HALF A CENTURY IN SPORTS BIOMECHANICS: BRIDGING THE GAP BETWEEN RESEARCHERS AND PRACTITIONERS

David Kerwin

Cardiff Metropolitan University

The lecture will analyse the development of the relationship between sports biomechanics and coaching over a period of 50 years. The key tenants of the Society's aims and ambitions will be central to the lecture. Foundations of the field of study as introduced by Geoffrey Dyson will be reviewed. Changes in methods of data collection and analysis will be considered alongside developments in computing from mainframe to smartphone. Examples will be drawn from studies throughout the period to illustrate the progress which has been made, with the challenges still to be met being highlighted along the way. The lecture will be a personal analysis of the subject's development through a summary of ideas and experiences which have influenced my thinking on the complex relationship between enhancing understanding of movement and transferring these ideas into practice.

I would like to use this opportunity to share with you my life in sports biomechanics. I have called the lecture 'half a century of sports biomechanics' - this is a little ambitious since I started in 1966 and it is not yet 2016, but at the end of the lecture I will speculate on the upcoming years and try to foresee what is likely to happen as we approach the Olympic Games in Brazil.

Little did I realise in 1966 what would happen in July 2013. Prior to commencing a college course, a reading list arrived, and amongst the 'essential reading' was 'The Mechanics of Athletics' by Geoffrey Dyson (1962). Here was a field of study which was new to me in the UK, and as I gathered later, new to more or less everyone else. It is very fitting that ISBS adopted Geoffrey Dyson as its namesake for the award. 'The Mechanics of Athletics' by Geoffrey Dyson, first published in 1962, was described by Track Technique No.14 (U.S.A) as '...the most significant single literary contribution to the technical advancement of track and field athletics in modern times'. By 1970, Dyson prefaced his fifth edition with the following words. 'Our knowledge of the mechanics of athletics continues to grow and we are now in possession of more relevant data. Yet, in some aspects of this subject, we await that creative step which finds order in that data; there is still more to learn'.

It is the last part of this introduction that I will use as a starting point for the lecture. 'Sport' will be substituted for 'athletics', but in every other sense the ideas proposed by Dyson about continuing growth in knowledge through the possession of more relevant data will be examined. However, as Dyson pointed out, data however relevant, is insufficient to advance understanding and the 'creative steps' that find order in that data is where the focus should be placed.

It would be impossible to talk of the development of sports biomechanics without paralleling this with the development of technology. Access to 'more relevant data' is made feasible by improvements in technology. Ecologically valid data collection in training and competition has been advanced through the development of video based technology. Muybridge and Marey showed at the end of the 19th Century that our understanding of the motion of animals, including humans, could be greatly enhanced by capturing sequential visual images throughout the action. Later cine-film was used to achieve the same goal but using greater numbers of images in longer sequences. These were the beginnings of all the motion analysis systems in use today. Video superseded cine-film in the 1980s and opto-electronic motion tracking systems continued this trend into the modern day. The next generation of motion analysis will undoubtable be based on marker-less systems. All these developments have provided sports biomechanics with substantive increases in spatial and temporal resolution, whilst dramatically enhancing the volume of data available for analysis. Video image based systems offer that great advantage of ecologically validity. Access to data derived from performances in international and Olympic championships by the elite competitors of the

world, comes at a cost. This form of data collection carries with it a huge commitment on behalf of the researcher to reduce the rich image content to manageable 3D data for analysis. In contrast, motion capture systems provide mountains of digitally reduced 3D data readily, and in some cases, in realtime. The cost here is the loss in ecological validity and the inability to use this form of data collection in the competitive arena.
Huge improvements in the sensing of forces, the capture of muscle EMG signals and the use of dynamometers with dynamic imaging of X-rays, CT and ultrasound scans have all added to the arsenal of equipment and technology at the disposal of sports biomechanics over the past 50 years. The single most important development however has been that of the computing power which has made all of these technological developments possible and underpinned substantive progress in simulation modelling of human movements.
Biomechanics in the sense of understanding and explaining human movement has been in existence for thousands of years, but modern biomechanics linked to sport is a development of the latter half of the 20th Century. The subject is often sub-divided into two main categories, improving performance and reducing injury, but the overriding aim remains to improve understanding of how humans move.
The international Society of Biomechanics in Sports states that its primary purposes are: To provide a forum for the exchange of ideas for sports biomechanics researchers, coaches and teachers; to bridge the gap between researchers and practitioners and to gather and disseminate information and materials on biomechanics in sports.
The lecture will examine the three goals against personal experience through examining the exchange of ideas, attempting to bridge the gap between researchers and practitioners and gathering and disseminating materials. Clearly in a single talk it is impossible to encapsulate 50 years of the development of the subject, but selected aspects will hopefully have resonance, value and interest.

FORUM

Goal one of the Society is aimed at ‘creating a forum for the exchange of ideas for sports biomechanics researchers’. Although all conferences aim to achieve this forum, not all succeed as well as ISBS. Although I have attended a range of international conferences in my career, my first experience of ISBS was in Konstanz, Germany. I was presenting a free communication on data from the Atlanta Olympic Games (Kerwin et al., 1998). Manfred Vieten was the host and it was the first conference at which I felt at home. Everyone showed great respect for research in sport. The quality of the work was varied but there were some exceptional contributions. The obvious passion and enthusiasm for the subject was evident throughout the week. The social program was spectacular and I left with a desire to return as often as I could. I have encouraged colleagues and students to contribute to ISBS since. When asked why is conference attendance valuable? Leaving aside the aspects associated with travel plans, accommodation, organisation, environment and facilities in the conference venue, development of friendships and enjoyment of the social program, my focus will be on the scientific content of a conference. I would like to reflect on conferences that have had an impact on my thinking; on events that have either triggered new thoughts or re-ignited forgotten ones. Clearly keynote lectures are memorable for a variety of reasons. The style of the presenter, the scope of the material, the relevance of the work to your own interests or even the contrast to your own research, can all make an impression. Many presenters have had an impact on me, but three have been selected to illustrate the spectrum of styles often seen at conferences. I saw Peter Cavanagh in 1987 in Amsterdam when he delivered the ISB’s Muybridge Lecture. Peter used glass slides in carrousels, which for many in the audience will be museum items. Once this was the de facto standard for all international conference presentations. His talk was superbly slick and faultless. Every slide and extract of music appeared without any apparent cues, every word was spoken without hesitation and the whole presentation progressed as if watching a pre-recorded television program. As a live performance it was amazing. This was both a tremendous motivator and a serious challenge.

I was relatively early in my research career and was wrestling with modal analysis of force plate mountings in an outdoor athletics track and here was Peter talking about a custom designed 1000 element piezo electric plate used to study running foot falls. In 1991 in Perth Australia, I witnessed McNeil Alexander give a stunning lecture on the mechanics of jumping, which was published two years later (Alexander, 2003). He drew examples from the animal kingdom to quietly walk the audience through a story using very simple hand drawn illustrations with no computer graphics or flashy images. He had the ability to make everything appear to be so simple and obvious that you felt completely at home in his company. It was only afterwards when speaking about his talk with others that I realised just how expert he was in being able to make everything appear so clear even when in reality the mechanics of jumping is anything but simple. The third presenter I would like to mention is Bruce Elliott. I have had the pleasure of listening to Bruce on numerous occasions, but the one that impacted most was when he visited the UK to present at the British Association of Sport and Exercise Sciences Conference in Worcestershire in 1998. He was talking about exactly what ISBS strives for - turning theory into practice. He appeared to be having a conversation with the audience. His illustrations were very clear but not at all flashy. His ideas were based on years of experience and his skill was in encapsulating many thoughts that I, and others, had experienced at times, but he managed to provide structure and organisation to those ideas and helped everyone to understand better what sports biomechanics could achieve. It was a demonstration of what Dyson had referred to as 'that creative step that finds order in that data'.

Free communications can be as memorable as keynote and award lectures. I heard a short paper by Karen Gruber (Gruber et al., 1987) on an early wobbling mass model of impact landings. I remember exactly where I sat in the auditorium and who was sitting next to me at the time. It was many years later that I found and recruited a PhD student capable of undertaking the challenging work necessary to follow up and extend those ideas. The student was Marianne Gittoes and the work resulted in a computer simulation model of females landing, a PhD thesis and a series of journal papers that explored the influences of wobbling masses on landings. Her research dealt with generic drop landings and has been used to explore mechanisms within landings as presented at ISBS conferences (e.g. Gittoes et al., 2006) and to study gymnasts dismounting from the beam apparatus (e.g. Gittoes et al., 2011).

One of the great benefits of attending a conference, and sadly one which I cannot enjoy at this one, is the down time, when people chat in bars or over meals. Ideas are exchanged and topics discussed. Sometimes an apparently innocent question from an inquisitive student can be just as thought provoking as a question from the floor from an eminent research professor. My view of conferences has changed over my career in two main ways: When I started I tried to go to every session and look for what was wrong with each study. I now select carefully, always look for what is good in the work presented. I judge a trip to a conference to be successful if I come a way with at least one new idea.

BRIDGE

Goal two of the Society features 'bridging the gap between researchers and practitioners'. Experiences from a project called SESAME will be used to illustrate this topic. The acronym stands for SEnsing for Sport And Managed Exercise and was the title of a four year Research Council funded project involving a collaboration between Cardiff and three world leading UK based research groups, Cambridge, UCL and the Royal Veterinary College. None were researching in sports biomechanics. Two messages stand out from the experiences of planning, executing and publishing research from this project. The first concerns the enhancements brought to research in sports biomechanics through collaboration with other disciplines. Although apparently obvious, the intensity and quality offered by world leading researchers in other disciplines, in this case in the fields of wireless technologies alongside specialist researchers in the development and application of sensors in the tracking of animal locomotion in the wild, transformed what was possible within sports biomechanics.

The second message from the project's intense collaboration was that base knowledge in sports biomechanics is still limited. This is not a criticism of sports biomechanics but simply a reflection of the enormity of the task that we are faced with and the relative youth of the subject. Trying to enhance understanding of the subtleties of human movement in all its aspects within so many diverse sports is daunting to what is still a small international community. Even when sport is reduced to a single activity, in our case sprinting, a sub-class of running, the activity that was referred to by Doris Miller at the second ISBS symposium in 1984 as the 'barometer' of research in sports biomechanics, the challenge is still substantial. Despite the apparent popularity of running and research into the biomechanics of running, the overall knowledge base in sprint running for example remains very limited. Questions like, 'what are the limiting factors to performance in sprinting?' or 'what are the key variables which we should aim to measure to enable the athlete to improve?' remain major challenges and all too often are reported in a largely descriptive fashion.

If we take the first question concerning limiting factors, studies of animal gait and historical studies of power output in humans and other animals indicate that the structure and function of the musculoskeletal system is important and that in sprinting, power output at the hips is likely to be a limiting factor. But where do we go from here? Interestingly the number of studies in sprinting is very small and has included different phases of a sprint race (e.g. Jacobs et al., 1992 - second step out of the blocks; Hunter et al., 2004 - the acceleration phase) and across a range of athlete abilities mostly sports students. Our project began in 2006 and even two years in we could only locate four studies that reported moment data during the maximum velocity phase of sprinting (Belli *et al.,* 2002; Kuitunen *et. al.*, 2002; Mann, 1981; Mann & Sprague, 1980) and only three, which reported power values in sprinting (Belli et al., 2002; Johnson & Buckley, 2001; Vardaxis & Hoshizaki, 1989). One paper alone had reported both forms of data and none had considered joint work contributions. The knowledge base on lower limb mechanics in maximum velocity sprinting was tiny. We added some insights through the PhD research of Ian Bezodis, one study of which concerned elite level sprinters and included one who was an Olympic 100 m relay gold medallist (Bezodis et al., 2008). For the first time we had some data on elite sprinters at maximum velocity, but in reality we had moment data of two foot contacts each for four sprinters. This highlighted the challenges we are constantly faced within sports biomechanics. One common argument is that we don't have the equipment to gain the data we need, and this is often true, but there is a parallel and even bigger problem, even when faced with the potential to develop the technology to address our needs, we still often don't know enough to say with confidence what the key aspects of information are that we need?

To address the dearth of knowledge, we adopted a number of approaches. We interviewed coaches of the elite sprinters (Thomson et al., 2009), analysed elite sprinters at major international events (Salo et al., 2010) and examined the underlying biomechanics to formulate a conceptual model, in a similar manner to that reported by Irwin et al., (2005). Even having established some target variables, three key factors became apparent in trying to convert research data into useful feedback to athletes. Ideally the athletes would prefer not to wear sensors at all, but if required they had to be tiny, very easy to put on and cause no interference to technique. Secondly all data transfer and storage needed to be invisible to the athletes and coaches and so had to be via wireless communication. Finally, control of the systems needed to be in the hands of the coach and in as familiar and convenient a format as possible. An integrated system was created to address these concerns (Cheng et al., 2010). Aspects of the system along with illustrations from the project will be provided in the talk to demonstrate the progress that was made in trying to bridge the gap between the demands of research and the needs of the athlete and coach. This on-going interactive process covering what we hope is a symbiotic relationship between athlete, coach and researcher is what we term the coaching-biomechanics interface (Irwin, et. al., 2013).

DISSEMINATION

The third goal of the Society, ‘to gather and disseminate information and materials on biomechanics in sports’, will be addressed through three examples from the biomechanics of gymnastics. The first will draw from experiences working with the national governing body of the sport in Britain. The second concerns bringing the sports governing body into the biomechanics arena and the third of taking biomechanics into the technical arena of the sports governing body in their own environment.

Through more than twenty-five years of working closely with gymnastics, the sport’s thirst for knowledge was evident but the mechanisms to deliver that knowledge were not. Creating coach education material and delivering lectures at coaching conferences was one obvious route, but the process is often not simple or straightforward. An example, based on the award winning work by Fred Yeadon from his 1984 PhD thesis on the mechanics of twisting somersaults, will be used to illustrate the issue. The mechanics of twisting somersaults has long been debated within the sport and many theories expounded, some of which do not stand up to scrutiny. Fred clarified twisting somersaults using computer simulations built on sound mechanics. He used graphical animations to illustrate the three methods for twisting and has been invited to present these and other related ideas at ISBS and many other conferences around the world since. However, gymnastics coaches are sometimes reluctant to listen to ‘scientific techno speak’ when ‘they know what works in the gym’. This illustrates stage one of the necessary communication process to bring about knowledge transfer. Stage two is usually ‘That sounds as though it might be interesting - how might it help me?’ Stage three is ‘Why isn’t this part of every coach education course, and can you write something on this for us?’ and finally stage four is ‘Oh that old stuff, who doesn’t know that. Tell me something new”. This cycle has been repeated many times on a range of ‘biomechanics topics’ but as the relationship with specific coaches builds over time, the process tends to reduce to cycles of stages two and three only. When a new coaching team is encountered, there is a tendency to revert to the four-stage process, so it is necessary to be patient. After years of painstakingly developing biomechanics materials in collaboration with senior coaches at British Gymnastics and former colleagues at Loughborough University, it is pleasing to be able to report that much of the material has been adopted by the Fédération Interantionale de Gymnastique (FIG) as part of the ‘Academy’ resources for international coach education.

Bringing coaches into the biomechanics environment is something that ISBS, and Ross Sanders through his Coach Education Network, have achieved for a range of topics. An example from the 1999 meeting in Perth will be used to illustrate how simple mechanics can be used to address a technical question. In the presentation as part of the gymnastics applied workshop, I used the example of the Diamadov to show how mechanics could explain apparent differences in the efficacy of different techniques. Two world champions’ contrasting actions were compared, and an explanation of why one was preferable to the other was given based on previously captured data and mechanics without the need for a new research study (Kerwin, 1999).

A third example illustrates biomechanics being taken into the sport’s own environment. This example comes from my role alongside colleagues Professors Peter Brüggemann and Jill McNitt Gray as invited members of the FIG’s Scientific Committee. Our overall remit has been to examine research and its relevance to the sport. There has been strong pressure from within gymnastics since 2004 to make the scoring system (Code of Points, 2009) more transparent through a closer alignment of the Codes for men and women in Artistic Gymnastics. Each have separate Codes and yet in many settings, the apparatus is identical (floor exercise), almost identical (vault) or similar (bars). The corresponding difficulty ratings however do not match. One specific question that I was asked to address was ‘could biomechanics help in the process of bringing the Codes closer together?’ Aspects of this debate will be used to illustrate ways that biomechanics has contributed by highlighting current anomalies and suggesting potential means for assessing difficulty scores in the future.

CONCLUDING REMARKS

More recent work centring on improving understanding of learning skills in gymnastics using biomechanics technology in the training environment brings new insights not possible when only single trials or very small data sets are available (Williams et al., 2012). The capacity offered by 3D motion tracking systems to record repeated trials and to supply data for the complex analyses presented by a former Dyson Lecturer (Hamill et al., 2006) is changing the nature, potential and scope of future research in biomechanics. Use of dynamical systems theory being applied to hundreds of trials creates the opportunity to seek patterns, and employ for example multiple correlation techniques, to gain better insights into motor learning. As newer marker-less technologies progress, this form of longitudinal study will appear more commonly outside the confines of single joint tasks in the laboratory. Theoretical biomechanics and computer simulation modelling in particular has demonstrated its power to enhance understanding of underlying mechanisms of skilled movement but continues to be challenged, like experimental studies, by the demands of customisation to meet individual needs. Modern data collection techniques are providing experimental biomechanics with the capacity to extensively develop the 'more relevant data' spoken of by Dyson all those years ago, but technology, although essential, is not sufficient to address typical research questions in sports biomechanics. Don't be seduced by the newest equipment - it is often insufficient in at least two senses. Technology often falls short of the ideal for the purpose at hand. Even when equipment is perfectly suited to the data collection task, without the crucial 'creative steps', built on a sound theoretical underpinning and precise formulation of the relevant questions, progress in enhancing understanding will not be forthcoming.

The collegiate spirit encouraged in modern multi-centre, multi-disciplinary research projects leads to greater productivity and progress. The positive, supportive environment fostered by ISBS through its conferences, the encouragement to emerging researchers and the celebration of transforming 'theory into practice' are all exciting and worthwhile goals. My challenge to the young people in the audience is to ensure that the theory, which is to be turned into practice, always leads in your thinking. This sounds simple, but to move from describing what happens during a complex skill to being able to understand how and why it works is anything but simple. I would encourage you to concentrate on one sport, because understanding say gymnastics has little cross over into canoeing and vice-versa. Experience gained in researching one sport can of course be very helpful when studying another in terms of data collection protocols and the use certain analysis techniques, but without knowing the right questions and without understanding the intricacies of the sport, it becomes very difficult to make more than a general contribution. I have studied three sports seriously in my career, gymnastics, athletics and football. Even gymnastics that I have spent most time working with remains a challenge and often a mystery. Oddly the sport that I have spent least time on, football, has received the most coverage in the media. There are many reasons for selecting a sport to research but having knowledge of and passion for a particular sport is a very good place to start.

Even when sound theory and compelling evidence provided via customised technology, have been amassed the process of providing feedback in suitable ways to communicate novel and effective information to athletes and coaches presents an equally challenging problem to complete the coaching-interface cycle.   This is a topic in its own right and one for another day.

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