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# Technique analysis in sports: a critical review

ADRIAN LEES*

*Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, 15–21 Webster Street, Liverpool L3 2ET, UK*

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This paper critically reviews technique analysis as an analytical method used within sports biomechanics as a part of performance analysis. The concept of technique as 'a specific sequence of movements' appears to be well established in the literature, but the concept of technique analysis is less well developed. Although several descriptive and analytical goals for technique analysis can be identified, the main justification given for its use is to aid in the improvement of performance. However, the conceptual framework underpinning this process is poorly developed with a lack of distinction between technique and performance. The methods of technique analysis have been divided into qualitative, quantitative and predictive components. Qualitative technique analysis is characterized by observation and subjective judgement. Several aids to observation are identified, including phase analysis, temporal analysis and critical feature analysis. Although biomechanical principles of movement can be used to form judgements about technique, little agreement exists about the number and categories of these principles. A 'deterministic' model can be used to identify factors that affect performance but, in doing so, technique variables are frequently overlooked. Quantitative technique analysis relies on biomechanical data collection methods. The identification of key technique variables that affect performance is a major issue, but these are poorly distinguished from other variables that affect performance. Quantitative analysis is not suitable for establishing the characteristics of the whole skill, but new methods, such as the use of artificial neural networks, are described that may be able to overcome this limitation. Other methods based on modelling and computer simulation also have potential for focusing on the whole skill. Predictive technique analysis encompasses these developments and offers an attractive interface between the scientist and coach through visual animation methods. I conclude that biomechanists need to clarify the underpinning rationale, framework and scope for the various approaches to technique analysis.

*Keywords*: predictive, qualitative, quantitative, technique analysis.

## Introduction

'Technique analysis' is the term given to an analytical method that is used to understand the way in which sports skills are performed and, through this understanding, provide the basis for improved performance. It is used primarily within the teaching and coaching of sports skills and within the field of sports biomechanics, although it is equally applicable in the clinical setting. Even though the term technique analysis is appealingly simple, it is infrequently used in this specific form. It appears more frequently as the 'analysis of technique' (Elliott, 1999), 'analysis of (sports) techniques' (Bunn, 1972; Hay, 1973), 'biomechanical analysis of technique' (Bartlett, 1999), 'biomechanical analysis of movements' (Adrian and Cooper, 1995), 'investigations of sports techniques' (Bober, 1981), 'analysis of sports skills' (Carr, 1997), 'analysis of human movements' (Hay and Reid, 1982), 'mechanical analysis of human performance' (Luttgens and Hamilton, 1997) or 'movement analysis' (Hall, 1991). Even though the preferred terms vary, the general purpose of the methods described by these authors is, in essence, the same. The term technique analysis is used in this paper as an umbrella term to refer to these general approaches.

Technique analysis has been practised for many years. However, its development into a systematic process incorporating scientific principles and methods is documented from only about half a century ago with the publication of texts linking scientific principles

* e-mail: a.lees@livjm.ac.uk

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to coaching practice (e.g. Bunn, 1955; Wells, 1966). Since then, there have been many developments in technique analysis as determined by the differing interests and needs of teachers, coaches and scientists. Although technique analysis has been described by authors of biomechanical texts in varying detail, no attempt has been made to review the background and developments of the method or to evaluate its current standing and assess its future potential. With the rapid technological developments within the science and practice of sport and the ever increasing demands for sporting success, it is timely to undertake such a review. The role of 'technique analysis' within the broader scope of 'performance analysis' is dealt with by Hughes and Bartlett (2002, this issue).

## A review of definitions of terms

The term *technique* is used widely but it is rarely defined. Writers presume that their audience has an understanding of the term; however, without a clear definition, it can be misinterpreted or misused. A general definition of technique is 'a way of doing something' (*Chambers 20th Century Dictionary*, 1972). Sport-related definitions of technique include: 'a specific sequence of movements or parts of movement in solving movement tasks in sports situations' (*Dictionary of Sport Science*, 1992); 'the pattern and sequence of movements' (Carr, 1997: 5); 'a particular process for resolving the problem of movement' (Hochmuth, 1984: 114); and, more complexly, 'the motion activity specified by biomechanical principles of human motion which utilize motor features of movement and body structure to obtain the best sports result' (Bober, 1981). Some authors (e.g. Cooper and Glassow, 1976: 112) avoid the term 'technique' altogether and prefer to use the term 'movement pattern'. These definitions and statements suggest that technique describes the relative position and orientation of body segments as they change during the performance of a sport task to perform that task effectively.

These definitions do not indicate how technique can be measured, but they imply that technique is characterized by variables that can be visually perceived. Bober (1981) is one of a few writers to specify that kinematic and temporal characteristics best characterize technique. Although no survey has been undertaken, most reports detailing investigations into 'technique' have reported linear and angular displacement and velocity variables and their temporal occurrence. These provide a useful starting point for establishing how technique should be characterized. Although other biomechanical tools such as dynamography, electromyography, accelerometry and kinetic analysis have been used to quantify characteristics of movement, they have not been as influential in determining the characteristics of technique as the methods that have provided kinematic and temporal descriptions of movement.

These definitions do not establish the criteria for how technique should be evaluated. It is implicit in the concept of technique that if a skill is performed with a 'good' technique rather than a 'poor' technique, performance will be better. However, some authors have cautioned against using performance as an indicator of good technique (Hay and Reid, 1982; Bartlett, 1999), as factors other than technique can affect performance. It is, therefore, not true that a better performance indicates a better technique, although generally a better technique will lead to improved performance.

These definitions do not establish the scope of technique. They do not make a clear distinction between different styles of performance (e.g. in high jumping the straddle *vs* the Fosbury flop) or between general technique (i.e. whole-body sequence of movements) and specific technique (i.e. limb or segment movements), even though such a distinction would be helpful to those undertaking an analysis.

The term *technique analysis* is less widely used and, although alternative terms (as noted above) are often preferred, they are similarly infrequently defined. One rare definition of technique analysis is that it is 'an identification of specific characteristics of technique which are studied with regard to their contribution to the specific process and overall achievement' (*Dictionary of Sport Science*, 1992). Technique analysis is frequently identified as a prerequisite to the process of improved performance (Bunn, 1972; Hay and Reid, 1982; Carr, 1997; Bloomfield *et al.*, 1994; Knudson and Morrison, 1997; Luttgens and Hamilton, 1997; Bartlett, 1999; Elliott, 1999). However, only a few authors (Adrian and Cooper, 1995; Elliott, 1999; McGinnis, 1999) have specified that technique analysis is used to improve technique and it is only through this that improved performance may result. This definition and these statements suggest that technique analysis is concerned not only with establishing 'how movements are made' (a descriptive goal), but also with studying the 'most effective way movements are made' and 'their effect on performance' (analytical goals). Thus several goals can be identified for technique analysis.

The descriptive goal of technique analysis is achieved through the determination of the variables that characterize technique. A distinction is rarely made between those variables that characterize technique and those that characterize performance; often these are reported together. This is a pivotal distinction for understanding the role of technique analysis in comparison to the broader 'biomechanical' analysis. A goal of biomechanists is to understand the mechanisms operating in a given technique, but it is unclear whether this is a further goal of technique analysis. The goal of understanding performance is, after all, a different goal from characterizing technique even if one is complementary to the other. Unfortunately, authors generally do not distinguish between 'technique analysis' and 'the biomechanical analysis of a technique'.

One of the analytical goals of technique analysis – the effectiveness of the way movements are made – has proved problematic for researchers because it has been difficult to define criteria for effectiveness and to quantify the effectiveness of a movement without recourse to the outcome. Another analytical goal of technique analysis – the effect that technique has on performance – has also proved a source of difficulty for researchers. Hochmuth (1984) cautions that 'technique' is only one of many factors that can affect the success of a performance; others include physiological, anthropometric and neuromuscular characteristics. This important limitation of technique analysis is one that is generally not acknowledged by contemporary writers.

Technique analysis is linked to improving performance, but there are at least two further steps associated with this. One is the diagnosis or identification of faults in performance and the other is the process of remediation or intervention to achieve the desired outcome (e.g. McPherson, 1990; Knudson and Morrison, 1997; Elliott, 1999). Although some writers (e.g. Hay and Reid, 1982; Carr, 1997; McGinnis, 1999) have detailed the process of diagnosis, it is not clear whether this is considered to be an integral part of technique analysis or some further goal. In qualitative technique analysis, it appears more readily incorporated, whereas in quantitative and predictive analysis, it seems to be generally excluded. The process of remediation receives scant attention from most authors. The general lack of comment on this issue in contemporary texts reflects an uncertainty of how technique analysis should achieve its promise of improving performance. From this we must infer that the role of technique analysis is limited to laying the foundation for intervention.

Although technique and technique analysis are commonly used concepts, their nature and scope are poorly defined. A lack of guidance by eminent authors on the conceptual framework for technique analysis leaves the development and implementation of the method open to widespread interpretation.

## General approaches to technique analysis

The contemporary origin of technique analysis in sport lies in coaching, as there was a need for coaches to improve the performance of their athletes. By applying the principles of mechanics to performance skills, they were better able to rationalize the coaching advice they gave. Thus, technique analysis evolved based on the application of mechanical principles, which later generally became known as the 'biomechanical principles of movement'. At the time, there were few observational and analytical aids available to coaches and so a qualitative approach to the viewing and analysis of technique developed. Thus *qualitative analysis* developed, based on scientific principles but subjective observation. The advantage of a qualitative analysis is that it can be used by a wide range of people and has spread into instructional (teaching) and clinical (movement rehabilitation) settings.

As scientific analysis methods have developed and become more widely available, it has become possible to measure those aspects of skills related to technique, often using kinematic and temporal variables. This approach has become known as *quantitative analysis*. Quantitative analysis provides a different challenge for the scientist and coach because the analytical methods result in small details being measured, which then need to be 'processed' in a way that reflects the essential characteristics of technique. The time-consuming nature of quantitative analysis has hindered its applicability within an applied setting, where the focus is still on the whole movement. In a clinical setting (e.g. gait analysis), quantitative analysis has evolved into a powerful tool for supporting clinical decision making, but such success is not yet apparent within sports technique.

More recently, technique analysis has benefited from developments in mathematical modelling and computer simulation of performance skills. Several researchers have developed models of multi-linked systems representing the human body in varying detail. These models can be used to produce dynamic simulations of a movement and change input and control conditions to answer hypothetical questions. This has been termed *predictive analysis* (Elliott, 1999), an approach to technique analysis that offers great potential. Even though it is still in its infancy, it offers the means to reach one of the analytical goals of technique analysis, that of studying the 'most effective way movements are made'. Although sophisticated in its development, it has the advantage of focusing directly on the technique used and, with graphical facilities for human body animation being increasingly available, can provide a direct visual communication system between the scientist and the coach or athlete.

The qualitative, quantitative and predictive approaches to technique analysis are all widely used in contemporary biomechanics and will be reviewed in turn.

## Qualitative approach to technique analysis

Qualitative analysis is characterized by the subjective interpretation of movement. It was defined by Knudson and Morrison (1997) as the 'systematic observation and introspective judgement of the quality of human movement for the purpose of providing the most appropriate intervention to improve performance' (p. 4). This definition contains a statement about the *method* of qualitative analysis as well as its *goal* and identifies the three main steps of the qualitative process – observation, evaluation and intervention. Several aids have been developed for the systematic use of observation. Evaluation is the defining process of the qualitative method and refers to the way 'introspective judgements' are made about the performance (fault diagnosis) and three main approaches have been used for this. The intervention process has received little guidance from authors and so this aspect of the qualitative approach will not be considered further.

### *Aids to observation*

Several authors have described observational models as a basis for undertaking qualitative analyses; these have been reported in detail by Knudson and Morrison (1997). As well as describing observational skills (e.g. Hall, 1991), many of these observational models also refer to aids that can be used to assist systematic observation. These emerge in the ideas of 'phase analysis', 'temporal analysis' and 'critical features'.

Phase analysis is the descriptive process of dividing up a movement into relevant parts so that attention can be focused on the performance of each part. Some authors (e.g. Knudson and Morrison, 1997; Bartlett, 1999) have identified three main phases to a skill (preparation, action and follow-through), whereas others have identified four or more phases (e.g. Hay and Reid, 1982; Lees, 1999a). Most authors acknowledge that these phases can be further broken down into sub-phases and that the distinction between one phase or sub-phase and another is arbitrary and determined by the particular skill and the needs of the analyst. Nevertheless, this process of breaking a skill down into its functional parts is an important first analytical step.

Temporal analysis is an attempt to specify the timing of a movement and builds on the sequence of spatial representation of movement established through a phase analysis. Adrian and Cooper (1995) refer to the temporal aspects of movement and relate this to timing and rhythm in the performance of a skill. The concepts of timing and rhythm have been dealt with by some other authors (e.g. Arend and Higgins, 1976; Cooper and Glassow, 1976), but surprisingly this is infrequently referred to in qualitative analyses. It should perhaps be noted that rhythm is a key characteristic of dance, which receives little attention in most sports biomechanics texts.

Critical features are defined by McPherson (1990: 2) as 'components of movement that are essential to the performance of a skill'. As an example, she uses the backswing in a tennis stroke, which most would agree is essential to the successful performance of that skill. She considers critical features as *observable* aspects of a movement and contrasts these with statements of mechanical principles, which are not. The term 'critical feature' seems to have been first introduced by Arend and Higgins (1976), who defined it as 'the parts or phase of a movement which can be least modified to achieve the goal'. This rather difficult phrasing is illustrated by an example that relates to the direction of application of force from the tennis racket to the ball. Although correct direction of the force is undoubtedly critical to the success of the performance, it is difficult to appreciate how this can be 'observed'. However, the general concept as described by McPherson (1990) seems appealing and has been taken up by Knudson and Morrison (1997) and applied to several general skills, including catching. From their examples, it is apparent that critical features are general statements that refer to position (e.g. for catching a ball – crouch with arms and legs flexed), presumed focus of attention (e.g. watch the ball) and motion (e.g. give with the ball, retract with the ball). These critical features then appear to relate to the very general characteristics of the skill, some of which may be expressions of selected underlying biomechanical principles of movement (see below).

These aids to observation are intended to be a starting point for the process of qualitative analysis and not ends in themselves, as is frequently the case in coaching texts and manuals. The use of 'phase analysis' is very popular, probably because of its simplicity. In contrast, observational aids that require more preparation and background knowledge, such as the use of critical features, appear to have achieved less widespread use, although the lack of evaluative research makes this difficult to assess. Although researchers are happy to offer methods for improving the quality of analytical tasks, they appear to be less interested in evaluating how widely and effectively these methods are used. This lack of knowledge prevents deeper understanding of the value of these aids.

### *Evaluation*

*Templates.* A model template is a representation of the ideal form of a movement in each phase, depicted in written, diagrammatic or pictorial form. It is used as an evaluative tool and is a logical extension of phase analysis. Coaching manuals tend to rely on the sequential breaking down of a skill into its various phases (see Hughes, 1994, for soccer skills) and provide descriptive (often visual) templates for relevant parts of the skill based on expert performance. In a field setting, this is achieved through the use of a demonstration or by observing an expert performer. This approach is readily used at the highest standard of performance and detailed phase analyses as model templates have been presented in coaching journals (see Hucklekemkes, 1992, for the hurdles; Tidow, 1990, for the long jump). The intention for the use of a model template is that deviations from it provide information from which a diagnosis of faults can be made, although account should be taken of variations in performance levels and individual differences. Several authors (e.g. Hay and Reid, 1982; Bartlett, 1999) have identified the pitfalls of this approach, which are mainly related to the fallacy that success equates with high technical skill. A further limitation of this method, frequently noted, is that it does not encourage critical thought about the technique used and may, therefore, be used inappropriately. Despite this, in other fields, the use of a model template is extensive and successful. Observational gait analysis (Malouin, 1995) is used in the clinical setting and is based on a normative template for walking. This is in the form of a two-dimensional record sheet that divides the gait cycle into various phases and sub-phases along one dimension and the observational points relating to the lower limb joints and trunk along the other dimension. The operator is expected to make judgements on the basis of this structured observation. The method appears to be well developed and its application controlled. The field is exceptional in that attempts have been made to investigate the validity and reliability of the systems used, and consideration has been given to issues of operator training and the statistical analysis of observational data (Malouin, 1995). This appears to be in stark contrast to the effort expended on these issues in sports analysis.

*Principles of movement.* The earliest and perhaps most widely used scientific approach to the evaluation of technique is the application of mechanical principles. As these have been articulated and developed, they have tended to be referred to as 'biomechanical principles of movement'. In general, these are a combination of principles based on simple mechanical relationships, multi-segment interactions and biological characteristics of the human musculoskeletal system.

Bunn (1955, 1972) identified a range of 'principles of movement' that were based on the laws of mechanics. He identified 53 principles that were categorized into equilibrium ($n = 6$), motion ($n = 7$), force ($n = 27$) and 'special' ($n = 13$) principles, the latter related to the effects of factors such as air resistance, projectile spin and muscle strength characteristics. He also referred to aspects of segment coordination (which might now be interpreted as proximal-to-distal sequencing) and utilization of the stretch–shortening cycle, although not specifically as principles. Interestingly, these statements also included predictions of how they should manifest themselves.

Attempts to identify principles of movement have been made by several authors. Northrip *et al.* (1974) identified 51 'principles of biomechanics', which they categorized based on conventional areas of mechanics into velocity ($n = 4$), acceleration ($n = 4$), force ($n = 12$), torque ($n = 4$), energy ($n = 5$), power ($n = 2$), linear momentum ($n = 3$), angular momentum ($n = 3$), collision ($n = 6$), aerodynamic ($n = 5$) and hydrodynamic ($n = 3$) principles. Cooper and Glassow (1976) identified 18 'principles of movement', which were largely statements of mechanical relationships interpreted in relation to the performance of sports skills; no rationale for these was given and they were not categorized further. Bober (1981) identified 'biomechanical principles of coordinated movement', which he categorized as universal principles (valid for all activities), principles of partial generality (valid for many skills) and particular principles (valid for specific skills). Bober did not amplify these categories but, based on his classification, Bartlett (1999) identified three universal principles and five principles of partial generality. Hochmuth (1984) was more focused in his selection and identified six principles – four 'biomechanical' (acceleration path: essentially the range of motion; initial force: essentially the stretch–shortening cycle; optimal time course of acceleration: essentially minimizing time; and chronological coordination of individual impulses: essentially proximal-to-distal sequencing) and two 'mechanical' (action–reaction and conservation of momentum).

Limited attempts have been made to reduce the large number of principles identified by other authors to a manageable form. Norman (1975) proposed 10 biomechanical principles for qualitative analysis, while Hudson (1995) presented 10 'core concepts of kinesiology' (Table 1). These core concepts contain a mixture of mechanical, multi-segment and biological principles that are not differentiated. Although there are some areas of agreement, differences are still apparent in the selection of key principles and the way in which these are described.

Although the principles stated by these authors originate from an application of the same mechanical laws applied to performance skills, there is little detailed agreement as to how they should be categorized and presented and no agreement as to the number or names of these principles. There is no agreement about what each principle is fundamentally based on – mechanical,

**Table 1.** Key principles of movement identified by Norman (1975) and Hudson (1995)

| | Norman (1975) Biomechanical principles | Hudson (1995) Core concepts of kinesiology |
|---|---|---|
| 1 | Summation of joint torques | Range of motion |
| 2 | Continuity of joint torques | Speed of motion |
| 3 | Impulse | Number of segments |
| 4 | Reaction | Nature of segments |
| 5 | Equilibrium | Balance |
| 6 | Summation and continuity of body segment velocities | Coordination |
| 7 | Generation of angular momentum | Compactness |
| 8 | Conservation of angular momentum | Extension at release |
| 9 | Manipulation of moment of inertia | Path of projection |
| 10 | Manipulation of body segment angular momentum | Spin |

multi-segment or biological principles. Even this distinction could be of value to potential users who understandably may be confused when trying to use biomechanical principles of movement to undertake a qualitative analysis. This lack of agreement presents an impediment to the competent use of this approach. Although simplified, the reduced set proposed by Hudson (1995) would appear to have some practical merit.

*Systematic models.* Several authors (e.g. Adrian and Cooper, 1995; Knudson and Morrison, 1997) have described a range of systematic models used in qualitative analyses to evaluate the important characteristics of a skill. The most influential of these is that proposed by Hay and Reid (1982). The model was not named specifically, but by the second edition of their book (Hay and Reid, 1988) the model was loosely referred to as 'deterministic'. Some authors have formalized this term (e.g. Knudson and Morrison, 1997), but others have referred to it variously as a 'factors-results model' (Adrian and Cooper, 1995), 'hierarchical model' (Bartlett, 1999), 'performance outcome model' (Lees, 1999a) and 'qualitative model' (Sanders, 1999). The model provides an approach that is based on a hierarchy of factors that are dependent on the result or outcome of the performance (see Fig. 1).

The main rule that Hay and Reid (1982) give for constructing the model is that each of the factors in the model should be completely determined by those factors that appear immediately below it either by addition or known mechanical relationships. However, they immediately deviate from this rule in the example they give (for the high jump, figure 163, p. 275), which includes generalized statements of 'physique' and 'position'. Although the high jump result is determined by the respective heights of take-off, flight and clearance, the initial conditions are clearly relevant and need to be incorporated within the model. In this example, the initial conditions are introduced by referring to the general anthropometrical status of the performer (i.e. physique) and the 'position' of the limbs at the moment of take-off, but cannot be combined using either of their rules. A further departure from their rule is evident in their detailed model for the high jump (figure 166, p. 278), in which the clearance of the bar is related to 'actions during clearance', which may be interpreted as an attempt to incorporate aspects of technique.

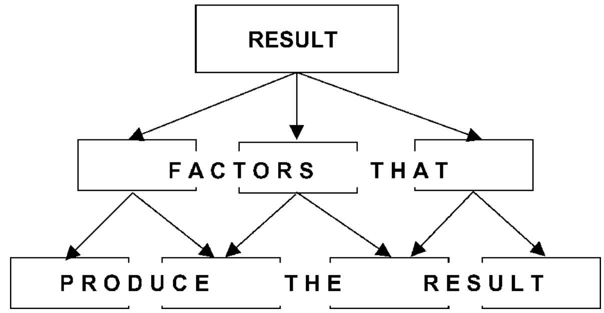


**Fig. 1.** The 'deterministic' model proposed by Hay and Reid (adapted from Hay and Reid, 1982).

Hay and Reid (1982) do not claim that their model is one for technique analysis, but it has been linked directly to technique by others (e.g. McGinnis, 1999). The model is outcome orientated and so it would be better classified as a 'performance' model. Being outcome driven it is inevitable that, for most sports skills, the outcome is dependent on initial conditions and impulse generated during the action phase of the movement. For example, in a golf drive, the model will tell us that the speed of the clubhead must be high at impact, but not how to achieve it. Information on how to use the arms and club as a two-lever system, weight shift and hip–shoulder rotation (Cochran and Stobbs, 1968) are beyond the scope of the model. In other words, the model is able to identify factors relevant to performance, but not aspects of technique relevant to these factors.

The model of Hay and Reid (1982) would appear to be valuable for identifying a range of factors that influence performance and providing a framework from which technique can be discussed. To do this requires the use of one or more of the methods described earlier. In this sense, it is not an alternative model for technique analysis but is complementary to these other methods. This is illustrated by Sanders (1999), who, in an analysis of swimming technique, used a deterministic model based on mechanical principles, which resulted in the identification of critical features. Exploration of these 'integrated' approaches is an interesting direction for qualitative technique analysis to take.

*Summary*

It is apparent that qualitative technique analysis requires a range of knowledge and experience about both the performance skill and the underpinning biomechanical principles. The lack of agreement about biomechanical principles, the failure to distinguish between mechanical, multi-segment and biological influences in these principles, and the failure to distinguish between technique and performance are indications of a poorly developed conceptual framework for qualitative analysis. There is no shortage of proposals on how a qualitative technique analysis should be undertaken, but information is lacking to identify what methods – or combination of methods – people use, how successful they are in their analysis and at what level of ability this success is most likely to be achieved. Until these shortcomings in qualitative technique analysis are addressed, it is doubtful whether the qualitative method will advance substantially from its current position even with alternative approaches based on an integration of methods.

## Quantitative approach to technique analysis

As methods for data collection have become more widely available, it has become practical to use them in the evaluation of technique; this is generally referred to as quantitative technique analysis. Although subjective estimation for quantifying variables has been used with some success (e.g. Douwes and Dul, 1991, for body angles; Runeson and Frykjholm, 1981, for weight lifted; Cutting and Kozlowski, 1977, for gait characteristics), the normal approach to quantitative analysis uses instrumentation. Consequently, most biomechanical texts describe a range of instrumented data collection methods for quantifying performance skills and usually include motion analysis, force analysis and electromyography. These biomechanical methods have been mainly used to address the descriptive goal of quantitative technique analysis. In a 10 year survey of one influential sports biomechanics journal (*Journal of Applied Biomechanics*, 1994–99 and its predecessor the *International Journal of Sports Biomechanics*, 1991–93), of the 216 original research articles, 65 were concerned with the analysis of sports technique. Of these, 43 were concerned with establishing the descriptive (kinematic or kinetic) characteristics of a skill or technique often in relation to performance (e.g. kinematic analysis of the barbell in weight lifting, Isaka *et al.*, 1996; three-dimensional kinematics of the throwing arm in water polo, Feltner and Nelson, 1996). Only seven were concerned with quantifying the effect of two or more different ways of performing a technique to identify key distinguishing variables (e.g. comparison of single, double and triple axels in figure skating, King *et al.*, 1994). Only 12 were concerned with establishing the effect of an independent variable on technique, such as methods of performance (e.g. outer *vs* inner grip technique in the gymnastics high bar, Takei *et al.*, 1995), movement style (e.g. arm action on baseball pitching characteristics, Escamilla *et al.*, 1998) or ability (twisting technique used in trampolining, Sanders, 1995). The remaining three articles were concerned with predictive analysis.

Some important issues are raised by these investigations. One is how 'key variables' that relate to technique are identified. Another is how the 'specific sequence of movements' used in a technique can be represented. A further issue is the efficacy of the previously identified 'biomechanical principles of movement'. These three issues will be addressed in turn.

*The selection of key variables*

*Previously established and 'logical' variables.* Perhaps the most widely used justification for the inclusion of a specific variable in a quantitative technique analysis is by reference to previous research and coaching articles. In other cases, a variable might be selected because it is thought to have some *a priori* importance for the movement (e.g. knee flexion angle in jumping). In these cases, it may be possible to justify the inclusion of a variable on a 'logical' basis (Lees, 1999b) rather than simply a hunch. If the skill under investigation has been well analysed in the past, then this approach is probably quite practical. However, it also has limitations, one being that previous research may have had a biased interest and have just simply not considered some key aspects of the performance. An example of this is the long jump, for which research before 1990 (see Hay *et al.*, 1986; Nixdorf and Brüggemann, 1990) had focused mainly on the approach and take-off phases. Later research (e.g. Lees *et al.*, 1993, 1994) began to look in detail at the touch-down to take-off phase, which is critical to the identification of appropriate take-off variables. In sports with a limited research base, there is little to guide the new investigator, who might be advised to undertake a prior qualitative analysis and use a 'logical' argument for the variables selected.

*Deterministic model of performance outcome.* The most widespread use of the deterministic model (Hay and Reid, 1982) has been for identifying key performance variables subsequently used as a basis for quantitative analysis. Contrary to the impression given in the major texts, this approach has taken some time to influence researchers. Early applications were by Hay and his co-workers (e.g. Hay *et al.*, 1986) but slowly an increasing number of examples have been evident in the literature, especially in recent years (e.g. Sanders, 1998; Takei, 1998; Feltner *et al.*, 1999; McLean *et al.*, 2000).

Having identified key variables from a deterministic model, an important question is their relative importance to one another. This is established by correlating variables at adjacent levels of the deterministic model. For example, in an analysis of long-jumping performance, Hay *et al.* (1986) correlated the official distance (performance) and the three deterministic variables that it immediately depended on. The highest correlating variable – flight distance – was then correlated with its dependent factors and so on until the final layer was reached in the deterministic model. The variables that mostly determined performance over all levels were speed at take-off, horizontal velocity at take-off and the horizontal velocity in the fourth last stride. The general interpretation of this finding – that approach speed determines performance in the long jump – was indeed confirmed by Hay (1994) for a wide range of speeds. Although rare, this approach has been used by others. For gymnastic vaulting, Takei (1992) related post-flight performance to various pre-flight and post-flight variables and found significant variables cascading down five levels of the deterministic hierarchy. This approach has the advantages of limiting the number of combinations between variables investigated and of indicating those variables that have the greatest influence on performance. However, there are also several limitations. One is that the variables identified are performance – rather than technique – variables. Secondly, the statistical approach implies a linear relationship between variables and performance. In some cases this is not true – for example, the relationship between release speed and projectile distance in jumping and throwing, evident from the mechanical formula for range. Thirdly, for a given group of athletes in a competition setting, the range over which each variable exists may be small, leading to anomalous results.

I stress again that the deterministic model focuses on the factors that influence the performance outcome and not the underlying characteristics of technique, and so it should not be conceived of as a quantitative technique analysis model. Few studies have tried to determine the influence of technique variables on performance itself. One recent exception is an investigation of the touch-down characteristics of high jump performance by Greig and Yeadon (2000). These authors studied a single high jumper during a training session who performed repeated jumps while varying the pace and length of the approach run. The outcome measure was jump height, the performance variable was approach speed (although the authors refer to this as a technique variable) and the two technique variables were touch-down leg plant angle and touch-down leg knee angle. They found that, when attaining a greater jump height, the approach speed, plant angle and knee angle all increased, although there was evidence of an interaction between these variables. Thus, the technique used was seen to change as the outcome changed. The systematic nature of these changes suggests that the technique variables are related to performance, although the nature of these relationships was, importantly, not always linear.

*Statistical models.* For many complex skills, performance is clearly related to aspects of technique that cannot be accounted for within a deterministic model of performance outcome. In many sports, joint angles, angular velocities and other kinematic variables are characteristics of technique that may have some bearing on performance. To identify the presence and strength of any such relationship between a measured variable and performance, researchers have tended to use a statistical approach. The method most frequently used is multiple correlational analysis, although care should be taken not to overstate the level of significance (e.g. by using a Bonferroni correction as used by Bartlett *et al.*, 1996). When the quantitative analysis uses two or more conditions (styles, ability, methods of performance, etc.), a differential analysis can be used. Takei (1991) reported on gymnasts performing a compulsory vault at the 1988 Olympic Games. In total, 75 variables were measured from the contact phase and post-flight phase of a handspring and were compared with similar data collected from a national championship 2 years earlier. He was able to identify several variables that differentiated between these two standards of performance. Such an analysis is helpful to identify variables that are worth developing by gymnasts during training and to focus on the measurement of these in subsequent analyses, perhaps as a part of a longitudinal monitoring process. With the increased capability for the collection of biomechanical data, one might expect that regression analysis techniques will become popular for investigating the relative importance of technique and performance variables, although to date this does not appear to have had a significant impact in the literature.

*Other approaches.* Although not widely acknowledged, the biomechanical principles of movement provide a logical basis for selecting technique variables. Some of the principles of movement provide a clear indication of what should be measured. One is the range of motion (see Table 1). In javelin throwing, Bartlett *et al.* (1996) used the length of the acceleration path of the javelin. In golf, Burden *et al.* (1998) used hip–shoulder separation. In soccer, Lees and Nolan (2002) quantified the pelvic rotation in the retraction phase of kicking. In these examples, the technique variables were selected either explicitly or implicitly on the basis of a principle of movement. The principles of movement have not been specifically identified in any text as a logical basis for the selection of technique variables, but there is a clear rationale for doing so. Their use is hindered by the lack of clarity in these principles, but they offer considerable potential for the future. This approach has the advantage of a clear focus on technique rather than being clouded by the influence of performance variables.

### *New approaches for representing technique*

*Neural networks.* One new analytical method reported in the literature may offer potential for the quantitative analysis of technique. This approach is based on the use of artificial neural network analysis. Artificial neural networks have been used for some time to classify objects (including movement types) based on a range of input data, which could be biomechanical data, and output categories. They draw relationships between input variables and output categories based on a system of non-linear weightings between the input variables and output categories. Possibilities for the use of artificial intelligence, including neural networks, for the analysis of sports technique have been suggested by Lapham and Bartlett (1995). Progress in applying these techniques to sport has been slow, probably because of the conceptual complexity associated with the method and also the difficulty in obtaining sufficient data to enable a reasonable classification of movement. A recent application of artificial neural networks to the shot put technique has been described by Yan and Li (2000), who reported reasonable success in identifying selected aspects of technique that differed between one athlete and a second, who was selected as an elite 'model' of performance. This application appears to be a more sophisticated version of the 'model template' approach referred to earlier, but one in which it is possible to incorporate many aspects of performance and technique that have non-linear relationships with each other.

Artificial neural networks can be used in different ways. Recently, an application has been developed that allows a range of input data to be represented as a two-dimensional graphical matrix, or Kohonen net (Barton, 1999), with the resulting 'picture' being a representation of the underlying data (Fig. 2). The artificial neural network can be used as a non-linear data reduction method, which can be viewed in a planar graphical form. Locations on the planar surface are thought to be associated with characteristics of the movement (i.e. technique). For any given technique, the challenge is to identify areas on the surface with a particular characteristic of the movement. This has been applied with some success in gait analysis by Barton *et al.* (2000) (Fig. 3) and in the analysis of sports technique (Fig. 4), where an individual performed a soccer kick with speed and accuracy as performance criteria. It can be seen that the shapes for gait and kick are distinctive, while the modification of the kick to reflect the speed of movement is also apparent.

*Quantification of coordination.* Quantitative analysis methods are very useful for investigating discrete variables and their time course, but the temporal relationships between variables is more difficult to establish. In the study of motor skills, there is a great interest in intra- and inter-limb coordination and their use to investigate underlying movement theories

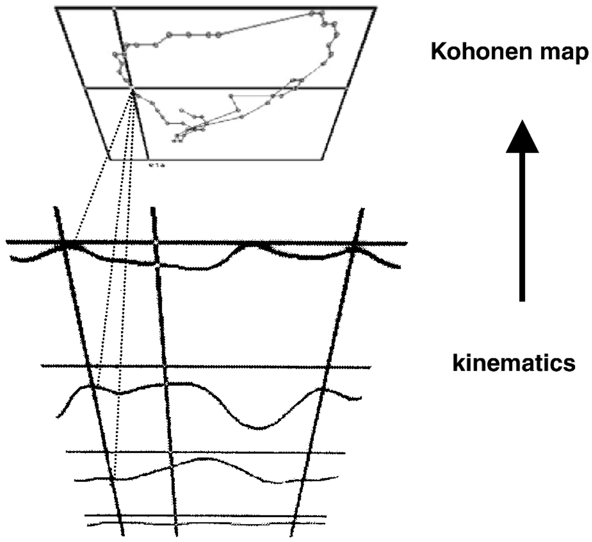


**Fig. 2.** The Kohonen neural network, which reduces input kinematic data to a planar topological map.

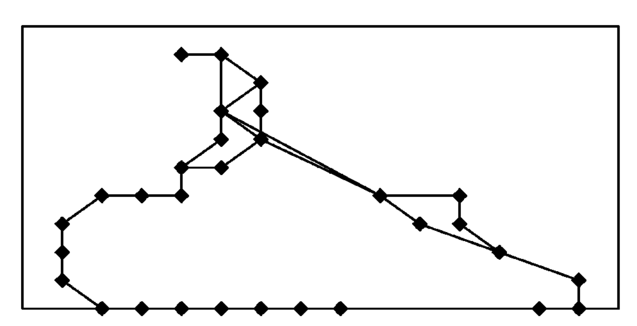

**Fig. 3.** The Kohonen neural map for a gait cycle (described by Barton *et al.*, 2000).

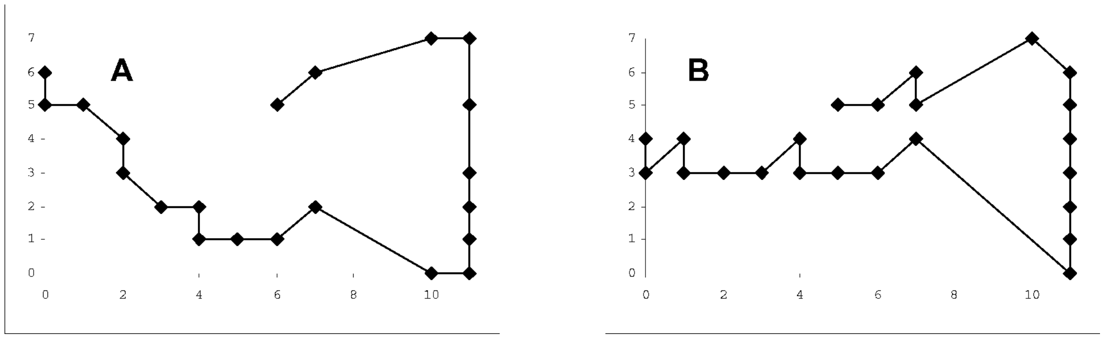


**Fig. 4.** The Kohonen neural map for a soccer kick performed under the condition of (a) speed and (b) accuracy. Although the general pattern is the same (and different from gait, Fig. 3), the specific differences in the lower part of each graph relate to the effect of speed of the movement.

(e.g. dynamical systems theory; Davids *et al.*, 2000). Intra- and inter-limb coordination might be considered to reflect technique (as a 'specific sequence of movements') and is typically quantified by the orientation of one segment of a limb relative to another (intra) or one limb relative to another (inter). Although coordination has been widely demonstrated qualitatively (see, for example, the angle–angle diagrams used to describe lower limb coordination in running; Cavanagh, 1990), the quantification of coordination has generally been achieved using a cross-correlation between, typically, the angular orientation between two segments or limbs. A positive cross-correlation value indicates that the relative motion of the two segments is in phase, whereas a negative value indicates they are out of phase. Examples are investigations into the effect of practice on kicking performance (Anderson and Sidaway, 1994) and differences between experts and novices in volleyball serving (Temprado *et al.*, 1997). The conjugate cross-correlation is a development of this (Amblard *et al.*, 1994) and computes cross-correlations between two sets of data over several positive and negative time lags between the two data sets. The peak of the resultant curve indicates the relative phase between two segments. The relative phase can be used as a measure of coordination and can be investigated as the performance of the skill develops, usually with training or experience. Although most applications within the motor skills literature are concerned with challenging theories of movement behaviour, this method has had some use in investigating aspects of sports technique. One such example, in javelin throwing, is described by Morriss (1998), who, using conjugate cross-correlation, reported that the throwing technique of an elite athlete did not change significantly over a 5 year period except for one year in which the athlete suffered an injury. The interest that biomechanists have in using this approach to investigate technique will probably increase, especially with further development of these and related methods to determine the discrete or continuous relative phases between two segments (see, for example, the review by Hamill *et al.*, 2000).

The neural network and coordination approaches to the analysis of technique have only recently been introduced into biomechanics. Because these methods quantify the 'specific sequence of movements', they offer great potential for the investigation of technique in a way that the direct use of quantitative biomechanical methods cannot do.

### *Biomechanical principles of movement*

Quantitative analysis methods have been used to investigate the mechanisms underlying the biomechanical principles of movement. It has already been noted that some of these principles have led to 'predictions' of how a complex biomechanical system should operate. One in particular (Bunn, 1972) related to proximal-to-distal sequencing (often referred to as the summation of speed principle), which stated that 'in throwing, jumping or kicking activities, where the highest speed possible at the moment of take-off or release is necessary . . . the movement of each member of the body starts at the moment of greatest velocity but least acceleration of the preceding member' (p. 10). This is depicted in Fig. 5 but has since been challenged by many researchers.

Quantitative analyses of many throwing and kicking movements have indeed shown that the proximal segment reaches its maximum angular velocity and starts to slow down well before the distal segment reaches its maximum angular velocity (Putnam, 1991). But Putnam also showed that the proximal-to-distal sequence was better described by segment angular accelerations and that as the distal segment accelerated, the proximal segment decelerated. She postulated that this was due to the net joint torque acting between the proximal and distal segments acting on both to produce these opposing effects. Whether this mechanism could be enhanced by the application of an additional torque

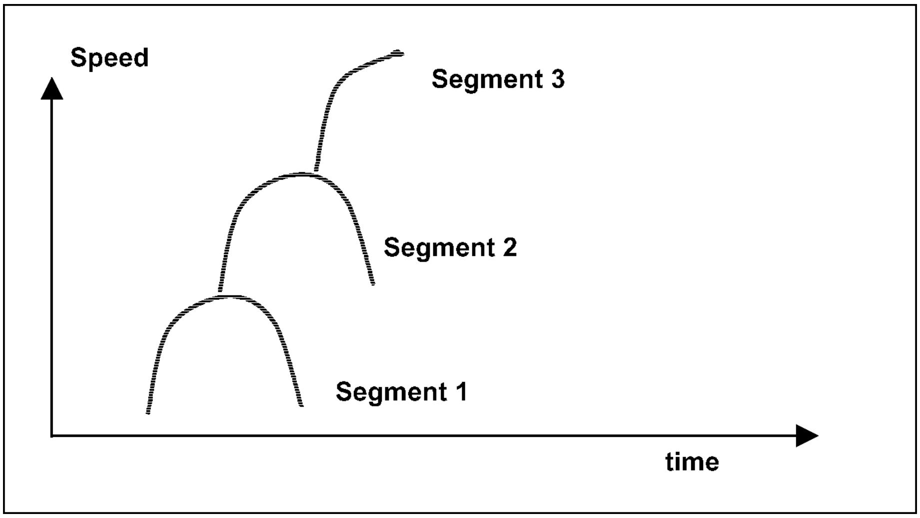


**Fig. 5.** Diagrammatic representation of the summation of speed principle in which the movement of each segment starts at the instant of greatest velocity but least acceleration of the preceding segment.

on the proximal end of the proximal segment to create a 'whiplash' effect was investigated by Sorensen *et al.* (1996) for martial arts kicking, but they found no evidence of this. Although an active muscle moment between the proximal and distal segments appears necessary for successful performance in kicking actions, in the golf drive the role of wrist torque is equivocal. Analysis based on a two-segment model (Jorgensen, 1994) suggests that the lower arm–club system acts like a 'flail', in that wrist torque does not effect clubhead speed. However, using a three-segment simulation, Sprigings and Neal (2000) suggested that wrist torque can lead to an increased clubhead speed. Although these studies have helped greatly to understand the true nature of proximal-to-distal sequencing, the phenomenon has provided still further scope for investigation. In an analysis of racket head speed in tennis and squash, Marshall and Elliott (2000) found that forearm rotation about its longitudinal axis is an important contributor to racket head speed; this rotation had previously been ignored in discussions of proximal-to-distal sequencing. This omission has largely been to do with inadequate analytical methods. Proximal-to-distal sequencing is a movement principle that is still being actively researched.

Other important biomechanical principles of movement have been the subject of detailed biomechanical analysis. One is the 'stretch–shortening cycle', which is thought to enhance the performance of a movement when a backswing, or retraction, is used to stretch the muscle–tendon complex immediately before the forward action or shortening phase of the movement. It should be noted that this is not included within the reduced set of principles and core concepts suggested by Norman (1975) and Hudson (1995). The general principles of the stretch–shortening cycle were outlined by van Ingen Schenau *et al.* (1997), who suggested that the stretch phase allows the muscles to develop a large force before starting to shorten (a pre-load effect), thus ensuring that the muscles exploit the most favourable part of the force–velocity characteristics of muscle (i.e. high force at low contraction velocities). To maximize this effect, the shortening should take place immediately after the stretch phase. This has been clearly demonstrated by Elliott *et al.* (1999), who investigated the effect of pause time on performance in the external–internal rotation of the upper arm during a constrained throwing movement. They found that when the shortening phase was delayed by 1.5 s, a 22% drop in performance resulted compared with a no-pause condition. Again it is likely that this phenomenon will be demonstrated in other more complex stretch–shortening actions and that the underlying characteristics of the phenomenon will be further elucidated.

Another biomechanical principle of movement is the 'range of motion' used during the 'action' phase of a movement. Although this has not been investigated as systematically as the two principles described above (and, indeed, may be linked to them), it has been used as a rationale for the selection of variables for quantitative analysis (see above).

The use of quantitative methods to investigate biomechanical principles provides a valuable link between the qualitative and quantitative approaches to technique analysis. The systematic investigation of the biomechanical principles of movement using quantitative methods is one that should become more widespread in the near future.

*Summary*

Quantitative methods are powerful and have much promise for technique analysis. However, although quantitative methods have been applied for some considerable time, they have only recently been used to make significant statements on aspects of sports technique. This is partly due to the time required to develop suitable data collection tools that can genuinely be applied to the study of performance skills; however, it is also affected by the lack of a conceptual base for the application of these methods. Much progress has been made in identifying the factors that affect performance; however, a clear distinction has yet to be made between 'technique' factors and those due to other influences. The methods used to quantify technique as a 'specific sequence of movements' have only recently been brought to the attention of biomechanists. It is probable that these will have a significant impact on the scope of quantitative technique analysis in the future.

## Predictive approach to technique analysis

Both the qualitative and quantitative approaches described above rely on the observation or recording of data from real movements. These analyses can only comment on the characteristics of technique that performers demonstrate. A predictive approach to technique analysis is provided by the simulation of human body models. These can range from simple point mass–spring models to rigid body models to highly complex representations of the musculoskeletal system. These models allow the behaviour of the modelled system to be simulated under different conditions and allow hypothetical questions to be investigated systematically.

Simple point mass models of a skill can be used to establish some of the basic characteristics of technique and the effect of technique on performance. One excellent example is the simulation of the high jump by Alexander (1990), which identified that approach speed and two technique variables – touch-down leg plant angle and touch-down leg knee flexion (leg stiffness) – affect performance outcome. These variables have been found experimentally to be related to performance in high jumping by Greig and Yeadon (2000).

Multi-segment rigid body models are likely to offer great potential for investigating aspects of technique because technique analysis is essentially concerned with 'a specific sequence of movements'. King *et al.* (1999) used a two-segment model, comprising arm segment and body segment, of a gymnast to identify the optimum pre-flight characteristics for the Hecht and handspring vaults, when controlled by initial conditions only and without the need to use any joint torque at the shoulder. Their simulation showed that a successful Hecht vault could be performed if, in the initial pre-flight, the centre of mass had a low vertical velocity and the body segment had a low angular velocity; the handspring required the opposite of these initial conditions. Sprigings and Neal (2000) have recently undertaken a simulation of the downswing of the golf drive using a three-segment model, comprising torso, arm and club. They showed that optimally timed wrist torque could produce a 9% increase in the clubhead speed. Furthermore, they were able to comment on the specific timing of the wrist torque as well as identifying that this was affected by the torque profiles used to rotate the torso and arm. These simulations not only provide an answer to a research question, but the method allows different or hypothetical aspects of technique to be investigated. A further point evident from these examples is that, while technique is characterized by the observable outcome in body segments moving relative to one another, the precursors of these movements are the initial conditions and joint torque profiles: it is these that the performer needs to vary to modify a technique.

More complex models exist that can be used to simulate the effect of body actions. One of the most successful is the model developed by Yeadon *et al.* (1990) for simulating flight movements of gymnasts. This model enables the effect of limb motions on somersault rotation and twisting to be investigated. The most sophisticated models are those that try to represent not only the articulating segments of the body, but the muscle activation and tendon mechanical properties as well. This presents a real challenge in modelling and implementation; although such systems are being developed, the computing time required for solutions prohibits a practical application of them at this time.

The modelling and simulation approach to technique analysis offers great potential, but is still in its infancy and substantial issues remain to be addressed, such as the need for subject-specific models and the tolerances within which changes in technique will not affect performance. Although it is a sophisticated method, it has the advantage that it focuses directly on the technique. This, combined with contemporary graphical facilities for human body animation, which are becoming increasingly available, can provide a direct visual communication system between the scientist and the coach and athlete to the benefit of all.

## Other aspects of technique analysis

This paper has been concerned with developing a knowledge and understanding of the technique used in a given performance skill and has been dominated by the conceptual framework and methods used to conduct a technique analysis. However, many authors state that the purpose of a technique analysis is to help improve performance; in this respect, the process has further stages to consider. One such stage is diagnosis – the identification of technique errors or faults; another is remediation – the process of intervention to correct faults. Although these processes are essential to the roles of teaching and coaching of sports skills, the sport biomechanist, who is more likely to be the person conducting any quantitative or predictive analysis, is less likely to be the person engaged in the remediation of technique faults. Therefore, a need exists to develop an ability to work and communicate with those who perform this function.

Knudson and Morrison (1997) give a detailed account of the process of diagnosis and remediation within the context of qualitative analysis, although this generally appears to be directed at the lower end of skilled performance, within the context of physical education and basic coaching. In the major biomechanical texts, few authors attend to the process of identification of technical errors and all are proposed within the framework of a qualitative analysis (Hay and Reid, 1982; Carr, 1997; McGinnis, 1999). It is surprising that this important aspect of technique analysis is dealt with in such little detail within biomechanics. No text specifically attends to these issues as applied to quantitative or predictive technique analysis, although two (Bartlett, 1999; Elliott, 1999) refer to the process, including the role of feedback. If technique analysis is considered to be essentially biomechanical, then it behoves biomechanists to address these stages of the process of improved performance.

A final stage that most authors fail to recognize is the need to evaluate the success of their efforts (Lees, 1999b). If the goal of technique analysis is to improve performance, there should be a concern about whether its use does lead to improved performance. This is difficult to show, not least because the biomechanist is rarely the person to implement any intervention. As has been referred to above, technique is only one aspect of performance and, in any given case, other factors may be more influential. The question the biomechanist then faces is how to evaluate one aspect of the 'improved performance' chain. To date, this problem appears not to have a specific solution. Biomechanists may do well to turn to the clinical field in which qualitative and quantitative technique analyses are used in the analysis of gait. Here the culture of evidenced-based practice is paramount and, although the problems dealt with are considerably different from those in sport, some important lessons may be learnt.

Biomechanists also have an interest in the prevention of injury and are beginning to see technique analysis as a method relevant to this, in addition to the improvement of performance (Bartlett, 1999). One important difference between these is that improving technique is an effective way in which performance can be improved, whereas preventing injury can be achieved much more effectively by reducing performance characteristics, such as the speed of the movement, rather than by modifying technique. It is only when maximal performance has been reached and poor technique is seen not as a limitation to performance but as a causative factor in injury that a change in technique would be warranted. There are few examples of this in the literature. One exception is the effect of fast bowling in cricket (Elliott, 2000), where a mixed bowling technique, which produces excessive rotation between the hips and shoulders during delivery, is replaced by a front-on or side-on technique, which reduces hip–shoulder rotation. Another problem is that changing technique to prevent injury – while maintaining performance – transfers load from one part of the musculoskeletal system to another. The consequences of this are not well documented in sports but, in the clinical setting, where running technique is changed by using orthoses, it is often the case that pain is moved from one part of the body to another. This is an interesting area of application of technique analysis, but one which is currently in its infancy.

## Conclusions

This paper has focused on the application of technique analysis as an analytical method within sports biomechanics. The concept of technique as 'a specific sequence of movements' appears to be well established, but the concept of technique analysis is less well developed. Although several goals for technique analysis may be identified, the main justification given for its use is to help improve performance. The conceptual frameworks underpinning the process of technique analysis are poorly developed and there is a poor distinction between technique and performance variables.

The methods of technique analysis have been categorized as qualitative, quantitative and predictive, but difficulties appear to be associated with each. Qualitative analysis of technique is characterized by observation and subjective judgement. Biomechanical principles of movement can be used to form judgements about technique, but the framework for these biomechanical principles of movement is poorly defined, with little agreement about the numbers and categories of these principles. Qualitative analysis also requires observation and evaluation; however, this process as described in the literature is lengthy and complex. It contrasts markedly with the simpler approach evident within sports coaching, frequently based on a template of 'model' performance. The frameworks proposed for qualitative analysis appear to be academically sound, but little evidence suggests that these systems are used in practice. If one looks at the approach taken in typical coaching manuals, it appears that qualitative analysis methods have had little impact. A widely adopted approach to qualitative analysis uses a deterministic model of performance. Although this provides a framework for the discussion of technique, it is not in itself a model for technique analysis, contrary to the impression gained from the many texts that advocate its use.

Quantitative technique analysis appears more suited to the definition and investigation of specific aspects of technique. Biomechanical methods have been used to address the descriptive and analytical goals of technique analysis. However, researchers have often been more concerned with establishing the key variables that influence performance, rather than those that relate to technique and their influence on performance. Quantitative analysis is ideal for a detailed investigation of some part of a sports technique, but is less suitable for establishing characteristics of the whole movement. New methods, such as the use of artificial neural networks, may be able to address this limitation. Other new methods based on modelling and computer simulation also have potential for focusing on the whole movement. Predictive technique analysis encompasses this development and offers an attractive interface between the scientist and coach through visual animation methods. However, to date, few individuals have the skills required to implement this approach and the modelling required has yet to cope with complex performance skills.

The qualitative, quantitative and predictive aspects of technique analysis have, through necessity, been considered in isolation. Biomechanists and other performance analysts will be familiar with each approach, perhaps to varying extents. In any given case, more than one approach may be used and the success of one approach is likely to depend on the earlier use of another. The integration of these three approaches, while embedded in biomechanical practice, is rarely evident from the published literature, although it is worthy of further study.

Technique analysis appears to be mainly the preserve of sports biomechanists, although qualitative technique analysis is used by other performance analysts as well. Biomechanists need to clarify the underpinning rationale, framework and scope for the methods used. If this paper helps to stimulate this development, then it will have served its purpose.

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