The coaching process is about enhancing performance by providing feedback about the performance to the athlete or team. Researchers have shown that human observation and memory are not reliable enough to provide accurate and objective information for high-performance athletes. Objective measuring tools are necessary to enable the feedback process. These can take the form of video analysis systems post-event, both biomechanical and computerised notation systems, or the use of in-event systems.

_Essentials of Performance Analysis in Sport 3rd Edition_ is fully revised with updated existing chapters and the addition of 12 new chapters. It is a comprehensive and authoritative guide to this core discipline of contemporary sport science. The book offers a full description of the fundamental theory of match and performance analysis, using real-world illustrative examples and data throughout. It also explores the applied contexts in which analysis can have a significant influence on performance. To this end the book has been defined by five sections.

In Section 1 the background of performance analysis is explained and Section 2 discusses methodologies used in notating sport performance. Current issues of performance analysis applied research, such as chance, momentum theory, perturbations and dynamic systems are explored in Section 3. Profiling, the essential output skill in performance analysis, is examined in depth in Section 4. The book’s final section offers invaluable applied information on careers available for performance analysts.

With extended coverage of contemporary issues in performance analysis and contributions from leading performance analysis researchers and practitioners, _Essentials of Performance Analysis in Sport 3rd Edition_ is a complete textbook for any performance analysis course, as well as an invaluable reference for sport science or sport coaching students and researchers, and any coach, analyst or athlete looking to develop their professional insight.

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Section I

The Background
1 The Importance of Feedback to Performance

Dana Maslovat and Ian M. Franks

1.1 Background

Participation in sport is typically undertaken with the intent to improve performance. One of the most important variables affecting learning and subsequent performance of a skill is feedback (see Schmidt et al., 2019, pp. 341–373, for an overview). Feedback involves sensory information resulting from a particular movement and one source of feedback is from the athlete’s own sensory channels (i.e., sight, hearing, touch, etc.), known as intrinsic or inherent feedback. Although some information from these sources provides a clear indication of performance (i.e., the ball missed the goal), the more detailed information (i.e., coordination of joint activity, amount of force produced, where to direct one’s attention) often requires experience in order for the performer to evaluate what they have just achieved. A second source of feedback usually comes from an outside source, typically a coach, and is meant to complement the intrinsic feedback. This information is known as extrinsic feedback and helps the athlete compare what was done to what was intended. This is usually achieved by drawing the attention of the performer to some key element of performance error.

For most complex skills, it is thought that extrinsic information accelerates the learning process and may be necessary to assist the athlete in reaching optimal performance levels (see Magill and Anderson, 2012 for a review). Presumably, the experience and background of the coach allows him or her to provide useful information about a given movement to aid in the development of that skill along with error detection and correction mechanisms. Thus extrinsic feedback can be thought of as a complement to intrinsic feedback. Extrinsic feedback can be delivered in two main forms; knowledge of results (KR) and knowledge of performance (KP). KR involves information pertaining to the outcome of the action (e.g., “you were 5 m away from the target”), while KP involves information pertaining to the movement pattern that caused the result (e.g., “you didn’t rotate your hips enough”). The majority of feedback from the coach involves KP, as often KR is inherently obvious from the athlete’s own feedback sources.
1.2 The Need for Valid and Reliable Feedback

In order to provide meaningful and reliable feedback, the coach must first observe and evaluate performance. Traditional coaching intervention has often involved subjective observations and conclusions based on the coach’s perceptions, biases and previous experiences. However, a number of studies have revealed that subjective observations are potentially both unreliable and inaccurate. Human memory systems have limitations, and it is almost impossible to remember accurately all the meaningful events that take place during an extended period of time (e.g., competition). These studies have shown, for example, that international-level soccer coaches could only recollect 30% of the key factors that determined successful soccer performance and were less than 45% correct in the post-game assessment of what occurred during a game (Franks and Miller, 1986, 1991). Furthermore even when experienced coaches are allowed to take notes whilst watching a game the probability of recalling critical events accurately was still only 59% (Laird and Walters, 2008).

If we consider how humans process information, the above results are not particularly surprising. Committing data to memory and then retrieving it at a later time is a complex process with many opportunities for interference. Distinctive portions of a competition (i.e., controversial decisions, exceptional technical performances, actions following stoppages in play, etc.) are often easily remembered by coaches and spectators alike, while non-critical events are more likely to be forgotten. This form of **highlighting**, when combined with emotions and personal bias of the observer, may cause a distorted perception of the game in total [for a review of episodic memory and its processes see Gronlund et al., (2007)]. Furthermore, our processing system has limitations which make it near impossible to view, assimilate and store all actions that take place within the playing area. These limitations result in the coach focusing attention on a specific area of play (usually what is considered to be the most critical area) with the peripheral action largely ignored.

Interestingly, the inaccuracies of subjective coaching observations are very similar to eyewitness reports during criminal situations, which are also typically considered to be unreliable and often incorrect (see Wright and Davies, 2007). In his paper on Eyewitness Testimony in Ulrich Neisser’s book “Memory Observed” Robert Buckhout (1982) explains succinctly the problem facing both eyewitnesses and coaches alike.

> The observer is an active rather than a passive perceiver and recorder; they reach conclusions on what they have seen by evaluating fragments of information and reconstructing them. They are motivated by a desire to be accurate as they impose meaning on the overabundance of information that impinges on their senses, but also by a desire to live up to the expectations of other people and to stay in their good graces.

Errors in eyewitness reports have been attributed to such things as increased arousal level (Clifford and Hollin, 1980), improper focus of attention (Wells and Leippe, 1981) or bias of the observer (Malpass and Devine, 1981). These factors are also present in a coaching environment. While accurate eyewitness testimony is of critical
The Importance of Feedback to Performance

importance during a criminal investigation, the same can also be said of coaching observations during competition situations, as this information forms the basis of the feedback presented by the coach.

The coaching process can be thought of as a complex ongoing cycle of performance, analysis and feedback, as shown in Figure 1.1 (flowchart adapted from Franks and Hughes, 2016). During and following athletic performance, it is the responsibility of the coach to observe and analyze the performance and combine this information with previous results and observances. This forms the basis for planning and implementation of upcoming practices to improve performance. Thus a successful coaching process hinges on the accuracy of collection and analysis of performance. Clearly, given the previous discussion, personal subjective observations are not sufficient and different observation tools are necessary for coaches to effectively instigate observable changes in athlete performance.

Surprisingly, given the importance of observation and analysis in the coaching process, there does not seem to be a standard or predefined system to monitor and evaluate performance. If reliance on the human information-processing system is problematic, we should find other ways to collect information during athletic performances. It should be apparent from the arguments presented earlier in this chapter that this information should be objective, unbiased and as comprehensive as possible. This can be achieved by creating a sport evaluation system, through the

Figure 1.1 Flowchart of performance, analysis, and feedback.
Source: adapted from Franks and Hughes, 2016.
use of notational analysis. One purpose of this book is to provide the reader with information pertaining to the development and implementation of such systems to improve coaching and performance in sport.

1.3 Video Feedback

Advances in technology have made the development of a notational analysis system a much less onerous task. Computerized recording allows for almost limitless storage, retrieval and analysis of data from a sporting competition in real time. Although these technologies will be further discussed in upcoming chapters, we introduce them now to highlight the importance of collecting objective information that can be used as feedback for athletes. Obvious benefits of interactive computer video analysis systems are that they can collect and store information that can be replayed to the athlete and reviewed numerous times. This reduces observer bias and enables a visual image of the event to be collected. It has been suggested that a potential drawback of using video is that too much information may be presented and the learner may not be able to concentrate on the important details of the skill. Thus, effective presentation of video feedback likely involves **cuing** from a coach (e.g., “focus on the release of the ball during the throw”) to highlight salient features during the viewing period (Kernodle and Carlton, 1992). Other alternatives include editing the videotape before showing it to an athlete or using slow motion to reduce the attention demands of the viewer. Use of video feedback also may change with the skill level of the learner. As opposed to experts, athletes at an early stage of learning will likely need considerable instruction from a coach to ensure they pay attention to the critical skill features and not be overwhelmed by the volume of information presented.

A further consideration is that analytical requirements differ greatly from sport to sport, thus resulting in a potentially very different video analysis system. For example, the coaching intervention for a team sport may differ greatly from that for an individual sport. Also, individual **closed** skills (in which events or the environment are predictable) may differ in their analysis when compared to individual **open** skills (in which events or the environment are unpredictable) (Del Rey, 1972). For individual sports involving closed skills (e.g., diving, gymnastics, golf), the focus of the evaluation typically revolves around how the pattern of movement is performed, as this is what primarily determines success in the sport. This is often achieved by comparing the movement pattern to a set criterion performance in order to determine where differences (errors) occur. To ensure this comparison is effective, clear criteria of expected performance must be established and understood by the athlete. Therefore, it is expected that the athlete should be involved in the analysis, such that they can improve their error detection and correction mechanisms to assist them with future attempts of the skill. When examining individual sports involving open skills (e.g., tennis, boxing, squash), a greater emphasis should be placed on the analysis of decision-making and tactics. Tactics play a much larger role in team sports, therefore the evaluation of performance should reflect this fact. For example, if we consider the involvement of the 22 players during a 90-minute soccer game, it becomes apparent that each player spends a majority of the time not in contact
with the ball. It is critical therefore that visual information related to “off the ball” behavior be taken into consideration.

1.4 Presenting Visual Feedback to Athletes

Even when reliable and valid information is collected about a performance the coach still has a number of decisions regarding how and when this feedback is to be presented (see Wulf and Shea, 2004 for a review). One consideration is the mode of presentation. Historically most coaches have tended to provide feedback verbally to their athletes; however, coaches are now realizing the benefits of presenting visual information in their instruction [a picture is really worth a thousand words (Weiss and Kimberley, 1987)]. One method of presenting this information to learners is via a model of performance. This model can be either the coach or peer demonstrating, or a video image (see Maslovat et al., 2010a for a review). This particular method of instruction has been shown to be more effective than simply allowing the performer to learn through practice alone (Ashford et al., 2006). The process of observing an image of correct performance has been extensively examined, due to the recent discovery of what is now known as the mirror neuron system (MNS): a network of neurons in the brain that activate during both physical performance and passive observation of a given movement (see Rizzolatti and Sinigaglia, 2010 for a review). This discovery provides neurophysiological evidence that during observation of a skill the body is experiencing similar neural activity in our motor system as if performing the skill, and may help explain why visual images of skilled performance are useful in accelerating the learning process. Watching a skill can be considered as a form of practice in which the brain performs all the same neurological actions required to perform the skill, yet the motor commands are inhibited from reaching the muscles and thus no movement occurs.

Interestingly, research has shown that the MNS is only active for movements with which the observer has had physical experience, or is part of the performer’s “motor repertoire”. For example, female ballet dancers show MNS activation while watching movements that are performed only by female dancers but do not show activation when observing movements that are performed only by male dancers (and vice versa for male ballet dancers), even though the dancers have watched movements of the opposite sex for many years (Calvo-Merino et al., 2006). In addition, watching a new dance routine did not produce MNS activation in observers, yet after five weeks of practicing the routine, MNS activation occurred during observation, confirming that motor experience with the task is necessary for this system to be active (Cross et al., 2006). The practical application of this research is that demonstrations should show the to-be-learned movement pattern at a skill level and manner similar to that being performed by the learner. For example, same-sex models have been shown to be more beneficial than opposite-sex models for observational learning (e.g., Griffin and Meaney, 2000). Similarly, showing a model that is learning the to-be-performed task can be a more effective demonstration than an expert model, especially if feedback is given pertaining to the errors made by the learning model (McCullagh and Caird, 1990). In both examples, it is
likely that the disparity between the motor repertoire of the observer and modeled movement pattern did not allow for MNS activation and thus reduced the effectiveness of the demonstration.

If familiarity with the model is an important factor in determining the usefulness of a demonstration, then it would be logical to assume that viewing oneself perform the action would be the most effective form of modeling. Indeed, self-observation has been considered to be superior to viewing another individual due to greater similarity in neural activation between observation and execution (Holmes and Calmels, 2008). Self-observation can be used as a feedback method, in which the observer watches the best attempt of the skill he or she has just performed, or in a feedforward method, in which a video of past performances is artificially manipulated to show the individual performing movements at a higher level than he or she can actually perform (known as self-modeling; see Dowrick, 1999 for a review). While both types of self-observation can be effective, feedforward self-modeling has been shown to significantly improve an athlete’s performance (Ste-Marie et al., 2011a; 2011b; see also Maile, 1985, as cited in Franks and Maile, 1991); however, it is important to realize that this method requires substantial time and effort by the coach to edit and assemble the appropriate videos.

1.5 Precision and Timing of Feedback

In addition to the mode of feedback presentation, the coach must also consider the precision and timing of this feedback. More precise feedback seems to be of more benefit; however, this does seem to be dependent on the skill level of the athlete. As the athlete’s skill level increases, so too must the precision of the feedback. Also dependent on skill level appears to be the amount of feedback. Although large amounts of feedback may be beneficial early on in the learning process, too much feedback later in learning may actually impair performance. It is thought that high-frequency feedback may result in a dependence on that feedback by the athlete, and therefore not allow him or her to perform correctly when the extrinsic feedback is no longer present such as during a competition situation (Schmidt et al., 1989). Thus, error detection and correction mechanisms may develop faster with reduced feedback or feedback that guides the athlete to the correction rather than simply changing behavior.

In terms of timing of feedback presentation, feedback during a skill will often interfere with performance as the athlete’s attention is divided between the feedback source and the skill itself (Maslovat et al., 2009). It also appears that feedback immediately following performance may not be optimal. Once an athlete performs a skill he or she should be encouraged to evaluate the performance and then compare the intrinsic feedback to the desired (even predicted) result. Providing feedback during this “self-reflection” timeframe can interfere with this process and in some cases may retard skill development, again by disrupting internal error detection and correction mechanisms (see Salmoni et al., 1984 for a review of KR timing). Thus although presentation of feedback is a critical role of the coach, there are many considerations to ensure this feedback is given correctly to maximize learning for the athlete.
1.6 Feedback and Attentional Focus

As we have summarized thus far, in order to optimize performance it is critical to understand the role of extrinsic feedback and carefully consider how and when feedback is presented. An area that has gained recent interest is the examination of feedback regarding where the performer should focus their attention (see Wulf, 2007 for a review). Attentional focus can broadly be considered as either internal (focus on one’s own movements) or external (focus on the environment or apparatus involved in the task). Although the difference between these foci can be subtle, research indicates that an external focus of attention improves skill learning, may prevent reliance on external feedback, and may even decrease the incidence of “choking” under pressure.

In one of the first studies to examine the role of the learner’s focus of attention, Shea and Wulf (1999) used a balancing task and instructed participants to focus on either their feet (internal focus) or the platform on which they were standing (external focus). Participants with an external focus outperformed those with an internal focus, a result that has been replicated many times with a variety of lab and sport-based tasks (e.g., Hodges and Franks, 2001; Wulf et al., 2002). In addition to the learning benefits, external attention may also allow for greater frequency of extrinsic feedback. Typically, providing feedback after every trial can actually hinder performance, as the learner may become too dependent on the extrinsic feedback, a situation known as the “guidance hypothesis” (Salmoni et al., 1984). However, an external focus of attention seems to negate the guidance effects of feedback, thus allowing for greater feedback frequency without the fear of overdependence by the performer (Wulf et al., 2002: 2010).

Another benefit of an external focus of attention relates to the phenomenon known as “choking”, whereby a skilled performer produces sub-optimal performance under the extreme pressures of competition (see Beilock and Gray, 2007 for a review). One explanation for choking suggests that highly practiced tasks are typically performed in an automatic nature, with little attention focused internally. However, under pressure the learner may shift attention to an internal focus, which is detrimental to performance (Beilock and Carr, 2001). Thus, feedback from an external source that encourages a shift in attention back to an external source (e.g., focus on the back of the rim for a basketball free throw rather than the release of the ball from the hand) may reduce or dispel the potentially harmful effects of choking, allowing the athlete to perform at an optimal level, even in high-pressure situations.

1.7 Summary

Extrinsic feedback provided by a coach has the potential to greatly affect performance by the athlete. Historically, coaching intervention has been based on subjective observations, which have been shown to be problematic. Bias, highlighting, limitations of memory and observational difficulties are just a few of the pitfalls associated with a subjective evaluation. Thus, successful coaching hinges on the collection and analysis of unbiased, objective data. Coaches should also carefully consider the many factors associated with feedback presentation, such as content,
amount and timing. Of prime consideration is the mode of feedback, with the use of appropriate visual demonstrations being one of the most useful methods to employ. In addition, thought should be given to providing feedback as to where the performer should direct their attention, in order to optimize performance within the stressful competition environment.
2 What is Performance Analysis?

Mike Hughes and Roger Bartlett

2.1 Notational Analysis

2.1.1 Introduction

Notational analysis is an objective way of recording performance, so that critical events in that performance can be quantified in a consistent and reliable manner. This enables quantitative and qualitative feedback that is accurate and objective. No change in performance of any kind will take place without feedback. The role of feedback is central in the performance improvement process, and by inference, so is the need for accuracy and precision of such feedback. The provision of this accurate and precise feedback can only be facilitated if performance and practice are subjected to a vigorous process of analysis.

Augmented feedback has traditionally been provided by subjective observations, made during performance by the coaches, in the belief that they can accurately report on the critical elements of performance without any observation aids. Several studies not only contradict this belief, but also suggest that the recall abilities of experienced coaches are little better than those of novices, and that even with observational training, coaches’ recall abilities improved only slightly. Furthermore, research in applied psychology has suggested that these recall abilities are also influenced by factors that include the observer’s motives and beliefs. The coach is not a passive perceiver of information, and as such his or her perception of events is selective and constructive, not simply a copying process. This importance of feedback to performance improvement, and the limitations of coaches’ recall abilities alluded to above, implies a requirement for objective data upon which to base augmented feedback, and the main methods of “objectifying” these data involve the use of video / notational analysis (Hughes and Franks, 1997, p. 11).

Coaches have been aware, consciously or unconsciously, of these needs for accuracy of feedback and have been using simple data gathering systems for decades. More recently, sports scientists have been using notational analysis systems to answer fundamental questions about game play and performance in sport. An early work, over some decades, on analysis of soccer was picked up by the then Director of Coaching at the Football Association, and this had a profound effect on the patterns of play in British football – the adoption of the “long ball” game. Generally, the first publications in Britain of the research process by notational analysis of sport were
in the mid 1970s, so as a discipline it is one of the more recent to be embraced by sports science. The publication of a number of notation systems in racket sports provided a fund of ideas used by other analysts. Because of the growth and development of sports science as an academic discipline, a number of scientists began using and extending the simple hand notation techniques that had served for decades. This also coincided with the introduction of personal computers, which transformed all aspects of data gathering in sports science. Currently hand and computerised notation systems are both used to equal extents by working analysts, although the use of computer databases to collate hand-notated data post-event makes the analyses much more powerful.

The applications of notation have been defined as:

1. tactical evaluation,
2. technical evaluation,
3. analysis of movement,
4. development of a database and modelling, and
5. for educational use with both coaches and players.

Most pieces of research using notation, or indeed any practical applications working directly with coaches and athletes, will span more than one of these purposes.

2.1.2 The Applications of Notation

2.1.2.1 Tactical Evaluation

The definition of tactical patterns of play in sports has been a profitable source of work for a number of researchers. The maturation of tactics can be analysed at different levels of development of a specific sport, usually by means of a cross-sectional design. The different tactics used at each level of development within a sport will inevitably depend upon technical development, physical maturation and other variables. The “maturation models” have very important implications for coaching methods and directions at the different stages of development in each of the racket sports. These tactical “norms” or “models”, based upon both technique and tactics, demonstrate how the different applications, defined above, can overlap.

Sanderson and Way (1979) used symbols to notate 17 different strokes, as well as incorporating court plans for recording accurate positional information. The system took an estimated 5–8 hours of use and practice before an operator was sufficiently skilful to record a full match actually during the game. In an average squash match there are about 1000 shots, and an analyst using this system will gather over 30 pages of data per match. Not only were the patterns of rally-ending shots (the Nth shot of the rally) examined in detail, but also those shots that preceded the end shot (N−1), to a winner or error, and the shots that preceded those (N−2), to a winner or error. In this way the rally-ending patterns of play were analysed. Not surprisingly, processing the data for just one match could take as long as 40 hours of further work. The major emphasis of this system was on the gathering of information concerning
What is Performance Analysis?

“play patterns” as well as the comprehensive collection of descriptive match data. Sanderson felt that “suggestive” symbols were better than codes, being easier for the operator to learn and remember. The main disadvantages of this system, as with all longhand systems, was the time taken to learn the system and the large amounts of data generated, which in turn needed so much time to process.

The 1980s and ’90s saw researchers struggling to harness the developing technology to ease the problems inherent in gathering and interpreting large amounts of complex data. Hughes (1985) modified the method of Sanderson and Way so that the hand-notated data could be processed on a mainframe computer. Eventually, the manual method was modified so that a match could be notated in-match at courtside directly into a microcomputer. This work was then extended to examine the patterns of play of male squash players at recreational, county and elite levels, thus creating empirical models of performance, although the principles of data stabilisation were not thoroughly understood at the time. This form of empirical modelling of tactical profiles is fundamental to a large amount of the published work in notational analysis. Comparing the patterns of play of successful and unsuccessful teams or players in elite competitions, world cup competitions, for example, enables the definition of those performance indicators that differentiate the two groups. This research template has been used in a number of sports to highlight the tactical parameters that determine success, and it has been extended in tennis to compare the patterns of play that are successful on the different surfaces on which the major tournaments are played.

Most of the examples for tactical applications of notation could appear in the other sections of direct applications of notational analysis, but their initial aims were linked with analysis of tactics. The interesting theme that is emerging, from some of the recent research, is that the tactical models that are defined are changing with time, as players become fitter, stronger, faster, bigger (think of the changes in rugby union since professionalisation in 1996), and the equipment changes – for example, the rackets in all the sports have become lighter and more powerful. Over a period of less than 15 years the length of rallies in squash, for elite players, has decreased from about 20 shots, to about 12 shots per rally. Reviews (Croucher, 1996; Hughes, Hughes and Behan, 2007; Nevill, Atkinson and Hughes, 2008;) of the application of strategies using notational analysis of different sports outline the problems, advantages and disadvantages associated with this function.

2.1.2.2 Technical Evaluation

To define quantitatively where technique fails or excels has very practical uses for coaches, in particular, and also for sports scientists aiming to analyse performance at different levels of development of athletes.

Winners and errors are powerful indicators of technical competence in racket sports and have often been used in research in notational analysis of net-wall games. It has been 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 decimalised. Rally-end distributions, winners and errors in the different position cells across the court, have often been used to define technical strengths and weaknesses. This use of these distributions as indicators is valid as long as the overall distribution of shots across the court is evenly balanced. This even distribution of shots rarely occurs in any net or wall game. Dispersions of winners and errors should be normalised with respect 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.

Similarly, performance indicators such as shots are insufficient and need to be expressed with more detail, for example shot to goal ratios (soccer). Even these, powerful as they are, need to be viewed with caution and perhaps integrated with some measure of shooting opportunities. In rugby union, simple numbers of rucks and mauls won by teams may not give a clear impression of the match; the ratio of “rucks won” to “rucks initiated” is a more powerful measure of performance. This too could be improved by some measure of how quickly the ball was won in critical areas of the pitch.

Many coaches seek the template of tactical play at the highest level for preparation and training of both elite players and/or teams, and also for those developing players who aspire to reach the highest position. Particular databases, aimed at specific individuals or teams, can also be used to prepare in anticipation of potential opponents for match play. This modelling of technical attainment has been replicated in many sports and forms the basis of preparation at the highest levels by the sports science support teams.

2.1.2.3 Movement Analysis

Reilly and Thomas (1976) recorded and analysed the intensity and extent of discrete activities during match play in field soccer. With a combination of hand notation and the use of an audio tape recorder, they analysed in detail the movements of English first-division soccer players. They were able to specify work-rates of the different positions, distances covered in a game and the percentage time of each position in each of the different ambulatory classifications. Reilly continually added to this database, enabling him to clearly define the specific physiological demands in not just soccer, but later all the football codes. This piece of work by Reilly and Thomas has become a standard against which other similar research projects can compare their results and procedures, and it has been replicated by many other researchers in many different sports.

Modern tracking systems have taken the chore out of gathering movement data, which was the most time-consuming application of notational analysis, and advanced computer graphics make the data presentation very simple to understand. Modelling movement has created a better understanding of the respective sports and has enabled specific training programmes to be developed to improve the movement patterns, and fitness, of the respective athletes.
2.1.2.4 Development of a Database and Modelling

Teams and performers often demonstrate a stereotypical way of playing and these are idiosyncratic models, which include positive and negative aspects of performance. Patterns of play will begin to establish themselves over a period of time but the greater the database then the more accurate the model. An established model provides for the opportunity to compare single performances against it.

The modelling of competitive sport is an informative analytic technique because it directs the attention of the modeller to the critical aspects of data that delineate successful performance. The modeller searches for an underlying signature of sport performance, which is a reliable predictor of future sport behaviour. Stochastic models have not yet, to our knowledge, been used further to investigate sport at the behavioural level of analysis. However, the modelling procedure is readily applicable to other sports and could lead to useful and interesting results.

Once notational analysis systems are used to collect amounts of data that are sufficiently large to define “norms” of behaviour, then all the ensuing outcomes of the work are based upon the principles of modelling. It is an implicit assumption in notational analysis in presenting a performance profile of a team or an individual that a “normative profile” has been achieved. Inherently this implies that all the variables that are to be analysed and compared have all stabilised. Most researchers assume that this will have happened if they analyse enough performances. But how many is enough? In the literature there are large differences in sample sizes.

These problems have very serious direct outcomes for the analyst working with coaches and athletes, in both practical and theoretical applications. It is vital when analysts are presenting profiles of performance that some measure of the stability of these data is known (Hughes, Evans and Wells, 2001; O’Donoghue, 2005; James, Mellalieu and Jones, 2005), otherwise any statement about that performance is spurious. The whole process of analysis and feedback of performance has many practical difficulties. The performance analyst working in this applied environment will experience strict deadlines and acute time pressures defined by the date of the next tournament, the schedule and the draw. The need then is to provide coaches with accurate information on as many of the likely opposition players, or teams, in the amount of time available. This may be achieved by the instigation of a library of team and/or player analysis files, which can be extended over time and receive frequent updating. Player files must be regularly updated by adding analyses from recent matches to the database held on each player.

Finally, some scientists have considered the use of a number of sophisticated techniques, such as neural networks, chaos theory, fuzzy logic and catastrophe theory, for recognizing structures, or processes, within sports contests. Each of these system descriptions, while incomplete, may assist in our understanding of the behaviours that form sports contests. Furthermore, these descriptions of sports contests need not be exclusive of each other, and a hybrid type of description (or model) may be appropriate in the future, a suggestion that remains only a point of conjecture at this time.
2.1.2.5 Educational Applications

It is accepted that feedback, if presented at the correct time and in the correct quantity, plays a great part in the learning of new skills and the enhancement of performance. Recent research, however, has shown that the more objective or quantitative the feedback, the greater effect it has on performance. However, in order to gauge the exact effect of feedback alone, complete control conditions would be needed in order to minimise the effect of other external variables, which is by definition impossible in real competitive environments. This experimental design is also made more difficult because working with elite athletes precludes large numbers of subjects.

Hughes and Robertson (1997) were using notation systems as an adjunct to a spectrum of tactical models that they have created for squash. The hand notation systems were used by the Welsh national youth squads, the actual notation being completed by the players, for the players. It is believed that in this way the tactical awareness of the players, doing the notation, was heightened by their administration of these systems. This type of practical educational use of notation systems has been used in a number of team sports, soccer, rugby union, rugby league, basketball, cricket, and so on, by players in the squads, substitutes, injured players, as a way of enhancing their understanding of their sport, as well as providing statistics on their team.

2.2 Biomechanics – What Is the Biomechanical View of Performance Analysis?

When the BOA set up the Performance Analysis Steering Group, bringing together biomechanists and notational analysts, there was some scepticism as to whether these two groups of sport scientists had enough in common to make the Group meaningful. After all, sports biomechanics is concerned with fine detail about individual sports techniques while notational analysts are more concerned with gross movements or movement patterns in games or teams. Furthermore, notational analysts are more concerned with strategic and tactical issues in sport than with technique analysis and the two disciplines do not share a common historical background.

However, the similarities between the two groups of analysts are far more marked than the differences. A crucial similarity is evident when we look at the other sport science disciplines: sports psychology and physiology (including nutrition) essentially focus on preparing the athlete for competition. Performance analysts, in contrast, focus on the performance in competition to draw lessons for improving performance and this is true of both notational and biomechanical analysis. Both are fundamentally concerned with the analysis and improvement of performance. Both are rooted in the analysis of human movement. Both make extensive use of video analysis and video-based technology. Although both evolved from manual systems, they now rely heavily on computerised analysis systems. Both have a strong focus on data collection and processing. Both produce vast amounts of information – this is sometimes claimed to be a strength of both sports biomechanics and notational analysis; however, it often requires careful attention in providing feedback to athletes and coaches. Many of these important topics were covered in a special issue of the
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In addition, biomechanists and notational analysts both emphasise the development of systematic techniques of observation. This is more obvious in notational analysis and, perhaps, in the somewhat-neglected “qualitative” analysis approach of biomechanics than in fully quantitative “computerised biomechanical analysis”, which seems somewhat out of fashion with coaches at present – for reasons that we will explore in a later chapter. Both have a strong focus on the provision of feedback to the coach and performer to improve performance and each group is now learning and adopting best practice from the other.

Biomechanics and notational analysis are, somewhat mischievously if with some justification, accused by other sports scientists of lacking theoretical foundations and being over-concerned with methodology: this might explain the attraction of notational analysis and qualitative biomechanical analysis to coaches as they are immediately seen as being of practical relevance. However, theoretical models do exist in both biomechanics and notational analysis. These can also be effectively represented graphically – by flowcharts for notational analysis and hierarchical technique models for biomechanics (Bartlett, 1999; Hughes and Franks, 1997). Both disciplines have “key events” as important features of their theoretical foundations. This again helps to present information clearly and simply to coaches and sports performers, as evidenced by the current popularity of “coach-friendly” biomechanical analysis packages, such as Dartfish (www.dartfish.com/en/), Silicon COACH (www.siliconcoach.com) and Quintic (www.quintic.com). These theoretical models can, at least in principle, be mapped onto the sophisticated approaches of artificial intelligence, such as expert systems and neural net processing, hopefully offering exciting developments in performance enhancement by the next decade. The theoretical models are highly sport, or technique, specific but with general principles, particularly across groups of similar sports or techniques. Both have strong theoretical and conceptual links with other areas of sport science and information technology, for example the dynamic systems approach of motor control.

Many practical issues which impinge strongly on performance improvement are common to biomechanics and notational analysis. These include optimising feedback to coaches and athletes, the management of information complexity, reliability and validity of data and future exploitation of the methods of artificial intelligence. Sharing of approaches and ideas has already began to have mutual benefits as was evident in the very successful NCF/BOA High-performance Coaches workshop held in Cardiff at Easter 1999, which was highly acclaimed by many of the coaches attending. But since then many biomechanists have clung to their more traditional roles and have shied away from direct involvement in performance analysis. Fortunately recent research into dynamic systems has opened common ground for notational analysts (perturbations and critical incident theories), biomechanists (variance in performance) and motor control analysts (skill-acquisition theory) – see McGarry and Franks (1996), Davids et al. (2003b), Hughes (2005) and Kelso (1997).

But, you might ask, is performance analysis really helpful in improving performance? Perhaps your sport uses sports psychologists, nutritionists, physiologists...
and conditioning consultants but no performance analyst of any “hue”. Well, biomechanics are employed in the sports science support teams for athletics, gymnastics, swimming and speed skating. Notational analysts are employed, for example, for netball, badminton, hockey, squash, sailing, cycling, canoeing, badminton, Taekwando and disability basketball. Cricket, from the ECB to county cricket clubs, uses the services of biomechanists and notational analysts, as do many other sports, such as golf and tennis (biomechanics) and rugby and soccer (notational analysis).

As to their value for the coach, biomechanics identifies the features of performance that relate to good and bad techniques, thereby helping to identify how techniques can be improved. It also facilitates comparative analysis of individual performers and helps to identify injurious techniques. The latter is well exemplified by the contribution made by biomechanists to establishing the link between low back injury and the mixed technique in cricket fast bowling (for a brief review, see Elliott et al., 1996). Notational analysis identifies the performance indicators that relate to good and bad team performance and identifies good and bad performances of team members. It, therefore, facilitates comparative analysis of teams and players. In addition, it helps to assess the physiological and psychological demands of various games (for examples, see Bartlett, 2001).

Of all the sports sciences, performance analysis is the one most influenced by technological changes. Digital video and improvements in computer processing speeds and capacities have transformed biomechanical and notational analysis almost beyond recognition in the last ten years, enabling faster turn-around times for feedback (another topic for a later article) and a far more realistic response to coaches and performers. The latter is evident, for example, by comparing crude “stick-figure” displays (Figure 2.1) of earlier biomechanical analyses (often only produced weeks after filming) by the models available in real-time from modern optoelectronic systems such as SIMM (Figure 2.2) (from the Motion Analysis Corporation of Santa Rosa, CA: www.motionanalysis.com) and Vicon (from Oxford

![Figure 2.1 Stick figure.](image-url)
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Dynamics: www.vicon.com). These systems are not yet routinely used by coaches and performers, but this is changing rapidly: the SRA is looking to install such a system for training and feedback in the squash centre in Manchester, where the English Institute of Sport Regional Centres have a staff of 29 analysts who use both notation and biomechanical software with a variety of sports, but mainly squash and cycling.

2.3 Conclusions

The use of systematic observation instruments provides researchers with a method of collecting behavioural data on both the coach and the athlete. These data can be analysed and processed in a variety of ways to provide a descriptive profile that can be used for giving both the athlete and the coach feedback about their actions. Advances in both computer and video technology can make this observation process more efficient and also provide the coach with audio-visual feedback about their