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The use of performance indicators in performance analysis

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The aims of this paper are to examine the application of performance indicators in different sports and, using the different structural definitions of games, to make general recommendations about the use and application of these indicators. Formal games are classified into three categories: net and wall games, invasion games, and striking and fielding games. The different types of sports are also sub-categorized by the rules of scoring and ending the respective matches. These classes are analysed further, to enable definition of useful performance indicators and to examine similarities and differences in the analysis of the different categories of game. The indices of performance are sub-categorized into general match indicators, tactical indicators, technical indicators and biomechanical indicators. Different research examples and the accuracy of their presentation are discussed. We conclude that, to enable a full and objective interpretation of the data from the analysis of a performance, comparisons of data are vital. In addition, any analysis of the distribution of actions across the playing surface should also be presented normalized, or non-dimensionalized, to the total distribution of actions across the area. Other normalizations of performance indicators should also be used more widely in conjunction with the accepted forms of data analysis. Finally, we recommend that biomechanists should pay more attention to games to enrich the analysis of performance in these sports.

Keywords: analysis, games, performance, performance indicators.

Introduction

Sport biomechanists and notational analysts are concerned with the analysis and improvement of sport performance. The practitioners of both make extensive use of video analysis and video-based technology. Recently, those involved in these two sub-disciplines of sport science have recognized some other commonalities, which suggest that the two should grow closer together, collaborate more and share ideas, theories and methods. The formation of the British Olympic Association's Performance Analysis Steering Group, which brings together biomechanists and notational analysts, is one such example. The issues that are common to both biomechanists and notational analysts include optimizing feedback to the performer and coach to improve performance (see Liebermann *et al.*, 2002; Smith and Loschner, 2002, both in this issue). Other common issues include the management of information complexity, addressing the reliability and validity of their data, and exploitation of the approaches and methods of artificial intelligence (see Lapham and Bartlett, 1995). The investigators from both disciplines study patterns of play involving the individual or 'constellations of individuals' (Shephard, 1999). One approach to theoretical-grounding that is similar to both of these elements of 'performance analysis' is the derivation of performance indicators (also called 'performance parameters' by sport biomechanists) from flowcharts for notational analysis (see, for example, Hughes and Franks, 1997) or hierarchical technique models for biomechanics (see, for example, Hay and Reid, 1988).

A performance indicator is a selection, or combination, of action variables that aims to define some or all aspects of a performance. Clearly, to be useful, performance indicators should relate to successful performance or outcome. Biomechanical performance indicators are often linked to the outcome through

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hierarchical technique models, such as that in Fig. 1, in which clear biomechanical relationships exist between the levels of the model (see also Lees, 2002, this issue). Mathematical modelling can often serve to reinforce this relationship, particularly in closed skills, as in Fig. 2 (from Best *et al.*, 1995). In this figure, an optimal combination of two javelin release parameters (performance indicators), here release angle of attack and release angle, produces a maximum throw: departures from that optimum result in a decrement in distance thrown. Such modelling techniques have not yet been applied to team games.

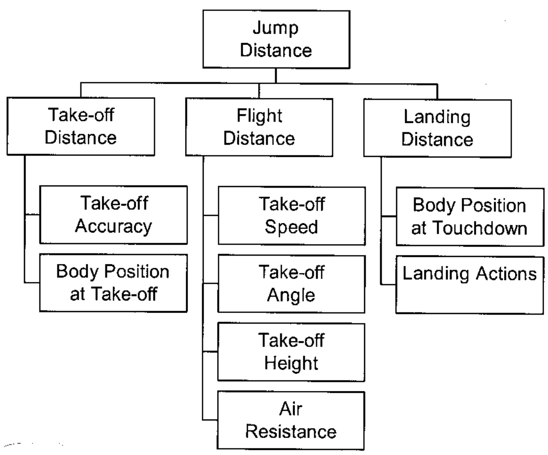

Fig. 1. Hierarchical technique model of the long jump (adapted from Hay and Reid, 1988).

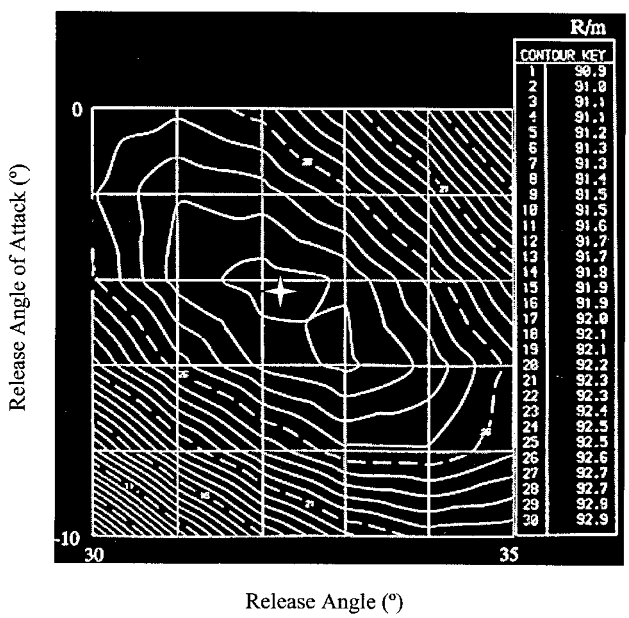

Fig. 2. Contour map of the distance a javelin travels (*R*) as a function of two release parameters, with all others held constant. Release angle is the angle between the direction in which the javelin's centre of mass is travelling (the javelin's velocity vector) and the horizontal; release angle of attack is the angle from the javelin's long axis to its velocity vector at release. Contour lines (every fifth one numbered) are lines of constant *R*; the cross marks the maximal value of *R* (92.9 m). Any departure from that optimum results in a reduction in *R* (adapted from Best *et al.*, 1995).

Analysts and coaches use performance indicators to assess the performance of an individual, a team or elements of a team. They are sometimes used in a comparative way, with opponents, other athletes or peer groups of athletes or teams, but often they are used in isolation as a measure of the performance of a team or individual alone.

Sport biomechanists have generally concentrated their analyses of performance on sports in which the movement technique is critical. Such sports involve predominantly closed skills and are classified as acrobatic (including gymnastics, trampolining, diving, freestyle skiing), athletic (including jumping and throwing) and cyclic (including running, swimming, skating and wheelchair racing) (Yeadon and Challis, 1992). The performance goal, or primary performance parameter (such as the distance jumped in the long jump), is initially partitioned into secondary performance parameters, such as the take-off, flight and landing distances in the long jump: these are sometimes based on phase analysis of the technique (e.g. Bartlett, 1999). In this example, these partial distances can be normalized by expressing them as ratios of the distance jumped; a similar approach is often used in the triple jump and, sometimes, in gymnastic vaults. The use of hierarchical technique models then allows these performance parameters to be related to the movements of the athlete that contribute to successful execution of the skill. All of these parameters and movement variables can be considered as performance indicators, providing that they do meaningfully contribute to the performance. These performance indicators are usually kinematic variables or parameters, such as body segment speeds or angles. When trying to relate such indicators to the mechanisms of the movement, net joint reaction forces and moments and electromyographic (EMG) descriptors of muscle activation patterns are also used.

Sport biomechanists have paid far less attention to team sports, perhaps because of the perception that biomechanical interventions are less important in those sports than fitness training, psychological preparation and tactics. There are some exceptions to this. They include analyses of fast bowling in cricket (see Bartlett *et al.*, 1996), studies of soccer skills (see Lees and Nolan, 1998) and limited studies of other games such as rugby and racquet sports. Even then, however, the focus is predominantly on isolated individual closed skills within the game. The lack of biomechanical analyses of team sports is regrettable, given that the most important requirement for success for any games player is *skill*, which is what most biomechanists try to understand and measure. The result is insufficient attention to the interaction of skill and successful play, clearly an important contribution to successful outcomes of games (Bartlett, 2000).

Notational analysis, on the other hand, has focused traditionally on team and match-play sports, studying the interactions between players and the movements and behaviours of individual team members – mostly open skills. Few studies of acrobatic, athletic and cyclic sports exist from a notational analysis perspective, despite the widespread use of dance notation systems. Clearly, however, notational analysis is far less relevant, if at all, to these sports than to team and match-play sports. Notational analysts have focused on general match indicators, tactical indicators and technical indicators and have contributed to our understanding of the physiological, psychological, technical and tactical demands of many sports. For example, in tennis, performance of a player may be assessed by the distribution of winners and errors around the court. In soccer, one aspect of a team's performance may be appraised by the ratio of goals scored to shots attempted by the team. Other examples, taken from published research, are shown in Table 1.

These indicators can be categorized as either scoring indicators or indicators of the quality of the performance. Examples of scoring indicators are goals, baskets, winners, errors, the ratios of winners to errors and goals to shots, and dismissal rates. Examples of quality indicators are turnovers, tackles, passes/possession, shots per rally and strike rate. Both types of indicator have been used as a measure of positive or negative aspects of performance in the analysis of a particular sport.

If presented in isolation, a single set of data (indicators for a performance of an individual or a team) can give a distorted impression of a performance, by ignoring other, more or less important, variables. From our reviews of recent research and the work of many consultants, it is clear that many analysts do not give sufficient data from a performance to represent fully the significant events of that performance. Presenting data from both sets of performers is often not enough to inform on the performance. For example, if two rugby teams are playing and team A have had 12 turnovers (handling errors that lead to a change in possession) and team B have had 8 turnovers, it would be tempting to assume that team B were having the better of the game. However, if team A had 48 possessions and team B 24 possessions, then their relative turnovers with respect to possessions (turnovers/possessions, T/P) will be:

$$(T/P)_A = 1/4$$

$$(T/P)_B = 1/3$$

Now team A could be said to be performing better than team B because, although they have conceded more turnovers, they are making these errors once in four possessions, whereas team B are making them in every three possessions.

The comparison of performances between teams, team members and within individuals is often facilitated if the performance indicators are expressed as ratios, as in the example above, such as winners to errors and goals to shots and the ratios of jump phases to overall jump distance. These proportions represent a binomial response variable (see Nevill *et al.*, 2002, this issue, for appropriate analytical methods). These examples are clearly non-dimensional as they divide a measure (e.g. number of goals or phase jump distance) by a similar measure (number of shots or total jump distance). Similar non-dimensional ratios are formed by expressing forces acting on the performer as ratios to body weight, and by normalizing EMG descriptors to the magnitude of that descriptor in a maximum voluntary contraction (MVC). More attention should be paid to this normalizing, or non-dimensional, approach. For example, Stockill (1994) found a difference in the magnitudes and times of occurrence of peak segment speeds in senior and junior cricket fast bowlers. However, when the times were normalized to the time from the start of delivery to release, these ratio times of peak speeds were the same; the ratio speeds were also comparable. Therefore, the difference between the groups was not in timing or in different segmental significance, but simply in speed of execution, a finding that is consistent with existing motor control literature (see, for example, Newell and Corcos, 1993).

Table 1. Published performance indicators used in notational analysis

Sport	Performance indicators
Soccer	Shots, passes, passing accuracy (see, for example, Hughes *et al.*, 1988; Winkler, 1996)
Rugby	Turnovers, tackles, passes/possession (see, for example, Carter, 1996)
Tennis	Winners to errors ratio, shots/rally, quality – service/return (see, for example, Taylor and Hughes, 1998)
Cricket	Strike rate, dismissal rate, fielding efficiency (see, for example, Hughes and Bell, 1999)

It is easy to see parallels with the use of non-dimensional analysis elsewhere; for example, indices such as the ratio of specific heats in high-speed flows, or non-dimensional groups such as Reynolds number in low-speed fluid mechanics. When flow conditions are very complex, so that the equations of motion cannot easily be solved, fluid mechanists use dimensional analysis to predict how one variable may depend on several others. This is then used to direct the course of an experiment or the analysis of experimental results. Sport science has not reached this degree of sophistication in the application of analysis of performance, but there are certain empirical recommendations that can be explored. Few of the non-dimensional ratios in performance analysis relate to the importance of various forces, with the exception of expressing ratios of forces to body weight. Many of the important non-dimensional groups in fluid dynamics are force ratios, and some of these are important for biomechanical analysis. The Reynolds number is the ratio of inertia to viscous forces; it is important in any sport in which drag forces are significant or in which lift forces are used to generate propulsion or improve performance. These sports include swimming, ski jumping, skiing, throws of an aerodynamic object – such as the discus or javelin – and ball games in which the ball spins quickly – such as golf and tennis. The Froude number is the square root of the ratio of inertia to gravity forces; it is important in sports in which the body moving through the water makes waves, for example fast front crawl swimming, sailing and canoeing.

As we have noted above, biomechanists use measured forces, performance distances and segmental peak speeds to compare performances. However, far more meaningful comparisons may be obtained by using simple ratios of force to body weight, partial distances or speed ratios. However, we need to be careful to avoid information being lost by normalization, which should be used to aid the evaluation of the measured results by adding relevant information. However, the most appropriate analysis of the results is best determined case by case and non-dimensionalizing is not always appropriate. An example of the last statement was provided by Fleissig (2001), who proposed comparing ground reaction forces between baseball pitchers of widely varying ages by normalizing forces (F) to body weight (W) to assess injury risk. However, tissue injury is related to the tissue stress (force/cross-sectional area), which is proportional to F/l^2, where l is an appropriate tissue dimension, such as radius, whereas F/W is proportional to F/l^3. Such incorrect use of normalization shows that performance analysts have much to learn from allometric scaling (see, for example, Schmidt-Nielsen, 1984).

Notational analysts use simple measures such as the number of shots per game in soccer. However, far more meaningful information is obtained from *ratios*, such as: number of shots per game to number of shooting opportunities; number of shots per game on goal to number of shots per game; and number of goals per game to number of shots per game (see Nevill *et al.*, 2002, for appropriate analytical methods for binomial response variables). In tennis, the winner and error distributions on their own are used to show relative strengths and weaknesses on the forehand and backhand; for example, 60% errors on backhand and 40% on forehand. However, such measures are meaningless unless expressed relative to the total shot distribution – the opponent could have been overloading the backhand (as is often the case) by 75% to 25% forehand: this dramatically changes the analysis. These simple examples demonstrate how misleading it can be to use only measured data to evaluate and analyse the complex factors that make for successful sport performance.

The aims of this paper are to examine the application of performance indicators in different team sports and, using the different structural definitions of games, to make general recommendations about the use and application of these indicators.

Performance indicators are also used in different ways. They have become increasingly popular in media coverage of sport; for example, possession, tackling and passing statistics in rugby and shot distribution patterns in cricket. They are also used in judging contests, in coaching and in other applications in sport science, such as monitoring team performance against that of rivals over a season in soccer (Olsen and Larsen, 1997). An interesting example of the usefulness of performance analysis is in ice hockey, where players are given a score after each game based on, for example, whether they scored or assisted and if the team scored or conceded when they were on the ice. These indicators are used both by the media and by the management when negotiating contracts. None of these applications is explicitly the focus of this paper.

Analysis of game structures

Read and Edwards (1992) classified formal games into three categories, net and wall games, invasion games, and striking and fielding games (see Fig. 3). This classification will be used in this paper as a starting point. The different types of sports are also subcategorized by the rules of scoring or ending the respective matches. These classes will be examined further to enable analysis of useful performance indicators and as a means of examining similarities and differences in the analysis of the different categories of game.

Net and wall games

Net games can be further sub-categorized into no-volley, bounce-and-volley and no-bounce games. Some examples of the more common sports that fall into these classes are shown in Fig. 4. The common wall games in Britain, squash and fives, are both bounce-and-volley games. There are many wall games from different parts of the world, each with their own rules that may well fall into the same sub-categories of the net games.

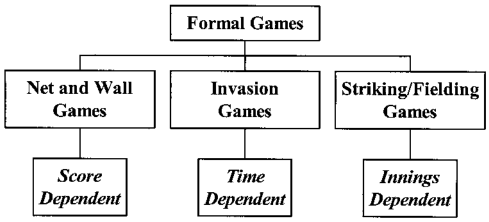

Fig. 3. Game classification (after Read and Edwards, 1992).

Despite the differences in the rules of these games, the performance indicators that have been used by different analysts are very similar. Figure 5 shows some of the different variables that contribute to success in all of these net and wall games.

The types of performance indicators that have been used in previous research further exemplify these variables; some are shown in Table 2. These general indicators have been classified as match descriptors, data that define the nature of the overall match, as well as biomechanical, technical and tactical. In some cases, these categories are similar, somewhat inevitably, since match descriptors and tactics will depend upon technical strengths and weaknesses, but we feel that keeping the distinction between the two will be useful.

All these indicators have been used as ways of indexing performances, without reference to other normative data and, in some cases, without reference to the opponents' data. The use of any of these variables in isolation is misleading.

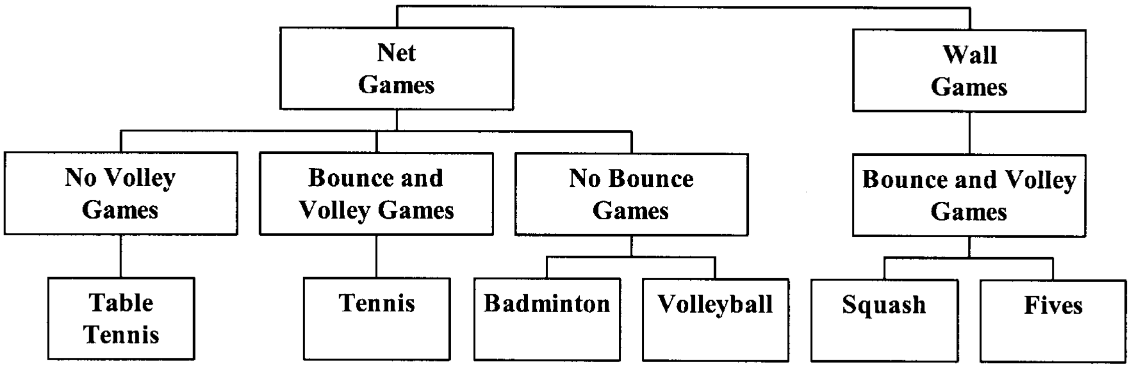

Fig. 4. Sub-categorization of net and wall games, with some common examples.

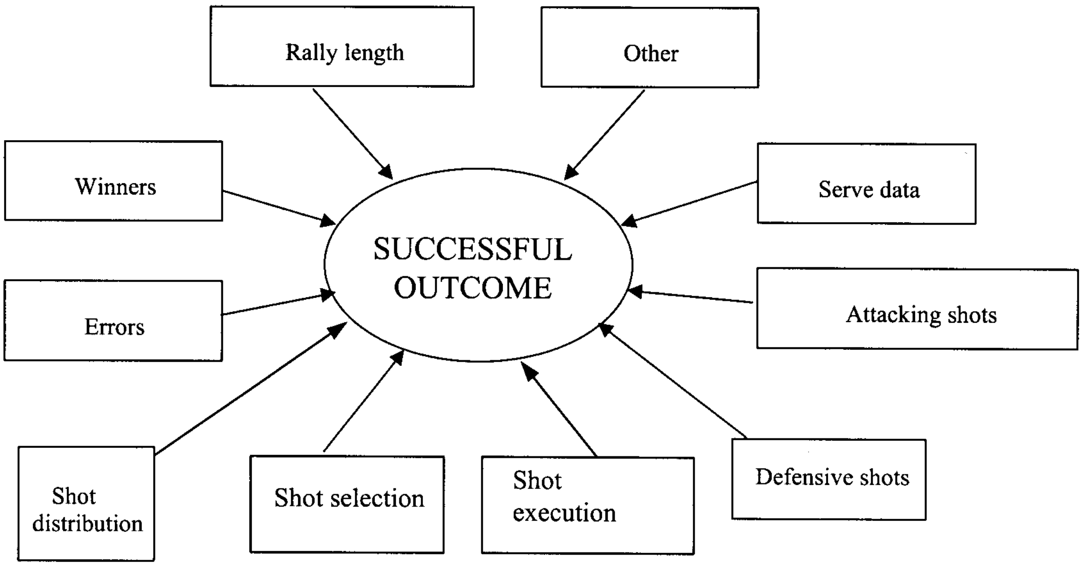

Fig. 5. Some factors that contribute to success or improved performance in net and wall games.

Table 2. Categorization of different performance indicators that have been used in analyses of net and wall games (example publications are indicated for each classification)

Match classification	Biomechanical	Technical	Tactical
No. of shots No. of rallies Scores Serve data 1st serve winner 2nd serve winner	Ball projection (release) velocity Racket, bat or hand speed at impact Kinematics of throwing or striking arm pronation/supination elbow extension sequence of segment movements Weight transfer into shot or stroke	Winners (W) Errors (E) Winning shot distribution Error shot distribution Serve data etc.	Shots per second Shots per rally Shot types – distribution Length of shot Winning shot distribution Error shot distribution Opponents winning shot distribution error shot distribution
For a review, see Hughes (1998); see also O'Donoghue and Liddle (1998), Taylor and Hughes (1998)	See, for example, Bartlett *et al.* (1995), Tang *et al.* (1995), Kasai and Mori (1998), Bahamonde (2000), Marshall and Elliott (2000)	For a review, see Hughes (1998); see also McGarry and Franks (1994)	For a review, see Hughes (1998); see also Furlong (1995), Hughes and Clarke (1995)

Match classification indicators

Consider the example of a squash match that had 250 shots in 50 rallies. What can be said about the match other than that the ratio of shots per rally was 5? This, as a performance indicator, is meaningless without some other reference point. If elite players, for whom the average equivalent data were approximately 1000 shots and 100 rallies, had played this match, then these figures would suggest that something unusual had taken place. It would seem that one player has beaten the other player very easily. If, however, the match had been played by recreational players, then the figures would suggest that the match was closely contested as the values are close to the averages for that class of player. So the same data can give two totally different messages. Providing comparative data from samples of the same playing standard allows the best assessment of the important features of any performances.

The effectiveness of a serve will always depend upon the returning skills of the opponent; even aces will vary with the positioning, reflexes and skill of the other player. Consequently, presenting serve data without the opponents' complementary data can be misleading. Equally important is to present the data with a frame of reference, as discussed with the previous match classification data. If Goran Ivanisevich has made 14 aces in a match, compared to 8 by his opponent, André Agassi, then this would seem to be a good performance for Ivanisevich and not so good for Agassi. If the average number of aces for elite players is 6 per match, then, by this standard, Ivanisevich is still having a good performance and Agassi is also playing well relatively. This is true, with the aggregate of elite players as a standard of comparison, and this contrast is a sound way of assessing players' strengths and weaknesses. Another way of assessing a particular performance of an individual or team is to compare that performance with the aggregated profile of previous performances at this standard of play. Ivanisevich averages 16 aces per match; Agassi averages 10 aces per match. Comparing the aces for this match to their individual averages of previous performances changes the interpretation of the data, with both players underachieving in this part of the game. These data have been presented in three ways, relative to each other, relative to players of the same standard and relative to their own profiles of previous performance. Each can give valuable comparisons, but it is important to remember that each of these comparisons illicits different interpretations of the quality of a performance. Consequently, to enable efficient interpretation of data, when using match classification indicators, it is very important to have comparative data from previous performances and also from peer group previous performances. Profiles of players will also vary depending upon whom they are playing; this, too, must be borne in mind when presenting information, ensuring that enough data are collected to present a normative profile (Hughes *et al.*, 2001).

The above comparisons could be made even more meaningful by incorporating biomechanical indicators, such as hitting speeds and segmental velocities. More important information could be provided if biomechanists developed qualitative analyses, which enabled the key features that contribute to a successful stroke to be recognized from direct observation. This happens, after all, in judging gymnastics and diving. Biomechanists have, to date, paid far too little attention to qualitative biomechanical analysis in their research, despite several well-known texts on the topic (e.g. Kreighbaum and Barthels, 1990; Knudsen and Morrison, 1997). These comments apply with equal validity to the technical and tactical indicators in racket sports, as well as to the other categories of games. The reliability and objectivity of measures based on human perceptions and judgements is clearly an issue. This needs to be addressed by validating such performance indicators against valid and reliable quantitative measures to which they are clearly related.

Technical indicators

Winners and errors are powerful indicators of technical competence and have often been used in research in notational analysis of net and wall games (Sanderson, 1983; Hughes, 1986; Brown and Hughes, 1995). However, there are dangers of misinterpreting a performance if they are used in isolation. Sanderson (1983) used a winner : error ratio as a performance indicator. He found that, for all standards of play in squash, if the winner : error ratio for a particular player in a match was greater than one, then that player usually won. (This was achieved with English scoring and a 19-inch tin.) Although this ratio is a good index of technique, it would be better used with data for both players, and the ratios should not be simplified or decimalized. Winner : error ratios of 0.9 and 1.1 respectively tell that the first player is losing but little else about the match. However, if the ratios had been presented as 9/10 and 44/40, then it is clear that this is a long hard match for players of this standard (103 rallies). The first player is playing defensively, making few errors but few winners. The second player is playing more aggressively, hitting many winners but also many errors. Perhaps the better way to present the processed data is as a combination of both forms, the former for an overview and the latter for more detail.

Rally end distributions – that is, winners and errors in the different position cells across the court – have often been used to define technical strengths and weaknesses (O'Donoghue and Liddle, 1998; Hughes *et al.*, 2000). The use of these distributions as indicators is valid as long as the overall distribution of shots across the court is evenly balanced on both sides of the court. However, this even distribution of shots across all the cells in a court rarely occurs in any net or wall game. For example, it could be that in a badminton match, player A has 20 drops from the backhand side of the court and 15 drops from the forehand. This would suggest that the backhand side of player A is the stronger and more aggressive flank. If, however, the overall total of shots on the backhand side was 120, and the equivalent total on the forehand was 60 shots, then the respective 'drops to total shots' ratio for each side is 20/120 (1 drop in 6 shots) or 0.167, and 15/60 (1 drop in 4 shots) or 0.25 (see Nevill *et al.*, 2002, for appropriate analytical methods for binomial response variables). Dispersions of winners and errors should be normalized to the totals of shots from those cells. It would be more accurate to represent the winner – or error – frequency, from particular position cells, as a ratio to the total number of shots from those cells.

Often rally end distributions are shot-specific (Hughes, 1986; O'Donoghue and Liddle, 1998), for example a distribution of volley winners in different position cells of a tennis court. The distribution of these volleys will reflect the respective volleying skills of the player and will indicate the areas of the court where the strengths and weaknesses lie. However, the pattern of winners will also depend heavily on the overall distribution of shots and the total distribution of volleys. So, by the same argument that was used to explain the need for normalizing the total shot distributions, the frequencies in this case should be standardized to the total distribution of volleys in each cell position and presented in both forms to give the complete picture.

Tactical indicators

Tactical performance indicators seek to reflect the relative importance of the use of pace, space, fitness and movement, and how players use these aspects of performance, of themselves and their opponents, targeting the technical strengths and weaknesses of the respective performers. These will be reflected in the ways that individuals and teams attack and defend, how they use the spaces in the playing surface and the variety of playing actions. The examples shown in Table 1 are representative of indicators used to identify these types of tactical play (Sanderson, 1983; McGarry and Franks, 1994).

The identification of the use of pace in net or wall games is not common; researchers have rarely used time bases to enable definition of the speed of play (Hughes and Clarke, 1995). When they are used, comparisons should be made to means of groups of peer performers. When players are trying to use perceived superior fitness in net or wall games, it will usually be reflected in the shots-per-rally indicators and the respective winner-to-error ratios. The latter will indicate which team or player is trying to sustain rallies in the hope of wearing down their opponents. Often the serve will be linked with control of the rally, sometimes through the scoring rules of the game. Therefore, linking the shots per rally to the respective serves is an additional way of using this indicator, which gives greater depth to the analysis and enables deeper insight into the tactics used in the game. Comparing these values to means of groups of peer performers will yield greater insight into the respective performances. The assessment of the importance of technical strengths and weaknesses is done using similar indicators to those discussed in the previous section – and the same provisos for their use apply.

Biomechanical indicators

The biomechanics of racket sports has received much less attention than other aspects of these games. For example, the proceedings of the first two Congresses of Science and Racket Sports (Reilly *et al.*, 1995; Lees *et al.*, 1998) contain only five and four biomechanics papers out of a total of 44 and 40, respectively. Five of these papers focused on tennis – one was a review; of the others, two were studies of the serve, one reported results on grip strength and one studied the effects of ball flight on several strokes. The emphasis on the serve reflects the closed nature of that skill compared with other skills, a trend that we shall see again for the other two categories of games discussed below. As we note below, biomechanical studies of the variability in stroke movement patterns and how these relate to the influence of opponents – and, in volleyball, the rest of the team – have received scant attention. Such studies in the future should afford great opportunities for collaboration between biomechanists and notational analysts.

Table 2 summarizes some of the biomechanical performance indicators most often measured in net or wall games. These range from the descriptive – such as bat or hand speed at impact – to variables that relate more to mechanisms. The importance of segmental sequencing is more complex for racket arm movements than for kicking movements of the leg (see below). This is because of the supination–pronation of the radio-ulnar joints and the external–internal rotation of the humerus. Although the relevance of these long axis rotations was recognized two decades ago (e.g. Waddell and Gowitzke, 1977), it was only recently that their role in the proximal-to-distal sequence was established (see Marshall and Elliott, 2000, for an overview). Their speed and timing could become important biomechanical performance indicators, although considerable scope remains for establishing the precise mechanisms that control and coordinate such strokes.

In all segmental analyses, the timing and speed of the segments should be normalized to the overall time of the stroke and the impact speed, so that we can ascertain whether differences between, for example, good, average and poor shots are due to timing differences or simply to speed.

Making detailed three-dimensional biomechanical measurements in racket sports – and many other games – is difficult and often impossible. It may also be unnecessary. If complex sports such as gymnastics and diving can be scored by judges in real time (perhaps not *always* validly or reliably), then why cannot biomechanists develop and validate qualitative indicators of successful stroke production in tennis, other racket sports and other games? Coaches already use similar indicators when they coach technique. This is an area that demands far more attention by performance analysts, interacting with coaches and players, to develop sets of valid and reliable skill-related performance indicators that can be assessed qualitatively in a game, or from video, together with other performance indicators.

Invasion games

Invasion games can be sub-categorized into goal-throwing games, try-scoring games and goal-striking games. Figure 6 shows these and some examples of common sports that fall into these categories. Despite the differences in the rules of these games, the performance indicators that have been used by different analysts are very similar.

As with net or wall games, we will consider the different variables that contribute to an improved performance. Figure 7 shows some of the factors that contribute to success in soccer. Although the different invasion games have very similar types of performance indicators, the specific terms used in each game, such as 'goal', 'try' and 'basket', make a general list impracticable. Consequently, we have used soccer as an example, but the same types of indicators have been used in all the other invasion games and are easily translated to other sports.

Some of the performance indicators that have been used in previous research in soccer are shown in Table 3. All these indicators have been, and are still, used as ways of indexing performances, without reference to other normative data and, in some cases, without reference to the opponents' data. As in the analysis of the net and wall games, the indicators can be classified as match descriptors, and indices of biomechanical, technical and tactical performances.

Match classification indicators

Match indicators for invasion games give simple information to describe and define that particular performance. Such information differs from sport to sport but, inevitably, there are similarities; in soccer, we have used examples such as scores, shots on and off

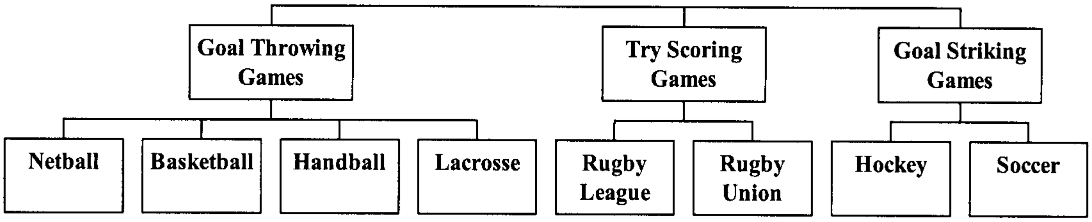

Fig. 6. Sub-categorization of invasive games, with some common examples.

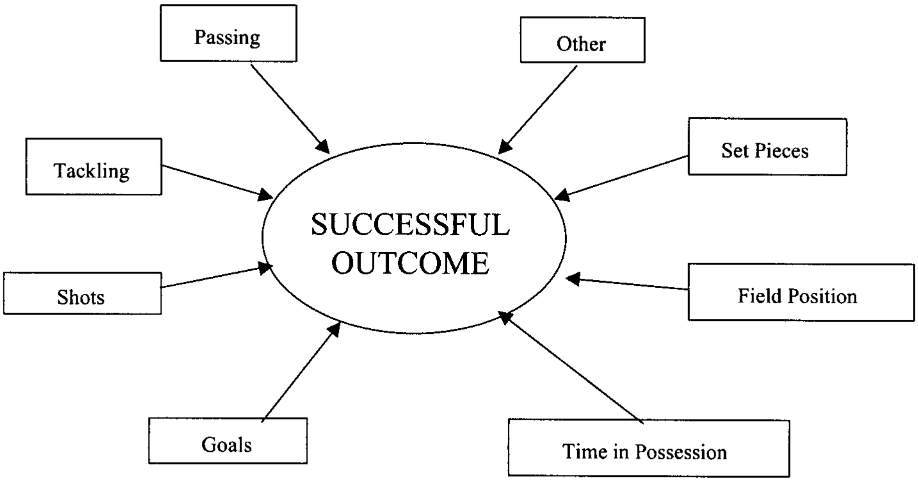

Fig. 7. Some factors that contribute to success or improved performance in invasive games.

Table 3. Categorization of different performance indicators that have been used in analyses of soccer, an example of invasion games (example publications are indicated for each classification)

Match classification	Biomechanical	Technical	Tactical
Scores No. of shots on target No. of shots off target Corners, etc. Crosses, etc.	Kicking Ball projection velocity and spin Kinematics and kinetics of kicking leg energy transfers sequencing of joint actions net joint forces and moments Throw-in Ball release velocity Kinematics of arms, including sequence of peak segment speeds	Passes to opposition Tackles won and lost Shots off target Dribbles Lost control On-target crosses Off-target crosses etc.	Passes/possession Pace of attack Shots Tackles won and lost Passing distribution Length of passes Dribbles etc.
For a review, see Hughes (1993)	For a review, see Lees and Nolan (1998); see also Putnam (1993)	For a review, see Hughes (1993); see also Pettit and Hughes (2001)	For a review, see Hughes (1993); see also Pettit and Hughes (2001)

target, corners and crosses. These can easily be translated to other sports. In rugby union, the equivalent indicators could be scores, penalties and drop goals – successful and otherwise – line-outs and incursions into the opponents' '22'. Similar examples could be inventoried for other invasion sports. The indicators for any of the invasion games can be seen to follow very similar rules of application to those of the net and wall games. Knowing the scores of the game will tell who won the match but, without knowing the average goals scored per match at this standard of play, it would not be possible to decide whether this was a high or low scoring performance. Similarly, the other match indicators can be seen to be potentially misleading without both the data of the opponents and the means of previous performances at this standard.

Technical indicators

Analysing and listing tactical indicators for invasion games such as shots on goal (soccer), missed shots at the basket (basketball), short corner conversions (field hockey), and so on, reflects the similarities again in the definition of these indicators. The differences in analyses will usually depend upon the questions the coaches have about their players, or the research question being posed.

Accuracy in passing is a common technical indicator in all invasion games (Hughes *et al.*, 1988; Carter, 1996). Any error or success frequencies of a player, unit or team should be normalized to the total number of passes made by that player, unit or team. Although it is a good index of technique for these sports, it should be used for both sets of players and, as explained above, the ratios could be presented first as simplified ratios or decimals and then as non-simplified, or non-decimalized, data. This will prevent any loss of information.

Loss of possession through any other action variables is another common way of assessing technical weaknesses in a team in an invasion game, whether the action variable is catching (netball), free hits (field hockey), line-outs (rugby union), tackles (rugby league), and so on. These should all be linked to totals of actions involved so that they do represent indices of the error frequency of the particular action with respect to that action's total frequency.

Other indices of technical success or failure – shots on goal (soccer), missed shots at the basket (basketball), short corner conversions (field hockey) – should also be normalized to these particular action totals. The total of this particular action variable could then be standardized by the overall number of possessions. This can also be seen to apply to all the indicators listed as examples used in research in soccer, and this rule should be applied to all technical indicators of invasion games.

Tactical indicators

Tactical performance indicators in invasion games seek to reflect the relative importance of teamwork, pace, fitness and movement, and to target the technical strengths and weaknesses of the respective performers – very similar to those of the net and wall games. The examples shown in Table 3 are representative of indicators used in recent research to identify these types of tactical play; examples in soccer include Reep and Benjamin (1968), Hughes *et al.* (1988), Partridge and Franks (1989a,b), Garganta *et al.* (1997), Olsen and Larsen (1997) and Pettit and Hughes (2001). Similar examples in other invasion games could be cited for their respective tactical indicators.

The nature of these tactical indicators can be seen to be the same as those in Table 2, and the rules for their use follow the same logic. If two players, A and B, have 4 and 6 shots on goal respectively, it is not appropriate to report that player B is having the better performance. What are the respective totals of shot attempts? Player A could have had 4 shot attempts, while player B could have had 12 shot attempts, thus resulting in shooting indices of 4/4 and 6/12 shots on target per attempt, respectively. Even this could be analysed further – how many shooting opportunities did each player have? Player A could have had a total of 12 opportunities but decided to pass 8 times instead of shooting; player B could have shot on all 12 of the possible opportunities that were presented. Does this now indicate that player B was having the better game? Analysis of the errors could show that the passing options adopted by player A were deemed better tactically for the team. This would lead to further analysis and so on. As noted above, simple analysis of the data induces simple interpretation, which is not always appropriate in sport. The indicators in Table 3 should all be normalized to the respective action totals.

Biomechanical indicators

In soccer, biomechanists have focused almost exclusively on kicking. Other invasive sports have received far less attention, except for basketball, where most studies have been of shooting skills (e.g. Miller and Bartlett, 1993, 1996). Soccer kicks occur in set pieces, such as penalties and free kicks, as well as in passing and shooting. Almost all of the reported studies are of maximum speed instep kicks of a stationary ball (Lees and Nolan, 1998). The many other kicks have been studied in far less detail, including passing – a crucial interaction between players, as noted above in the section on tactical performance indicators. The biomechanical performance indicators reported by researchers are summarized in Table 3. These vary – as with net and wall games – from the descriptive, such as ball projection velocity and spin, to those that cause the movements, such as net joint forces and moments. The sequencing of joint actions has also been studied, showing a clear proximal-to-distal kinematic sequence, unlike that for arm movements. This has led to the magnitudes and timings of segment peak speeds becoming recognized biomechanical performance indicators; their non-dimensionalizing – that is, normalizing to ball speed or total duration of a phase of the movement (see below for cricket) – has not yet been explored. Overall, the contribution of biomechanists to our understanding of various information-processing aspects of the game, including the control and coordination of movements, remains limited. One factor is the complexity of multi-segmental movements. This has led, *inter alia*, to different interpretations of the causes of segmental deceleration in kicks (see, for example, Putnam, 1993), calling into question fundamental biomechanical tenets about proximal-to-distal sequencing and momentum transfer along segment chains. Marshall and Elliott (2000) have recently demonstrated the lack of a clear proximal-to-distal sequence in the tennis serve.

There has been far less research into other skills in the sport. Studies of heading have concentrated exclusively on injury risk factors rather than performance variables (see, for example, Shephard, 1999). The throw-in has received some attention; the main biomechanical performance indicators for this skill are summarized in Table 3. Goalkeeping skills, crucial to successful outcome, have been largely neglected by biomechanists.

Soccer is a team game in which individual skills have to fit within the tactical demands of the game. It is unfortunate, although understandable, that biomechanists have, to date, concentrated on the more closed skills, such as kicking a stationary ball and the throw-in. Considerable light might be shed on interactive aspects of the game if performance analysts could agree on, and then measure and validate, the important skill-related performance indicators in passing movements, tackling and dribbling. This could add rich skill descriptions to the other outcome-focused performance measures. Although in a cross, for example, the outcome might relate primarily to the positions of the ball, attackers and defenders, the execution of the crossing technique is hardly irrelevant. David Beckham is a supreme exponent of this skill mainly because he reproduces the skill consistently under pressure.

Clearly, a cross is more difficult to analyse biomechanically than a kick or throw-in, but that should not prevent us from trying; after all, science does not progress by avoiding difficulties. As we have argued above, these measures should be qualitative so that they can be recognized in the game or from video by trained observers. They might include balance, in all these movements, minimizing the foot-to-ball distance and its variability in dribbling, and so on. Knudsen and Morrison (1997) advocated a 'critical factors' approach to qualitative skill analysis of soccer kicking (and other skills), each associated with observable clues. This approach might serve as a starting point for developing valid sets of qualitative skill indicators.

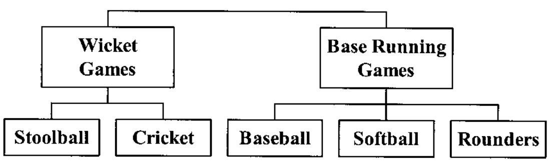

Fig. 8. Sub-categorization of striking and fielding games, with some common examples.

Striking and fielding games

These games can be sub-categorized into wicket games and base running games; Fig. 8 shows these and some examples of common sports that fall within these categories. Despite the differences in the rules of these games, the performance indicators that have been used by different analysts are very similar. As with the approach to net and wall games, we consider the different variables that contribute to an improved performance. Figure 9 shows some of the factors that contribute to success in cricket as an example of such games.

The types of performance indicators that have been used in previous research in cricket can also further exemplify these factors; some are shown in Table 4. All these indicators can be categorized by the same process used for the net and wall and invasion games.

Match classification indicators

The indicators to be discussed here for cricket can be seen to follow very similar rules of application to those of the net or wall games and invasion games. The interaction of the bowlers and the batters is the crux of the relative performances; a bowler having an outstanding performance can make an excellent batter appear ordinary and vice versa. Consequently, the match classification indicators can be seen to be potentially misleading without the opponents' data. As with all other sports, it is essential to place a team or individual performance in the context of previous performances; it is necessary then to compare each performance with the means of previous performances at this standard.

Technical indicators

These indicators for the example of cricket can be readily translated to other sports. They reflect the interactive nature of these sports – a batting performance is difficult to contextualize without some analysis of the bowling performance (and the fielding). Consequently, it can be seen that these variables are similar to the technical indicators discussed in the previous sections. The indices of technical success or failure, types of shot, type of ball, and so on, should also be normalized to either the particular action totals or the overall number of actions. This can also be seen to apply to all the indicators listed as examples used in research in striking and fielding games.

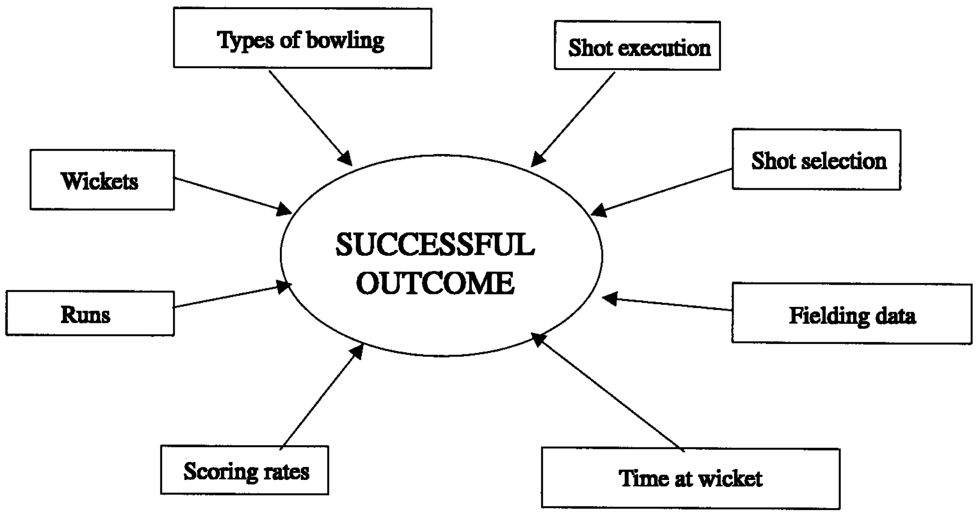

Fig. 9. Some factors that contribute to success or improved performance in striking and fielding games.

Tactical indicators

Some of the variables listed are a short-hand representation of the way actions have been analysed in cricket to interpret tactical decisions made by the players. The variables reflect the interaction of the batter and the bowler. For example, (types of ball)$_{shot}$ indicates the frequency of the different types of ball bowled that produced a particular shot made by a batsman. Similarly, (types of shot)$_{ball}$ indicates the frequency of the different types of shot made by a batsman from a particular ball bowled. These could be further subdivided into the areas of the pitch into which the batter hit the ball, depending upon the analyses.

These tactical indicators are similar to those in Tables 2 and 3, and the rules for their use follow the same logic. The indicators shown in Table 4 should, as above, all be normalized to the respective action totals.

Biomechanical indicators

The two striking and fielding games that have attracted most attention from biomechanists are baseball and cricket, with pitching and bowling respectively being the most studied skills. This skill selection reflects the importance of these skills to the two games and their closed nature compared with batting and fielding skills. The latter of these presents far greater problems in data acquisition and the analysis of the former relies not only on the skills of the batter but also those of the bowler. The selection also reflects an interest in the causes of the overuse injuries that often affect fast bowlers and baseball pitchers. The incidence of low back injuries in cricket, for example, has been shown to be far more prevalent in mixed-technique bowlers than in front-on or side-on bowlers (see Elliott *et al.*, 1996; Elliott, 2000).

Ball release speed is crucial to successful fast bowling performance. Biomechanical analysis of fast bowling has identified various indicators that contribute to ball release speed. These include run-up speed and delivery stride length. The technique used (side-on, front-on or mixed) is mainly used in identifying injury risk; counter-rotation of the shoulders also affects the acceleration path of the ball and, possibly, its release speed (see also Table 4 and Bartlett *et al.*, 1996).

The sequence of segment peak speeds has received some attention, although it is more constrained than in many sports by the rule that prohibits the extension of the delivery arm before release. Few studies have non-dimensionalized the peak speeds and their timing, although, as noted in the Introduction, this helps to identify whether differences between bowlers of different ages are due to speed or segmental coordination (Stockill, 1994).

There are far fewer studies of batting techniques in cricket; all of them do, however, focus on performance indicators rather than injury risk factors (see Stretch *et al.*, 2000, for a review). This research has concentrated on only a few of the many cricket strokes – the forward defensive and the front foot drives. The identified performance indicators are mostly kinematic, including the body position in the stance, the height of the backlift, the movements of the front foot and knee, and weight transfer. The kinematics of the arms and bat have also been measured, including pre- and post-impact bat (and ball) speeds. The grip force has also received some attention (Stretch *et al.*, 1998).

Many of these performance indicators have been shown to substantiate recognized coaching tips for the skill, but none has yet been shown to correlate with successful batting performance; more research into batting skill will be needed before such associations

Table 4. Categorization of different performance indicators that have been used in analyses of cricket, an example of striking and fielding games (example publications are indicated for each classification)

Match classification	Biomechanics	Technical	Tactical
Runs Wickets Overs Batting – individual data Bowling – individual data, etc.	Batting Timing of phases of stroke Front foot movement, front knee angle and weight transfer in stroke Arm kinematics and grip force Pre- and post-impact bat and ball speed Kinetic variability Bowling Run-up speed and ball release speed Class of technique (side-on, front-on, mixed) and shoulder counter-rotation in delivery stride	Types of shot Types of ball Types of dismissal Shot – position etc.	$(\text{Types of ball})_{\text{shot}}$ $(\text{Types of shot})_{\text{ball}}$ Field placing $(\text{Shots})_{\text{field-posn/ball}}$ etc.
See Hughes and Bell (2001)	See reviews by Bartlett *et al.* (1995), Stretch *et al.* (2000); see also Cook and Strike (2000) for a rare study of throwing in cricket	See Hughes and Bell (2001)	See Hughes and Bell (2001)

emerge. No non-dimensional indicators have been studied to date; this type of analysis could help to identify if differences between similar strokes are due to different segmental recruitment patterns or simply faster execution. Although Stretch *et al.* (1998) did measure variability in grip force, no attempt has been made to 'establish the role of compensatory variability in the skill of striking a moving cricket ball with a moving cricket bat' (Stretch *et al.*, 2000). This would mark an important step forward for biomechanists involved in performance analysis, as it would begin to identify interactions between the bowler and the batsman.

Such interactions are a key feature of games. For example, if a batter intends to play a cover drive to the boundary but instead hits the ball directly to extra cover or edges a catch to the slips, was the ball too good, could the batter not read cues or is there a technique defect? If the last of these, what is the problem? This approach could be developed to include the effects of field placement on the selection and successful execution of batting strokes and to evaluate fielding and catching skills.

Summary and conclusions

Through an analysis of game structures and the performance indicators used in recent research in performance analysis, basic rules emerge in the application of performance indicators to any sport. In every case, success or failure in a performance is relative, either to the opposition or to previous performances of the team or individual. To enable a full and objective interpretation of the data from the analysis of a performance, it is necessary to compare the collected data to aggregated data of a peer group of teams, or individuals, which compete at an appropriate standard. In addition, any analysis of the distribution of actions across the playing surface must be normalized with respect to the total distribution of actions across the area.

Performance indicators, expressed as non-dimensional ratios, *can* have the advantage of being independent of any units that are used; furthermore, they are implicitly independent of any one variable. Mathematics, fluid dynamics and physics in general have shown the benefits of using these types of parameters to define particular environments. They also enable, as in the example of bowling in cricket, an insight into differences between performers that can be obscure in the raw data. The particular applications of non-dimensional analysis are common in fluid dynamics, which offers empirical clues to the solution of multivariate problems that cannot easily be solved mathematically. Sport is even more complex, the result of interacting human behaviours; to apply simplistic analyses of raw sports data can be highly misleading. Further research could examine how normative profiles are established – how much data is required to define reliably a profile and how this varies with the different types of data involved in any analysis profile. Hughes *et al.* (2001) have completed an empirical study but this area of research needs more exploration and understanding.

Many of the most important aspects of team performance cannot be 'teased out' by biomechanists or match analysts working alone – a combined research approach is needed. This is particularly important for information processing, both in movement control and decision making. We should move rapidly to incorporate into such analyses qualitative biomechanical indicators that contribute to a successful movement. These should be identified interactively by biomechanists, notational analysts and coaches, sport by sport and movement by movement, and validated against detailed biomechanical measurements in controlled conditions. Biomechanists and notational analysts, together with experts in other sports science disciplines – in particular, motor control – should also seek to agree on, and measure, those performance indicators that are important from this perspective.

For the different types of games considered, it has become clear that the classification of the different action variables being used as performance indicators follow rules that transcend the different sports. The selection and use of these performance indicators depend upon the research questions being posed, but it is clear that certain guidelines will ensure a more clear and accurate interpretation of these data. These are summarized below.

Match classification

Always compare with opponents' data and, where possible, with aggregated data from peer performances.

Biomechanical

Compare with previous performances and with team members, opponents and those of a similar standard. As well as presenting the original data analysis, consider presenting normalized data when a maximum or overall value both exists and is important or when inter-individual or intra-individual across-time comparisons are to be made.

Technical and tactical

The technical and tactical variables should be treated in the same way. Always normalize the action variables with the total frequency of that action variable or, in some instances, the total frequency of all actions, and present these data with the raw frequency or processed data.

Most of the research community in performance analysis have not followed these simple guidelines to date. We feel that the utility of performance analysis could be considerably enhanced if its practitioners agreed and implemented such conventions in the future.

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