# FUTURE TRENDS IN SPORTS BIOMECHANICS – REDUCING INJURY RISK OR IMPROVING PERFORMANCE?

**Roger Bartlett**
**School of Physical Education, University of Otago, Dunedin, New Zealand**

In this paper, I reflect on some of the applied sports biomechanics projects in which I have been involved over the last 30 years, focusing on how injury risk can be reduced through biomechanical research and interventions, how sports biomechanists can help to improve sports performance, and how we can best feedback information to achieve performance improvements or reduce the risk of injury. Finally, I consider some of the changes that have occurred in that period and speculate on some possible future trends.

**KEYWORDS:** cricket injury, feedback, future trends, sports performance, variability

**INTRODUCTION:** From the viewpoint of this Geoffrey Dyson Memorial Lecture, 2005 is 25 years after my first invited conference lecture, to the Bushmills' School of Sport in Northern Ireland in 1980. This provides my link with Geoffrey Dyson; he attended my lecture but I did not have chance to speak to him straightaway and thought I'd catch him later, not knowing he was leaving the Conference soon afterwards. I got close to meeting the great man, but missed my chance.

It is also 30 years since the start of the first single-honours degree in sport science in the UK, at what is now Liverpool John Moore's University, in which I was involved from the outset. It is, therefore, timely for me to reflect on some applied sports biomechanics projects in which I have been involved over that period, to consider some of the changes that have occurred and to speculate on some future trends.

This presentation will touch on the three major aspects of sports biomechanics on which I focussed in my keynote address to the International Society of Biomechanics in 1995 – exactly 10 years ago, another milestone for me (see Bartlett, 1997).

- How injury risk can be reduced through biomechanical research and interventions.
- How sports biomechanists can help to improve sports performance.
- How we can best feedback information to achieve performance improvements or reduce the risk of injury.

**REDUCING INJURY RISK:** Injuries arise from loads on bones and soft tissue that exceed their failure tolerance. At the highest standards of sports performance, the loads on the body exceed considerably those encountered in sedentary life. Furthermore, sports performers often repeat movements many times during an event or in a game, as in running, or in training: overuse injuries can be a consequence. To understand fully why injuries occur, we need to know not only the loads on the bones and soft tissues, but also the tissue biomechanical (or material) properties - the tissue load-deformation or stress-strain characteristics. We also need to establish how these are affected by the frequency and timescale of loading. To reduce injury, we need intervention strategies to reduce the load. This can involve changes in the performer's technique, better footwear, improved sports surfaces or protective equipment. Alternatively, we need to reduce the frequency of loading, through more efficient training methods or by prescriptions on, for example, the number of overs bowled by young fast bowlers in cricket.

**The mixed technique in cricket fast bowling:** I have been involved in research that has examined several aspects of sports injury, including studies of tissue mechanical properties and load sharing using inverse optimisation. For me, the most important has been trying to devise intervention strategies to reduce injury risks in fast bowling in cricket, involving close collaboration with coaches, performers, and other sport scientists. Much research into cricket bowling has focused on low-back injuries in fast bowlers, who are far more prone to lumbar spine stress fractures (spondylolysis and spondylolisthesis) than are the normal population. There is also a widespread incidence of degeneration or bulging of intervertebral discs.

These injuries have multifaceted etiologies involving overuse, poor physical preparation, hard surfaces, poor footwear, abnormal biomechanics and incorrect technique.
Although the exact mechanisms that cause disc bulging and degeneration, and subsequent neural arch fractures, have not been established, the association between these injuries and the so-called mixed bowling technique are very strong. In this technique (Figure 1 left side), the bowler has a front-on upper body at back foot strike at the start of the delivery stride, looking at the batter from inside the front arm. As the stride progresses, the bowler rotates to a side-on, or more closed position, by counter-rotating the upper body away from the batter; the bowler is now looking at the batter from behind his front arm. Elliott *et al.* (1992) reported that shoulder counter-rotation was significantly related to low back injury. Six of the 17 bowlers in this group had stress fractures of the lumbar spine, and 7 soft tissue injuries. This finding has been supported by many later studies. The causes are probably: forced rotational stress in the lumbar spine, which is greater for mixed technique bowlers owing to the counter-rotation of the shoulders with respect to the hips in this technique; hyperextension, or backward arching, and lateral flexion of the lumbar spine, again, greater in mixed bowlers; and the high impact forces with the ground experienced by all fast bowlers.
While fast bowlers are prone to these injuries - and those with a mixed technique apparently more so, does the etiology of these injuries support the role of that technique? As an example, Farfan *et al.* (1981) outlined the mechanical etiology of spondylolysis and spondylolisthesis as flexion overload, unbalanced shear forces – caused by flexion, hyperextension or lateral flexion - and forced rotational stress, with the last being considered the most disruptive. The etiology does seem to support the implication of mixed technique, although the precise mechanisms need clarifying.

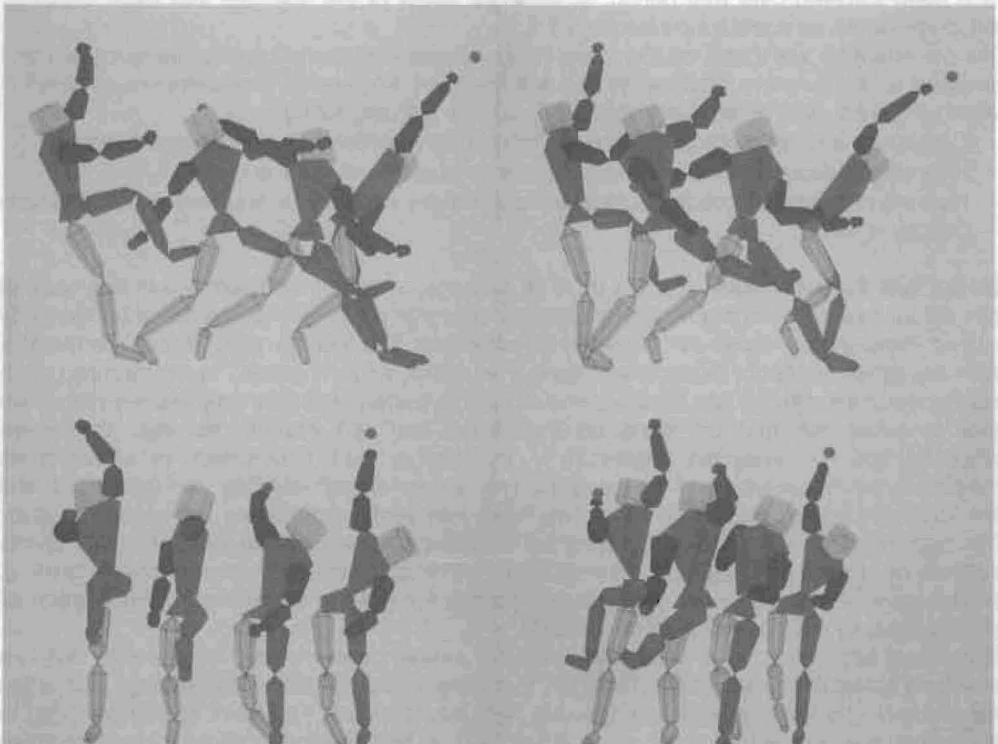

**Figure 1 Fast bowling in cricket; left: 'mixed technique'; right: front-on technique.**

One criticism of research into fast bowling injuries has been the use of shoulder alignment, the angle between the lines joining the two acromion processes and the two hip joints, to represent lumbar spine motion. Elliott *et al.* (2002) used 3 markers on the thorax to give a virtual shoulder alignment. Their results showed that thorax alignment is estimated well by the three-dimensional (but not two-dimensional) shoulder alignment angle between back- and front-foot strike, lending confidence to earlier three-dimensional studies of fast bowling but casting doubt on the two-dimensional alignment angle used in most previous studies of the mixed technique.

**Reducing the risk:** Identification of a technique that is associated with injury is one thing; doing something to reduce or eliminate it is another thing altogether. Burnett *et al.* (1996) reported the inability of a coaching seminar, which highlighted the dangers of the mixed technique, to decrease the rate of disc degeneration in young fast bowlers over a 2½ year period. Elliott and Khangure (1999) looked at the effects of a coaching course and six training sessions emphasizing the side-on and front-on techniques. The programme did reduce shoulder counter-rotation and the number of mixed bowlers but not the incidence of disc degeneration. Wallis *et al.* (2002) studied the effectiveness of a bowling harness on selected bowling characteristics after an eight week coaching programme. The bowling harness decreased the use of the mixed technique when worn but bowlers did not retain any desirable changes to technique after the intervention when the harness was removed. These examples are creditworthy attempts at evaluating interventions and show that much research remains to be done into how to change successfully the bowling action of mixed technique bowlers to reduce their risk of low-back injury.

Nigel Stockill, I and others at Manchester Metropolitan University (MMU) in the 1990s were involved in a ten-year research and intervention programme with the England and Wales Cricket Board (ECB) to eliminate the predominant mixed technique in young fast bowlers. The results of our intervention have been:

- Improvements of floor surfaces in indoor cricket nets to reduce load through the use of shock pads.
- The ECB coaching guidelines and manuals have been revised, with advice to coaches on how to prevent their young bowlers from adopting a mixed technique and how to help them to switch to a side-on or front-on technique. The front-on technique (Figure 2), which is typical of many West Indian fast bowlers, was not previously mentioned in the ECB coaching manual.
- Our recommendations for reducing the number of overs bowled by young cricketers both in competition and in net sessions have also being implemented by the ECB.

This emphasises that to be effective, sports biomechanics have to work closely with coaches and performers to reduce sports injuries. Our influence was reinforced by Nigel Stockill's appointment as the ECB's physiologist, travelling with and advising the England men's team all around the cricketing world.

**Future research:** As scientists, we are always looking to extend our research and to make our practical interventions even more effective. To this end, we might look to follow-up studies of intervention effectiveness and its improvement. Studies to date have been somewhat inconclusive. We need also to validate the injury risk of mixed techniques through more detailed measurements of lower back movements and modelling of the loads in that region of the body. As the two-dimensional shoulder-hip alignment angle does not estimate thorax-to-pelvis rotation accurately, ffuture studies should use valid measures of low-back movements. Classifications of mixed bowlers have used varying amounts of counter-rotation, and there is a need for researchers to agree which variables to measure and how, and to agree a classification of techniques. Exact mechanisms for low-back injury in fast bowlers need to be identified.

**IMPROVING PERFORMANCE:** Now I want to turn to my second theme - how sports biomechanists can help to improve sports performance. The example I have used summarises a decade of providing sport science support to top UK javelin throwers. This also draws on fundamental research using computer simulation modelling and optimisation. I will look further at provision of feedback to coaches and performers within the context of that project.

**Computer optimisation:** In javelin throwing, Russell Best, I and Richard Sawyer identified the javelin release parameters to include in a computer simulation model; then we measured the relevant forces and moments acting on the javelin using wind tunnels. Finally, we established, by computer optimisation, the optimum release conditions for specific throwers. We validated these findings against our measurements from elite throwers in top competitions (Best *et al.*, 1995). The results of our computer simulations raise many practical issues for coaching and training that we have yet to address fully. Contour plots of range variation with release parameters showed that for a given thrower and javelin, only one set of release parameters will give a maximal throw, as shown by the black star in Figure 2. However, any sub-optimal throw can be generated by any set of values of these parameters that lies on that range contour (e.g. that on which lie the four black diamonds). This supports the view that variability in sports movements - in this case, we call this sub-optimal variability, can have functional significance.

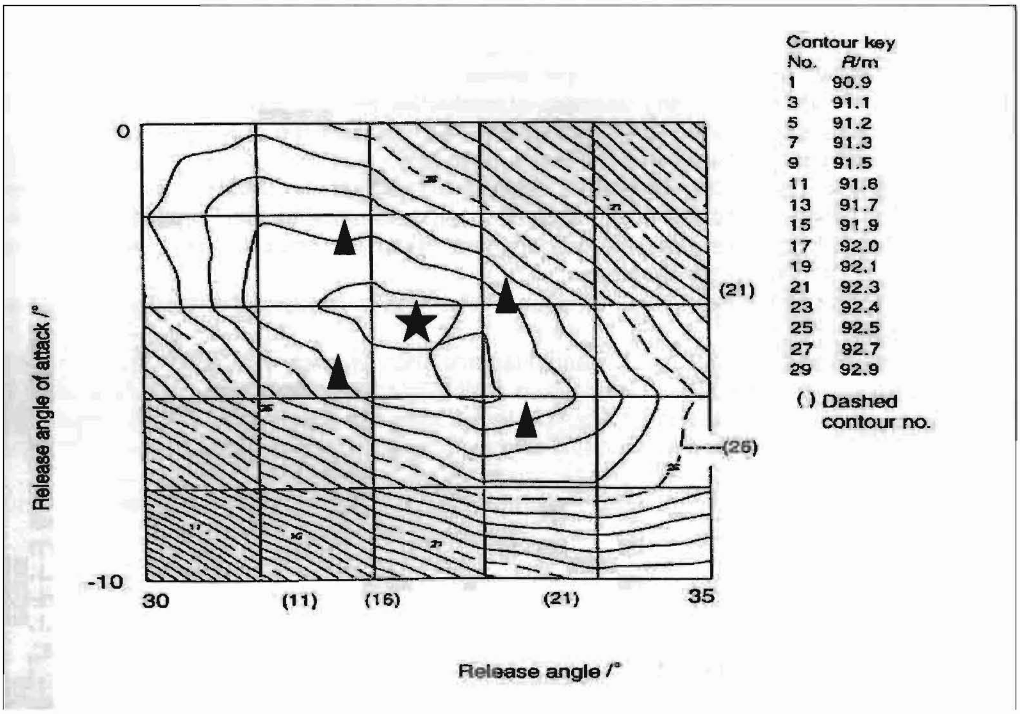


**Figure 2 Contour lines of equal distance thrown (range) as a function of release angle and release angle of attack.**

**Feedback:** Throughout the 1990s, Calvin Morriss and I worked with the top British throwers and their coaches to analyse and improve the throwing techniques, and hence performances, of these athletes, with some success. When we began our work with the UK national javelin squad, we initially based our feedback on the optimization model. However, this failed to excite enthusiasm from the coaches and throwers: it did not provide them with what they wanted. So, instead, we developed detailed, one-on-one feedback of computerized analyses of the throws, given at weekend training camps. Then, after exhaustively establishing those technique elements needing attention, we switched emphasis again – to qualitative video analysis in training and competition, and to strength and conditioning. Calvin went on to become strength and conditioning adviser to British Athletics and, later, to a similar role with English Rugby Union. What we learnt from this is that feedback must address the needs of coaches and athletes and that immediate feedback is not always what is needed, particularly when looking at retention of new elements of a skill.

**Variability:** One topic of theoretical and practical significance that was highlighted by our research in javelin throwing, and which is currently receiving due attention, is the role of variability in sports movements - the theme of my presentation to last year's congress (Bartlett, 2004). As evidence for such variability, I cited: the predictions of sub-optimal variability by our javelin simulation model (Figure 2); our measurements from elite javelin throwers in competition (Figure 3); our findings of within-thrower movement variability across skill levels in javelin throwing; variability in skills requiring both speed and accuracy – basketball shooting; and variability in running – through the research of Joe Hamill and his co-workers at the University of Massachusetts, and the running research of Jon Wheat, myself and others at Sheffield Hallam University and the University of Otago. The existence of movement variability challenges several of the assumptions that we often make in our work with elite athletes, such as the existence of an optimal performance model, and the use of 'representative trials'.

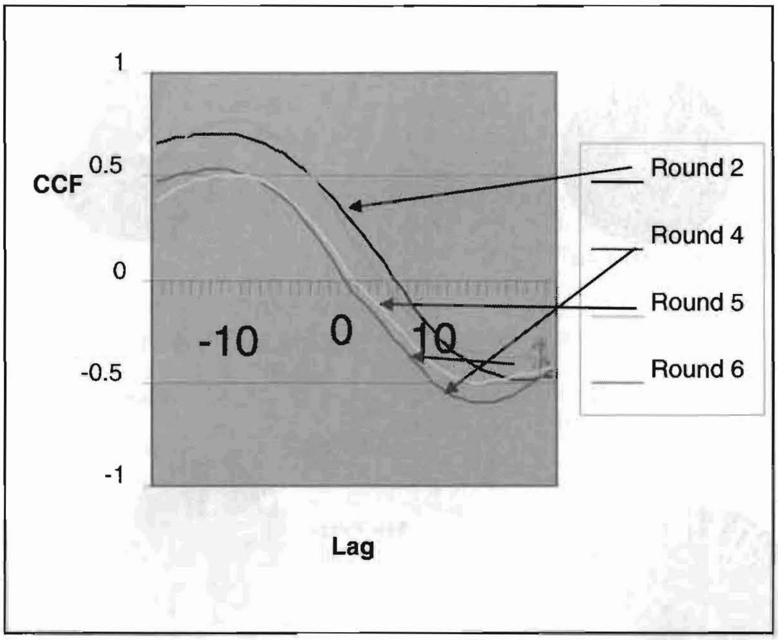


**Figure 3 Cross correlation function (CCF) for various lags between the throwing arm shoulder and elbow angles for the 1996 Olympic men's gold medalist.**

**Measuring variability:** We, therefore, set off on a research programme to study further the variability in, and coordination of, sports movements; most of these studies are in very early stages. For sports biomechanists, measuring variability without the use of markers – as has to be done at present in competition - is very important and was the topic of our first study. We used treadmill running with and without markers, in a laboratory-based two-dimensional study, in near ideal lighting conditions. Four experienced operators manually digitised the video records, as well as SIMI auto-tracking the marker condition. Five running trials were digitised in pseudo-Latin square designs on five successive days; with all no-marker trials first.

With markers, the predominant source of variability in lower limb joint angles by far was that between trials – movement variability; all operators, in single individual designs, were almost as good as SIMI autotracking and all very similar to one another (e.g. Figure 4 top left). However, without markers, intra-operator variability (day-to-day) increased to what I would deem to be an unacceptable proportion of the total variability; operators could not digitise sufficiently reliably even when experienced (Figure 4 top right). Looking across operators in a group design, movement variability was still the predominant source in the marker condition

(Figure 4 bottom left). However, in the no-marker condition, the movement variability accounted for less than half of the total, with inter-operator variability being very large (Figure 4 bottom right). In the no-marker condition, the objectivity – or inter-operator reliability - was poor.

In summary, we could not assess movement variability sufficiently accurately or reliably without markers, although it did account for most of the variance when only one operator digitised the trials. We definitely could not assess movement variability objectively without markers, hindering comparisons between studies (Bartlett *et al.* 2005). Our findings, for conditions far better than those in competition and in three-dimensional estimation of joint axes of rotation, suggest serious problems in studying variability in competition until we can perform markerless tracking accurately. This is also clearly a major problem if movement patterns in competition differ from those in training, as some evidence suggests.

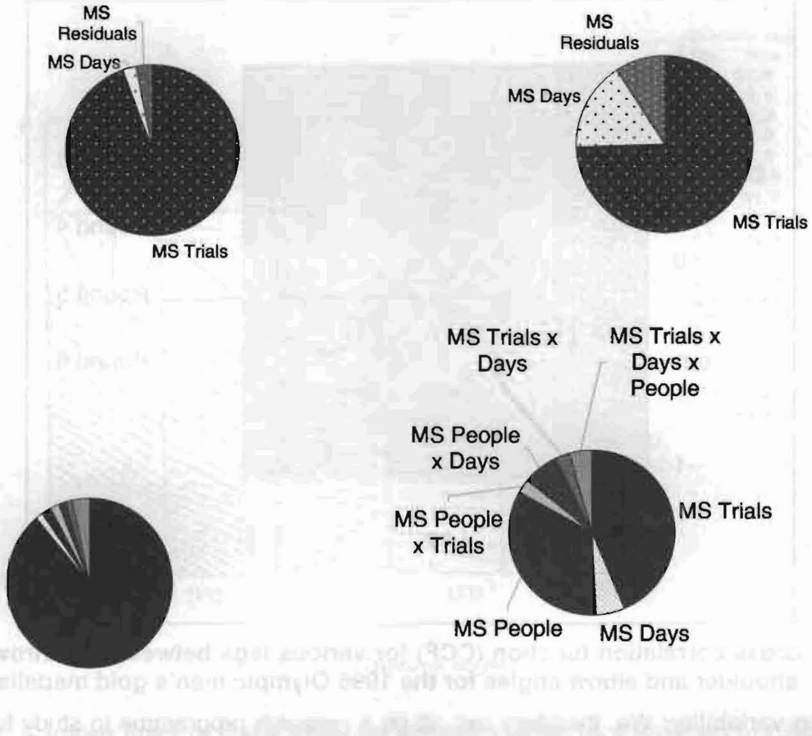


**Figure 4 Partitioning of variability (as mean squares, MS) in knee joint angle between its various sources: Top left: Marker condition, one operator; Top right: No-marker condition, one operator; Bottom left: Marker condition, group of four operators (shadings as in bottom right figure); Bottom right: No-marker condition, group of four operators.**

**THE DRIVERS OF CHANGE:** I find it interesting to reflect on changes that have taken place over the last 30 years. I have classified some of these in Table 1 below, predominantly from a UK perspective although much will apply universally.

**Table 1. The drivers of change 1975-2005.**

| 1975 | 2005 |
|---|---|
| **Our Profession** | |
| Few post graduates in sport and exercise biomechanics. | Many masters' courses and opportunities for PhD research. |

| | |
|---|---|
| Fourth meeting of International Society of Biomechanics previous year.<br>Few journals publishing sport biomechanics papers.<br>Few coaches and performers trained in biomechanics.<br>Little, if any, biomechanical support for top performers.<br>Very few books on the subject: Dyson's 'The Mechanics of Athletics almost rules supreme. | ISB and ISBS well established, also ISEK etc. Many national societies.<br>Many journals publish good sport biomechanics papers.<br>Many coaches and practitioners trained in biomechanics.<br>Biomechanists work closely with coaches to enhance performance.<br>Many good books on sport and exercise biomechanics. |
| **Computers** | |
| Microcomputers new.<br>Serious sports biomechanics done on minicomputers or mainframes.<br>Memory (RAM) of micros minute (around 32 kbytes) and expensive, with no hard discs and crude operating systems.<br>No CD-ROMs.<br>Graphics incredibly basic on virtually all computers.<br>Programming linear and unstructured (unreliable).<br>Interfacing difficult.<br>Dot matrix printers.<br>Computer simulation in its infancy, all done on mainframes or minis using programmes like FORTRAN.<br>No use of artificial intelligence in sports biomechanics. | Microcomputers abound.<br>Almost all sports biomechanics done on micros, mostly PCs.<br>RAM cheap and 2 Gigabytes common; multi-Gigabtye hard discs, reasonable operating systems.<br>DVD-ROMs etc.<br>Stunning PC graphics, not far behind Silicon Graphics.<br>Structured programming, software development tools; some software unreliable.<br>Interfacing easy - 'plug&play'.<br>High quality colour printers common.<br>Much computer simulation can now be done on PCs using special simulation packages, such as SIMM.<br>Artificial neural networks finding uses in sports biomechanics. |
| **Motion Analysis and Other Technology** | |
| Video technology in its infancy, using 25 frames per second analogue cameras.<br>Video cameras bulky; reel-to-reel tape recorders.<br>Most biomechanists working with cinematography (often at 64 Hz, sometimes up to 500 Hz).<br>Few on-line motion analysis systems: first version of Selspot - an active marker system.<br>Force plates often designed and built by users; pressure mats in early days.<br>EMG mostly hard-wired. | Digital technology taken over. Quality, cheap domestic cameras up to 50 Hz: fairly inexpensive high-speed ones to 10,000 Hz.<br>High quality camcorders. Digital cameras can record direct to hard disc or to RAM.<br>Cinematography almost redundant.<br>Real-time on-line motion analysis systems at 250-500 Hz; expense reducing. Technology driven mainly by animation.<br>Many commercially reputable and inexpensive force and pressure systems.<br>EMG often telemetred. Trend to data logging systems has been very slow. |
| **The Theory Revolution** | |
| Biomechanics seen as driven by data and methods; theoretical underpinnings seen as Newton's laws.<br>Little research into coordination of movements in sport and exercise or variability, beyond recognition of sequencing.<br>Little interface between biomechanists and motor skill specialists. | Biomechanists increasingly looking to non-linear dynamical systems theory as a model for their research.<br>Increasing interest in coordination and movement variability (if at times too methodological).<br>Strong links between motor skills specialists, biomechanists and performance analysts. |

**SUMMARY AND FUTURE TRENDS:** As I hope this presentation has shown, sports biomechanists can help both to improve sports performance and reduce injury, if our research is translated into intervention strategies with the involvement of performers and coaches. But what are the future trends – what will we see when we look back from 2015? What follows is a very individual view of things.

Our work with elite sports performers will be increasingly scrutinised from a medal perspective, meaning that we will have to justify our applied research and demonstrate a link between our work and medal success. This is already happening in the UK and New Zealand, for example. This increased scrutiny will force us to evaluate fully our interventions and feedback from the perspective of the coach and performer. To improve still further the research base needed to provide such support to the performer, we will need to investigate further both coordination of, and variability in, sports movements and the practical implications for the sports performer and coach. We will undoubtedly be working side-by-side with other performance analysts, motor skills experts and conditioning specialists. We will have recognised fully the importance of non-linear dynamical systems theory in biomechanics and much of our research will centre on the implications of this theory for the performer and coach, for example, in devising technique training programmes. Novel approaches, such as artificial intelligence, will be far more commonplace than they are now, even though some of them might prove to be research dead-ends. We will be working, in all probability, with markerless autotracking systems and computers that will make those we use today look as obsolete as do the ones we used in the 1970s.

In a similar vein, we will need to prove to the sports world that we can identify the mechanisms behind sports injuries and establish the efficacy of our interventions to reduce injury, as well as to improve performance. It would take a braver and more foolhardy person than I to speculate that we will have solved the redundancy problem in biomechanics, but we will have a far greater knowledge both of the magnitudes of the loads in tissue during vigorous sports movements and the response of tissue to those loads. To these ends, sport biomechanists will collaborate with sports medicine practitioners far more. Finally, ISBS will have grown considerably, certainly to be far larger than the ISB.

**REFERENCES:**

Bartlett, R.M. (1997). Current issues in the biomechanics of athletic activities: a position paper. *Journal of Biomechanics*, **30**, 477-486.

Bartlett, R.M. (2004). Is movement variability important for sports biomechanists? In M. Lamontagne, D.G.E. Robertson and H. Sveistrup (eds.) *Proceedings of the XXII^nd International Symposium on Biomechanics in Sports* (pp. 521-524). Ottawa: Faculty of Health Sciences.

Bartlett, R.M., Bussey, M. and Flyger, N. (2005). Movement variability cannot be determined reliably from no-marker conditions. Communication to the 2005 New Zealand Sports Medicine and Science Conference, 3-5 November.

Best, R.J., Bartlett, R.M. and Sawyer, R.A. (1995) Optimal javelin release. *Journal of Applied Biomechanics*, **11**, 371-394.

Burnett, A.F., Khangure, M.S., Elliott, B.C., Foster, D., Marshall, R.N. and Hardcastle, P. (1996). Thoracolumbar disc degeneration in young fast bowlers in cricket: A follow-up study. *Clinical Biomechanics*, **11**, 305-310.

*Medicine Training and Rehabilitation*, **3**, 113-130.

Elliott, B.C. and Khangure, M.S. (1999). The link between fast bowling technique and disc degeneration in young cricketers: Preliminary data from a follow-up study. In W. Herzog and A. Jihha (eds.) *Abstracts of the XVII International Society of Biomechanics Congress* (pp. 145-146). Calgary: International Society of Biomechanics.

Elliott, B.C., Wallis, B., Sakurai, S., Lloyd, D. and Besier, T. (2002). The measurement of shoulder alignment in cricket fast bowling. *Journal of Sports Sciences*, **20**, 507-510.

Elliott, B.C., Hardcastle, P., Burnett, A.F. and Foster, D. (1992). The influence of fast bowling and physical factors in radiological features in high performance young fast bowlers. *Sports*

Farfan, H.F., Gracovetsky, S. and Lamy, C. (1981). Mechanism of the lumbar spine. *Spine*, **6**, 249-255.

Wallis, R., Elliott, B.C. and Koh, M. (2002). The effect of a fast bowling harness in cricket: An intervention study. *Journal of Sports Sciences*, **20**, 495-506.