for competitive performance and further understanding of the reported increased risk of injury towards the end of the game. A future focus on the relationship between injury occurrence and fatigue during actual competitive match play should be beneficial. For example, motion analysis techniques could be employed to examine whether players are more at risk of injury after intense periods of high-intensity exercise.

4. Overview

A thorough understanding of the physical demands of soccer via information on player work-rates is required so that optimal training and preparation strategies can be constructed. As shown in the present review, an ever-increasing number of scientific investigations based on motion analysis techniques are providing important information on elite soccer play. These investigations have identified the activity profiles and physical requirements of contemporary elite soccer as well as the demands of individual playing positions. Motion-analysis research has also allowed investigators to determine the extent of fatigue experienced by players during competition as well as variations in physical performance over the course of the season. There are also possibilities to link fitness data to work-rate assessments and to determine the effects of training interventions on match performance.

Many of these investigations into work-rate have been possible due to major advances in computer and video technology which are providing more efficient ways of obtaining and analysing data especially on a larger scale. A plethora of commercial analysis systems is now available albeit with a price range varying by many thousands of dollars. The cost of many systems currently used in elite soccer is often prohibitive to all but the wealthiest clubs.

Similarly, many researchers are still using older techniques, given that they do not have access to these more advanced technologies due to the large costs associated with using them.

Using information derived from these latest techniques, academics could start to test and build upon existing research by exploring some of the gaps and questions identified throughout this review. Furthermore, conducting research into how these technologies are actually being put into use within coaching contexts would be pertinent as there is little appreciation about how effectively and efficiently they are being translated and adopted by practitioners to prepare and develop members of their squad. This reservation applies both to the operator's comprehension and coaches' use of data derived from these tools. Additionally, the measurement precision and reliability of systems proven on the basis of sound scientific evidence have not always been satisfactorily demonstrated. No current method has been accepted as the 'gold' standard approach to work-rate analysis and few investigators have attempted to make comparisons between different methodologies and technologies. It is imperative that researchers investigate the scientific legitimacy of these systems so that applied practitioners and the academic community can be assured of their accuracy when employing these methods. Nevertheless, the perfecting of motion analysis technologies will no doubt continue as it has done over recent years with real-time analysis and application becoming the norm.

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Table I. Contemporary systems and studies of their workings used to analyse work-rate in contemporary elite soccer

Company/Institution	System	System type	Web Site	Study
Cairos Technologies AG (Germany)	Cairos	Electonic transmitter	http://www.cairos.com	
Citech Holdings Pty Ltd	Biotrainer	Electonic transmitter	http://www.citechholdings.com	
Chukyo University (Japan)	Direct Linear Transformation	Automatic Video tracking		Toki and Sakurai[40]
Inmotio Object Tracking BV	LPM Soccer 3D	Electonic transmitter	http://www.abatec-ag.com	
Feedback Sport (Australia)	Feedback Football	Automatic Video tracking	http://www.feedbacksport.com/	
GPSports (Australia)	SPI Elite	GPS Tracking	http://www.gpsports.com/	Edgecombe and Norton[24]
Hiroshima College of Sciences (Japan)	Direct Linear Transformation	Automatic Video tracking		Shiokawa et al.,[38]
National Defense Academy (Japan)	Triangular surveying	Triangular surveying		Miyagi et al.,[29]
Noldus	Observer Pro	Manual Video Coding	http://www.noldus.com	Bloomfield et al.,[21,23,26]
Performance Group International (UK)	DatatraX	Automatic Video tracking	http://www.datatrax.tv	
ProZone Holdings Ltd (UK)	ProZone	Automatic Video tracking	http://www.pzfootball.co.uk	Di Salvo et al.,[35]
Real Track Football	Real Track Football	GPS Tracking	http://www.realtrackfutbol.com	
Sport-Universal Process SA (France)	AMISCO Pro	Automatic Video tracking	http://www.sport-universal.com	
Sportstec (Australia)	TrakPerformance	Computer Pen and Tablet	http://www.sportstecinternational.com	Edgecombe and Norton[24] Burgess et al.,[30]
Tracab (Sweden)	Tracab	Automatic Video tracking	http://www.tracab.com/	
Trakus Inc (USA)	Digital Sports Information	Electonic transmitters	http://www.trakus.com	
University of Campinus (Brazil)	Dvideo	Automatic Video tracking	http://www.sport-universal.com	Barros et al.,[25]

Table II. Summary of data on the total distances run and according to playing position by contemporary elite football players from 1999-2007

Reference	League/Competition level (sex)	Number	Total Distance (m)	Fullback	Central defender	Midfielder	Forward	Method of measurement
Anderssen et al.,[19]	International Swedish/Danish (F)	11	10000					Manual video analysis
	Elite Swedish/Danish (F)	11	9700					
Barros et al.,[25]	Brazilian 1st Division (M)	55	10012	10642	9029	10537*	9612	Automatic tracking on video
Brulé et al.,[33]	French Professional	1	11000			11000		Automatic tracking on video
Burgess et al.,[30]	Professional Australians (M)	36	10100	8800#		10100	9900	Manual computer pen & tablet
Di Salvo et al.,[34]	Profession European Leagues (M)	300	11393	11410	10627	12009*	11254	Automatic tracking on video
Di Salvo et al.,[76]	Champions League matches (M)	791	11010		10020	11570		Automatic tracking on video
Fernandes et al.,[39]	Portugese first division (M)	3	12793	14199#		12958	11224	Automatic tracking on video
Helgerud et al.,[87]	Elite Norwegian Juniors (M)	9	10335					Manual computer pen & tablet
Hewitt et al.,[59]	International Australian (F)	6	9140	9010#		9640	8510	Global Positioning System
Holmes[60]	Elite English (F)	5	12400					Manual video analysis
Krustrup et al.,[16]	Elite Danish (F)	14	10300					Manual video analysis
Impellizzeri et al.,[17]	Italian junior professionals (M)	29	9890					Manual video analysis
Miyagi et al.,[29]	Japanese professionals (M)	1	10460					Triangulation/Camera potentiometer
Mohr et al.,[15]	Italian professionals (M)	18	10860	10980~	9740~	11000~	10480~	Manual video analysis
	Elite Danish (M)	24	10330					
Odetoyinbo et al.,[83]	English professionals (M)	_	10659					Automatic tracking on video
Rampinini et al.,[36]	European professionals (M)	18	10864					Automatic tracking on video
Randers et al.,[65]	Danish Premier league (M)	23	10800					Manual video analysis
	Swedish Premier League (M)	23	10150					Manual video analysis
Rienzi et al.,[62]	South American professionals (M)	17	8638					Manual video analysis
	English professionals (M)	6	10104					Manual video analysis
Scott and Drust[61]	International English (F)	30	11979	12636	11099	12971	11804	Manual video analysis
Strudwick and Reilly[13]	English professionals (M)	24	11264	11433	10650	12075		Manual video analysis
Thatcher and Batterham[57]	English Professionals (M)	12	10274					Manual video analysis
	U/19 Professionals (M)	12	9741					
Zubiglia et al.,[74]	Champions League matches (M)	18	10461					Automatic tracking on video

* Combined results for central and external midfield players

Results did not distinguish between fullbacks and central defenders

~ Results for each playing position were calculated from a combination of data obtained for both groups of players

Table III. Comparison of distances covered by elite soccer players during the first and second halves of competitive match-play.

Study	Nationality	Total Distance run (m)	1st Half (m)	2nd Half (m)	Difference (%)
Barros et al.,[25]	Brazilian	10012	5173	4808	-7,1
Burgess et al.,[30]	Australian	10100	5300	4800	-9,4
Di Salvo et al.,[34]	European	11393	5709	5684	-0,4
Miyagi et al.,[29]	Japanese	10460	5315	5141	-3,3
Mohr et al.,[15]	Italian	10860	5510	5350	-2,9
	Danish	10330	5200	5130	-1,3
Rienzi et al.,[62]	South America/English	9020	4605	4415	-4,1
Zubiglia et al.,[74]	English	10549	5297	5252	-0,9
	Spanish	10339	5121	5218	+1,9

Figure I. An example of a T-pattern incorporating regularity of movements by a centre-forward in a F.A. Premiership match.