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Assessment of Sports Performance With Particular Reference to Field Games

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Objective data on performance of game players provide a useful basis for monitoring the contributions of individuals towards the team's collective efforts. Notation analysis and motion analysis are different methods of recording patterns of play- and work-rate of players, respectively. These types of observations yield profiles from which sport-specific tests may be designed. Examples are given from soccer, rugby football, and field hockey. The observations are also useful in the design of laboratory-based sports-specific protocols for the design of experimental work. With the rapidly evolving technologies of performance analysis, this area of work is likely to increase in future.

Key Words: football, hockey, match analysis, notation analysis, work-rate

Key Points:
•Performance in games can be analysed by notating players' actions.
•Work-rate can be measured and depends on fitness.

1. Introduction

Excelling in the performance of his or her chosen sports event is the major aim of any elite athlete. Sports such as running, swimming, downhill-skiing, cycling, and so on, entail competing directly against other individuals. The race is won by the first past the finishing line, or the level of performance is gauged by the time taken to reach a set distance. In horizontal or vertical jumping, the performance is indicated by the distance or height of the jump. Similarly, in throwing events, competitive performance is measured by the distance the missile is propelled. In all these events, performance is easily measured, but in certain sports like kayaking, ski-jumping, and 3-day eventing, the result may be altered on the basis of style characteristics or faults in execution.

In certain circumstances, competitive racing incorporates team contests, with the principles of scoring varying between sports. In rowing, for example, the performance criterion is the same for team and individual classes, as is also the case in relay racing in both swimming and track and field athletics. In cross-country running, the team race is decided on an aggregate score based on individual finishing positions. All of these nuances lead to the view that the concept of performance can range in complexity from the parsimonious to the multivariate. The issues are most complex when it comes to analyzing performance in field games.

Issues relating to the analysis of performance measures have been reviewed by Atkinson and Nevill (1). They outlined the types of questions researchers should ask themselves prior to

starting their study. Whereas fundamental research might entail examining links between biological variables and performance variables, with a view to explaining the mechanisms of action in the latter, field workers are primarily concerned with what might make worthwhile differences in performance. In an assessment of performance capability, as employed by sports science practitioners, the reliability, objectivity, and validity of the measuring instrument must be taken into consideration. These principles are especially important in view of the impact that small increases in performance capabilities can have on performance within competition.

Recently, the anthropometric factors contributing to performance in a range of sports have been the subject of review (11). For example, in the throwing events, body mass is one determinant of performance, along with the acceleration of the implement prior to its release. Body mass is also relevant in events such as rowing, where propulsion of the shell or boat is a function of the absolute power that the oarsperson generates. Individual characteristics besides body mass may include other anthropometric dimensions (e.g., body size, body composition, relative segmental lengths), physiological factors (e.g., muscle strength and power, anaerobic capacity, aerobic capacity, maximal oxygen uptake) and biomechanical variables (e.g., mechanical efficiency) and psychological variables. In sports in which complex skills and intricate team-work are required, the link between individual characteristics and performance capability is not a straightforward relationship. In games like basketball and volleyball and in jumping in the line-out in Rugby Union, stature provides an advantage but is less apparent in sports such as field hockey and association football (soccer), where there can be a great degree of variability between individuals within one team (see 34, 35).

The focus in this review is on analyzing performance in the context of field games and measures of assessing individual performance capabilities for such sports. Victory in the field games is secured by scoring more goals (or points) than the opposition. Pollard and Reep (27) used logistic regression analysis to calculate the possibility of scoring a goal by studying all the team possessions and identifying the characteristics of those that led to a shot on goal. In this way they broadened the concept of performance indicators.

In a team game, individual team members must harmonize into an effective unit in order to achieve the desired outcome. In such contexts the assessment of how well the team is playing and how much individuals contribute to team effort presents a challenge to the sports scientist. Furthermore, there is a need in such sports for test measures that will give a reasonable prediction of performance capability in applied contexts. There is also a need to find exercise models relevant to specific sports so that they may be validly studied in laboratory conditions.

First, various methods for describing performance in games contexts are outlined. Such methodologies include both notation analysis and motion analysis, which are employed either for tactical or physiological interpretations. In monitoring individual profiles, an emphasis is placed on field tests, where measurements must have relevance to the sport in question and be both administratively and socially convenient. A sample of field tests in current use with games teams is considered before representative laboratory protocols are presented in finalizing this review.

2. The Analysis of Field Games

2.1 Notation Analysis

Notation analysis constitutes a means of recording observations in an objective manner in order to collate statistical details of performance parameters. According to Hughes (15), the main uses of notation systems include investigation of movements during play, evaluation of technical and tactical aspects of play, and compilation of statistical data. Principles of notation date back to use of hieroglyphs by the ancient Egyptians to read dance and primitive methods of the Romans to record gestures. The evolution of notation analysis through to contemporary use in sports science has been outlined by Hughes and Franks (17).

At first, behavioral events were recorded manually by means of short-hand codes. The more sophisticated notation systems required considerable learning time. By the mid 1980s, computerized notation systems had been designed. These systems were used in conjunction with video recordings, analyzed either in real-time or at a self-directed pace after the game was over. The game may be represented digitally with data collected directly onto the computer, which can then be queried in a structured way. The whole game is represented and can utilize a large database for manipulation. The performance of a team as a whole, or individual team members, can be examined in this way, as well as particular aspects of performance such as attacking or defensive play.

Detailed aspects of performance have been described by means of notation analysis. The player (or players) involved, the action concerned, and the location of the pitch can be entered into the computer for every event. This approach has been applied in a range of field games (15), in court games such as squash (17), and other racket sports (16). Applications to field games have incorporated analyses in field hockey (36), rugby football (33), lacrosse, hurling, and the various national football codes (34). Specific uses in association football have included the characteristics of the successful patterns of play by France during the 1998 World Cup for football and during Euro 2000 (14), and the changes in patterns of play between 1990 and 1999 (47). A further example is the identification of behavior in attacking players that is most successful in winning free kicks in the final third of the pitch. Attempting to dribble past the defense was the single most successful maneuver, followed by challenging for possession and receiving a pass (see Figure 1 from Ensum et al., 2000). Applications in Gaelic football have included an evaluation of rule changes in the 1990s, the technique enabling the researchers to identify precisely how changes in rules have affected patterns of play (39).

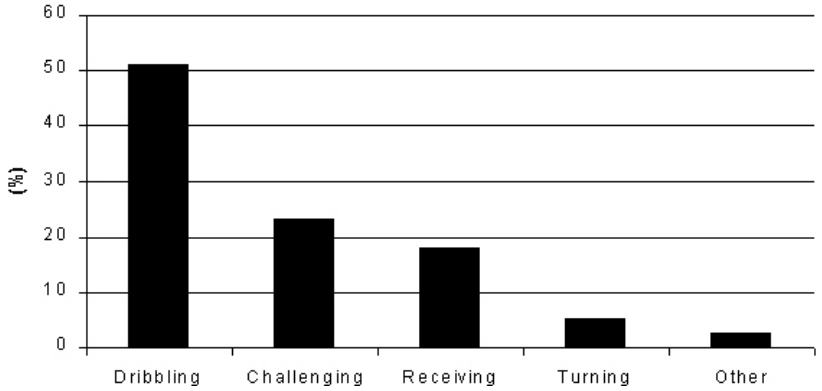

Figure 1 — Reasons for free kicks in attacking third (from 10).

The development of sports science support programs hastened the acceptance of notation analysis by coaches. Olsen and Larsen (26) described how notation analysis had benefited the national football team of Norway in competing with the best teams in the world. Currently its main use is in analyzing team performance post-event (e.g., 13). In conjunction with video-editing facilities, it can provide interim feedback to players and coaches, for example, in half-time team talks. Surveillance information may also be provided about the style of play of forthcoming opponents. Whilst largely a descriptive tool, notation analysis could be employed by sports scientists to address theory-driven questions. Such issues might include potential links between performance and individual variables characteristic of fitness or talent (see 43).

2.2 Time and Motion Analysis

Investigation of the physiological demands of field games can be conducted by making relevant observations during match-play or by monitoring physiological responses in real or mock-up games. The type, intensity, and duration (or distance) of activities can be observed by means of motion analysis. Work-rate profiles of players within a team can be established according to the intensity, duration, and frequency of classified activities (e.g., walking, moving sideways or backwards, jogging, cruising, and sprinting).

A global index of work-rate is provided by the overall distance covered during a game, the principle being that energy expenditure is directly related to total work (distance covered) or power output (4, 41). The various methods employed to determine the distance covered during a soccer match have been reviewed elsewhere (9, 30, 31). The early approaches focused on the use of hand notation systems for the recording of activity patterns. Such systems tracked players' movements on a scale plan of the pitch. Systems that followed made use of coded commentaries of activities recorded on audio tape, in conjunction with measurements based on stride characteristics taken from video recordings to evaluate the total distance covered during the 90 min of the match. Alternative methods have included cinefilm movies taken from overhead views of the pitch for computer-linked analysis of the movements of the whole team and synchronized cameras positioned to overlook each half of the pitch; activities are then calculated using trigonometric principles (7, 24). The most advanced method in contemporary use employs six cameras, three placed high on the stand on each side, allowing observations to be made on all 22 players on the pitch. This type of system is now used by a number of top European professional football clubs, although formal validation studies have not yet been reported.

Practical methods now favor the use of computerized notation systems to analyze previously recorded video footage of individual players. The total distance covered in each activity classification is estimated by determining stride frequencies on the playback of the video, provided the stride length for each activity is determined separately for the individual concerned. Alternatively, players' movement patterns around the pitch in each activity category can be plotted, with estimations of the total distance covered being based on predetermined pitch dimensions. Following the coordinates of individual player positions on the representation of the pitch, velocity (and acceleration) data can be computed and distance covered over time calculated.

Work-rate profiles may be presented either in distances covered at different intensities or on a time-base from which exercise-to-rest ratios can be calculated. The former is useful in

monitoring individual variation from game to game and in identifying the onset of fatigue. The latter may be the more useful in determining the metabolic systems stressed by the game and in designing appropriate training protocols. Exercise-to-rest ratios have been calculated for association football (32) and Rugby Union football (33); data interpretation is assisted when it is possible to record physiological responses at the same time, as has been done with match referees (5).

Work-rate in soccer is influenced by factors such as positional role, environmental factors, and level of competition (35). Work-rate profiles are also influenced by physiological factors such as maximal oxygen intake (41), endurance capacity (2), and carbohydrate stores (45). Profiles also vary with style of play, the more intensive European leagues producing higher work-rates than international match-play in South America (see Figure 2 from Drust et al., 1998). They can also be related to anthropometric characteristics, although anthropometric characteristics are relatively heterogeneous among elite football teams (see 11).

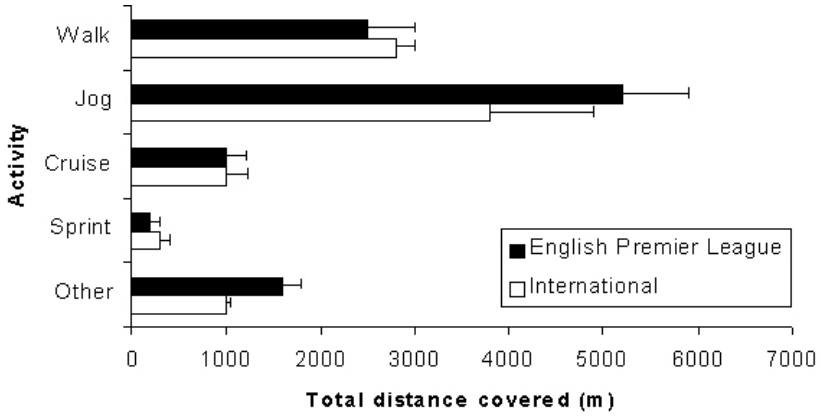

Figure 2 — Total distances covered in each activity category (mean ± *SD*) for South American International players and English Premier League players (from 7).

In Rugby Sevens competition, as opposed to the 15-per-side version of the game, there is a greater need for mobility around the pitch. Anthropometric characteristics of players in the Rugby-Sevens international tournament were significantly correlated with work-rate components, mesomorphy and muscle mass being negatively related to the amount of high intensity activity during the game. Nevertheless, neither anthropometric profiles or work-rate measures necessarily determine whether at this level of play a game is won or lost. With respect to soccer at the international level, Rienzi et al. (44) reached the same conclusion.

It is not possible to conclude that the work-rate profiles of individual players necessarily reflect the true demands of the game. This is because the intensity of exercise "off-the-ball" is self-chosen by each player. McLean (21) tried to overcome this limitation by focusing on play, as represented in televised recordings of international Rugby matches. The downside of the approach is that while activity directly related to play is monitored, movement "off-the-ball" is not.

Both notation and motion analysis techniques, separately or combined, provide means of evaluating performances of athletes and are a valuable source of feedback in team games in particular. They yield data with respect to the demands that involvement in the game imposes on

players. The performance capabilities of players are influenced by fitness factors and the demands that players are voluntarily prepared to impose on themselves. Whilst there has been a tradition of testing athletes in laboratory conditions for physiological functions such as maximal oxygen uptake (VO_{2max}) and "anaerobic threshold" or responses of blood lactate to incremental exercise (see 20), the current trend is to use field tests of fitness where possible. The use of field measures increases the social acceptability of fitness testing, saves time when group members can be accommodated together, and the sports-specific elements of the test battery are obvious to the practitioners. The traditional laboratory-based physiological assessments are used preferentially when individual players require comprehensive and detailed personal diagnosis, as might occur when starting with a new club, prior to returning to play following injury, or evaluating training interventions.

3. Performance Tests for Field Conditions

3.1 Generic Tests

Field tests are designed so that they can be implemented in the typical training environment. Their convenience is that they do not necessarily require a visit to an institutional laboratory for the assessments to be carried out. Furthermore, the tests can be performed without recourse to complex monitoring equipment. The underlying assumption is that any change in performance of the field test has relevance for performance capability in a competitive context.

The Eurofit test battery (see 11) offers a range of fitness items for which norms are available to help in interpreting results. The tests utilize performance measures such as runs, jumps, throws, and so on, but they are designed to assess physiological functions such as strength, power, muscle endurance, and aerobic power, albeit indirectly.

The 20-m shuttle run test was first validated for estimating maximal oxygen uptake (18) and represented a progressive step for sports science support programs. Individuals may be tested as a squad in a gymnasium or open ground such as a football pitch or a synthetic sports surface. The pace of moving between two lines 20 m apart is controlled by instructions given on an audio tape recorder and using an incremental protocol. The pace is increased progressively, analogous to the determination of VO_{2max} on a motor-driven treadmill, until the athlete reaches exhaustion. The final stage reached is recorded and the VO_{2max} can be estimated using appropriate tables (28). Separate prediction tables for children are available and have been validated for estimating VO_{2max} by Leger et al. (19).

Alternative tests of aerobic fitness have employed runs, either distance run for a given period of time, such as the 12-min run of Cooper (6) or a set distance such as the 3-km run validated by Oja et al. (25). Cooper's test has been used as a field test in football players, whilst the latter has been used mainly for purposes of health-related fitness. Data have been reported for the Brazilian national soccer team and for professional players in the U.S. (29). The test has not been used much in recent years, since the recognition that tests with specificity to the sport have greater utility value. A number of such tests for field games have been outlined in Eston and Reilly (11).

3.2 Repeated Sprint Tests

Field games incorporate acyclical patterns of movement, the intensity of exercise varying in a relatively unpredictable manner. In soccer, for example, there is a call for an all-out sprint every

90 s on average and a run at effort at least every 30 s. The period in between these bouts will also vary and may be in some instances too short to permit a full recovery before having to sprint again. The timing of runs is also important in view of the context in which activity takes place. The fitness requirements therefore are for quick movements, speed, fast recovery, and an ability to sustain activity.

The capability to reproduce high intensity sprints may be examined by means of requiring the athlete to reproduce an all-out sprint after a short recovery period. A distance of 30 m is recommended. Timing gates may be set up at the start, after 10 m, and at 30 m. There is then a 10-m deceleration zone for the athlete to slow down prior to jogging back to the start line. The recovery period is variable, but 25 s is recommended (48). When the interval is reduced to 15 s, test performance is significantly related to the oxygen transport system (38). An illustration of performance by two players is given in Table 1.

Table 1 Performance Times for a Games Player in a Repeated Sprint Test with 15-s Recovery Between Sprints

Sprints	10 m (s)		30 m (s)	
	Player 1	Player 2	Player 1	Player 2
1	1.49	1.70	4.05	4.24
2	1.51	1.72	4.07	4.31
3	1.60	1.80	4.10	4.40
4	1.61	1.84	4.18	4.46
5	1.68	1.90	4.28	4.60
6	1.89	1.96	4.46	4.66
7	1.83	2.02	4.55	4.83

Seven sprints are recommended for determining peak acceleration (over 10 m) and speed (time over 30 m). A fatigue index can be calculated both for acceleration and speed over 30 m, based on the drop off in performance over the seven sprints. The mean time for the seven sprints is indicative of the ability to perform several short sprints within a short period of time within a game. Generally, the best performances are in the first and second sprints, the poorest over the sixth or seventh.

3.3 Sports-Specific Tests

3.3.1 The Yo-Yo Test. The so-called "yo-yo" tests were designed by Bangsbo (3) to determine one's capability to tolerate high-intensity activity for a sustained period. In the tests, which have relevance to field games, the player performs repeated 20-m shuttle runs interspersed with a short recovery period during which the player jogs. The time allowed for a shuttle is decreased progressively as dictated by audio bleeps from a tape recorder. The test ends when the athlete is unable to continue, with the recorded score being the number of shuttles completed.

The ability to perform intense exercise repeatedly after prolonged intermittent exercise is evaluated in the yo-yo intermittent endurance. A 5-s rest period is allowed between each shuttle, and the duration of the test in total is between 10 and 20 min.

The ability to recover from intense exercise is evaluated by means of the yo-yo intermittent recovery test. Running speeds are higher than in the yo-yo intermittent endurance test, but a 10-s period of jogging is allowed between each shuttle. The test is typically between 2 and 15 min in duration.

Both tests have two levels, one for elite footballers and another for recreational players. The tests are conducted on a football field, with the players wearing football boots and can be completed in a relatively short period of time with a whole squad of up to 30 players tested at the same time. The yo-yo intermittent recovery test is now compulsory for football referees in Italy and Denmark. Both tests have been employed by professional teams in various European countries.

3.3.2 Soccer-Dribbling Test. Some of the more skilful movements of the game may be incorporated into so-called field tests. Soccer-dribbling tests, for example, can include a sprint as fast as possible over a zig-zag course whilst dribbling a football. This procedure incorporates an agility component, calling for an ability to change direction quickly. The tests formed part of a battery designed for monitoring young soccer players by Reilly and Holmes (40) and have been employed in talent identification programs (42).

The slalom dribble designed by Reilly and Holmes (40) calls for total body movement in which the subject has to dribble a ball around a set obstacle course as quickly as possible. Obstacles comprise plastic conical skittles 91 cm high and with a base diameter of 23 cm. Two parallel lines, 1.57 m apart, are drawn as reference guides. Intervals of 1.83 m are marked along each line, and diagonal connections of alternate marks 4.89 m long are made. There are five cones placed on the course itself, and a sixth is positioned 7.3 m from the final cone, exactly opposite it and 9.14 m from the starting line. On the command, *go,* each subject dribbles the ball from behind the starting line to the right of the first cone and continues to dribble alternately round the remainder in a zig-zag fashion to the sixth, where the ball is left and the subject sprints to the starting line. The time elapsed between leaving and returning past the starting line is recorded to the nearest one-tenth second and indicates the individual's score. Subjects are forced to renegotiate any displaced cones. A demonstration by the experimentor and a practice run by the subject is undertaken before four trials are performed, with a rest of 20 min between trials, the aggregate time representing the subject's score.

An alternative test is the "straight dribble," which has been used to discriminate between elite young soccer players and their sub-elite counterparts (42). In the test, five cones are placed in a straight line perpendicular to the start line: the first 2.74 m away, the middle two separated by 91 cm, and the remainder 1.83 m apart (see 11 for illustration). Players dribble around alternate obstacles until the fifth is circled and then must return through the course in similar fashion. The ball has to be dribbled from the final obstacle to the start line, which now constitutes the finish. The aggregate score from four test trials constitutes the overall test score.

3.3.3 Field Test for Rugby Union Football. McLean (22) described a functional field test for application to Rugby Union. The structure and content of the test were designed so as to relate to the effort and skill patterns a player is called upon to produce in the game. The test was used by the Scotland international squad in preparing for the 1991 Rugby World Cup.

The distance run is about 100 m. The course is run twice, with a 45-s recovery which allows the drop-off in performance over the second run to be identified. Errors in the skills elements of the test result in point-deduction penalties.

The player starts the run with the ball in hand. Skills elements include passing the ball, running around flags, diving to win the ball on the ground, driving a crash pad, jumping and crash-tackling, a tackle bag, and picking the ball from the ground. McLean (22) reported that performance in the test could discriminate players of different ability levels.

3.3.4 Field Test for Hockey. A battery of field tests was described by Reilly and Bretherton (37) for use in assessing female hockey players. The tests consist of a sprint, a T-run dribbling test, and a "distance and accuracy" skill test.

The sprint over 50 yards (45.45 m) is timed to 0.01 s, the fastest of three trials being recorded. The T-run is over 60 yards (54.55 m) while dribbling a leather hockey ball around skittles. The test involves as many circuits of the T-shaped course as possible in 2 min. All subjects are practiced in the drill, which excludes use of reversed sticks, and the best of the three trials is recorded. The distance and accuracy test involves a combination of dribbling a ball and hitting it at a target, a set sequence being repeated as often as possible within 2 min. Distance traveled is calculated to the nearest 2.5 yards (2.27 m), and relative accuracy is calculated by expressing the number of accurate shots as a percent of the number of hits. All subjects are familiarized with the drill before testing takes place.

4. Simulations for Laboratory Studies

The analysis of work-rates during match-play has also been useful in designing experimental studies relevant to field games. Such game-related protocols have almost exclusively been related to soccer. The principles involved are, first, to employ an exercise regime in which high-intensity activity is intermittent and, second, that the physiological responses on average bear close correspondence to the stress of competitive play. The overall physiological strain associated with such protocols is greater than physiological responses to continuous exercise at the same average power output.

Drust et al. (7) designed a soccer-specific protocol consisting of reproducible 15-min cycles of activity in which the intensity is varied at least every 30 sm, ranging from walking to sprinting. The protocol as a whole entails 2×45-min period, separated by a 15-min rest (see Figure 3). It was used to examine the influence of pre-cooling the body on body temperature responses (8). It could be utilized to examine the physiological consequence of nutritional or other interventions.

An alternative approach to examining interventions relative to soccer is provided by the Loughborough Intermittent Shuttle test or LIST. The work-rate corresponding to physiological responses to soccer play is maintained in shuttle running for 75 min. When this time has elapsed,

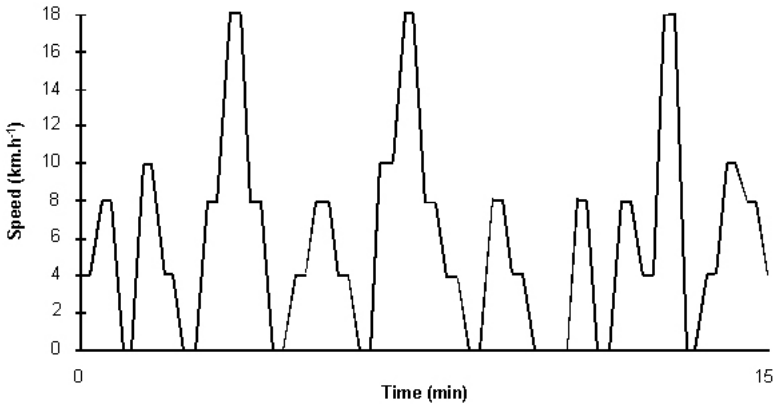

Figure 3 — The soccer-specific intermittent protocol developed for laboratory simulation of the game intensity (from 8).

experimental participants continue but alternate between 55% and 95% VO_{2max} every 20 m up to voluntary exhaustion. The protocol has been used to compare different sports drinks (23) and to study muscle soreness (46). A modification of the test has been used to evaluate knee-joint stability after exercise deemed equivalent to playing a soccer game (12).

5. Overview

The application of scientific principles to field testing has progressed to a point where existing tests are continually refined and new tests designed. In such instances, one difficulty is that baseline and reference data become obsolete with the use of new versions of a particular test. Applied sports scientists ultimately have to choose between protocols that allow direct physiological interpretations of results or have proven utility for determining game-related performance.

It is inevitable that practitioners will seek to have available tests that have some validity for assessing performance capabilities in their sport. Competitive performance is not a static concept, and performance profiles in field games are altered in a progressive upward spiral as intensity of competition increases. Whilst the field games were the main topic of this review, similar approaches may be adopted in analyzing court and indoor games alongside the assessment of the performance capabilities of their players.

References

1. Atkinson G, Nevill AM. 2001. Selected issues in the design and analysis of sports performance research. J Sports Sci. In press.

2. Bangsbo J. 1994. Physiology of soccer—with specific reference to intense intermittent exercise. Acta Physiol Scand 619(suppl.):151, 169.

3. Bangsbo J. 1998. Performance testing in soccer. Insight: The FA Coaches Association Journal, 2(2):21-23.

4. Bangsbo J, Norregaard L, Thorsoe F. 1991. Activity profile of competition soccer. Can J Sports Sci 16:110-16.

5. Caterall C, Reilly T, Atkinson G, Coldwells A. 1993. Analysis of the work rates and heart rates of association football referees. Br J Sports Med 27:193-96.

6. Cooper KH. 1968. A means of assessing maximal oxygen intake correlating between field and treadmill running. JAMA 203:201-4.

7. Drust B, Reilly T, Rienzi E. 1998. Analysis of work-rate in soccer. Sports Exercise and Injury 4:151-55.

8. Drust B, Cable NT, Reilly T. 2000. Investigation of the effects of pre-cooling on the physiological responses to soccer-specific intermittent exercise. Eur J Appl Physiol 81:11-17.

9. Ekblom B. 1986. Applied physiology of soccer. Sports Med 3:50-60.

10. Ensum J, Williams M, Grant A. 2000. An analysis of attacking set plays in Euro 2000. Insight: The Football Association's Coaching Association Journal 4:36-39.

11. Eston R, Reilly T. 2001. Kinanthropometry and exercise physiology: a laboratory manual 2nd ed. vol. 1 and 2. London: E and FN Spon.

12. Gleeson NP, Reilly T, Mercer TH, Rakowski S, Rees D. 1998. Influence of acute endurance activity on leg neuromuscular and musculoskeletal performance. Med Sci Sports Exerc 30:596-608.

13. Grant A, Williams M. 1999. Analysis of the final 20 matches played by Manchester United in the 1998–99 season. Insight: The FA Coaches Association Journal 3(1):42-45.

14. Horn R, Williams M, Grant A. 2000. Analysis of France in World Cup 1998 and Euro 2000. Insight: The Football Association's Coaching Association Journal 4(1):40-43.

15. Hughes M. 1988. Computerised notation analysis in field games. Ergonomics 31:1585-92.

16. Hughes M. 1998. The application of notation analysis to racket sports. In: Lees A, Maynard I, Hughes M, Reilly T, editors. Science and Racket Sports II London: E and FN Spon, p. 211-20.

17. Hughes M, Franks IM. 1994. Dynamic patterns of movement in squash players of different standards in winning and losing matches. Ergonomics 37:23-29.

18. Leger L, Lambert J. 1982. A maximal 20-m shuttle run test to predict VO_{2max}. Eur J Appl Physiol 49:1-12.

19. Leger LA, Mercier D, Gadoury C, Lambert J. 1988. The multistage 20 metre shuttle run test for aerobic fitness. J Sports Sci 6:93-101.

20. MacDougall JD, Wenger HA, Green HJ. 1991. Physiological testing of the high-performance athlete. Champaign, IL: Human Kinetics.

21. McLean DA. 1992. Analysis of the physical demands of Rugby Union. J Sports Sci 10:285-96.

22. McLean DA. 1993. Field testing in Rugby Union football. In: Macleod DAD, Maughan RJ, Williams C, Madeley CR, Sharp JCM, Hutton RW, editors. Intermittent high intensity exercise: preparation, stresses and damage limitation. London: E and FN Spon, p. 79-83.

23. Nicholas GW, Williams C, Lakomy HKA, Phillips L, Nowitz A. 1995. Influence of ingesting a carbohydrate electrolyte solution on endurance capacity during intermittent, high intensity shuttle running. J Sports Sci 13:283-90.

24. Ohashi J, Togari H, Isokawa M, Suzaki S. 1988. Measuring movement speeds and distances covered during soccer match-play. In: Reilly T, Lees A, Davids K, Murphy W, editors. Science and football. London: E and FN Spon, p. 320-23.

25. Oja P, Laukkanen R, Pasanen M, Vuori I. 1989. A new fitness test for cardiovascular epidemiology and exercise promotion. Ann Med 21:249-50.

26. Olsen E, Larsen O. 1997. Use of match analysis by coaches. In: Reilly T, Bangsbo J, Hughes M, editors. Science and football III. London: E and FN Spon, p. 209-20.

27. Pollard R, Reep C. 1997. Measuring effectiveness of playing strategies at soccer. The Statistician 46:541-50.

28. Ramsbottom R, Brewer T, Williams C. 1988. A progressive shuttle run test to estimate maximal oxygen uptake. Br J Sports Med 22:141-44.

29. Raven PR, Geltman LR, Pollock ML, Cooper KH. 1976. A physiological evaluation of professional soccer players. Br J Sports Med 10:209-16.

30. Reilly T. 1994. Motion characteristics. In: Ekblom B, editor. Football (soccer). Oxford: Blackwell Scientific, p. 78-99.

31. Reilly T. 1996. Science and soccer. London: E and FN Spon.

32. Reilly T. 1997. Energetics of high intensity exercise (soccer) with particular reference to fatigue. J Sports Sci 15:257-63.

33. Reilly T. 1997. The physiology of Rugby Union football. Biol Sport 14:83-101.

34. Reilly T. 2000. Endurance aspects of soccer and other field games. In: Shephard RJ, editor. Endurance in sport, 2nd ed. London: Blackwell Scientific, p. 900-30.

35. Reilly T. 2000. The physiological demands of soccer. In: Bangsbo J, editor. Soccer and science: in an interdisciplinary perspective. Copenhagen: Munksgaard, p. 91-105.

36. Reilly T, Borrie A. 1992. Physiology applied to field hockey. Sports Med 14:10-26.

37. Reilly T, Bretherton S. 1986. Multivariate analysis of fitness in female field hockey players. In: Day JAP, editor. Perspectives in kinanthropometry. Champaign, IL: Human Kinetics, p. 135-42.

38. Reilly T, Doran D. 1999. Kinanthropometric and performance profiles of elite Gaelic footballers. J Sports Sci 17:922.

39. Reilly T, Doran D. 2001. Science and Gaelic football: a review. J Sports Sci. In press.

40. Reilly T, Holmes M. 1983. A preliminary analysis of selected soccer skills. Physical Education Review 6:64-71.

41. Reilly T., Thomas V. 1976. A motion analysis of work-rate in different positional roles in professional football match-play. Journal of Human Movement Studies 2:87-97.

42. Reilly T, Williams AM, Nevill A, Franks A. 2000. A multidisciplinary approach to talent identification in soccer. J Sports Sci 18:695-702.

43. Rienzi E, Reilly T, Malkin C. 1999. Investigation of anthropometric and work-rate profiles of Rugby Sevens players. Journal of Sports Medicine and Physical Fitness 39:160-164.

44. Rienzi E, Drust B, Reilly T, Carter JEL, Martin A. 2000. Investigation of anthropometric and work-rate profiles of elite South American international soccer players. Journal of Sports Medicine and Physical Fitness 40:162-69.

45. Saltin B. 1973. Metabolic fundamentals in exercise. Med Sci Sports 5:137-46.

46. Thompson D, Nicholas CW, Williams C. 1999. Muscle soreness following prolonged intermittent high intensity shuttle running. J Sports Sci 17:387-95.

47. Williams M, Lees D, Reilly T. 1999. A quantitative analysis of matches played in the 1991–92 and 1997–98 seasons. London: The Football Association.

48. Williams M, Borrie A, Cable T, Gilbourne D, Lees A, MacLaren D, Reilly T. 1997. Umbro conditioning for football. London: Ebury.

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