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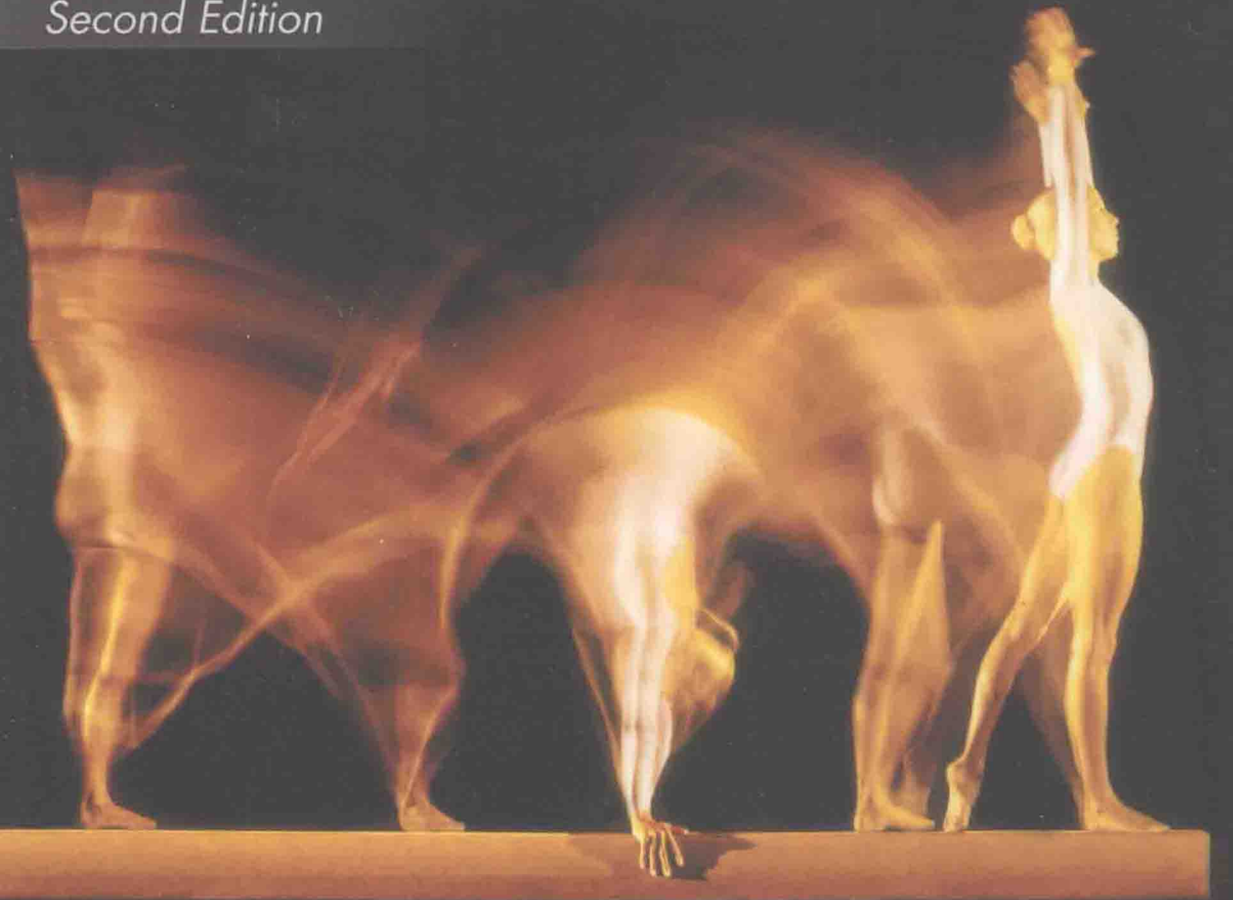

SPORTS BIOMECHANICS

REDUCING INJURY RISK AND IMPROVING PERFORMANCE

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ROGER BARTLETT
AND MELANIE BUSSEY

ROUTLEDGE

Sports Biomechanics

Reducing injury risk and improving sports performance

Second edition

Roger Bartlett and Melanie Bussey

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Sports Biomechanics

When working with sports men and women, the biomechanist is faced with two apparently incompatible goals: reducing injury risk and improving sports performance. Now in a fully updated and revised edition, *Sports Biomechanics* covers the fundamental principles that underpin our understanding of the biomechanics of both sports injury and performance, and explains how contemporary biomechanical science can be used to meet both of those goals simultaneously.

The first four chapters of this book look closely at sports injury, including topics such as the properties of biological materials, mechanisms of injury occurrence, risk reduction, and the estimation of forces in biological structures. The last four chapters concentrate on the biomechanical enhancement of sports performance, including analytical techniques, statistical and mathematical modelling of sports movements, and the use of feedback to enhance sports performance.

Drawing on the very latest empirical and epidemiological data, and including clear concise summaries, self-test questions and guides to further reading in every chapter, this book is essential reading for all advanced undergraduate and postgraduate students with an interest in biomechanics, sports injury, sports medicine, physical therapy or performance analysis.

Roger Bartlett is Professor of Sports Biomechanics in the School of Physical Education, University of Otago, New Zealand. He is an Invited Fellow of the International Society of Biomechanics in Sports and an Honorary Fellow of the British Association of Sport and Exercise Sciences, of which he was Chairman from 1991–4. Roger is a former editor-in-chief of the *Journal of Sports Sciences,* and *Sports Biomechanics*. He is the author of *Introduction to Sports Biomechanics: Analysing Human Movement Patterns* and co-editor of several other sports science books.

Melanie Bussey is a Senior Lecturer in Biomechanics and Sports Injuries in the School of Physical Education, University of Otago, New Zealand. She is a member of the International Society of Biomechanics, Sport Science New Zealand and Sports Medicine Association of Australia. She publishes in a broad spectrum of sport, clinical and biomechanical journals including the *Journal of Biomechanics, Clinical Biomechanics, Journal of Medicine and Science in Sport* and *Manual Therapy*.

Preface

Sports biomechanics has two main concerns, on which this book focuses: the reduction of injury risk and the improvement of performance. It is a scientific discipline that is relevant to all students of the exercise and sport sciences, to those intending to become physical education teachers, and to all those interested in sports performance and injury. This book is intended as the companion volume to *Introduction to Sports Biomechanics: Analysing Human Movement Patterns*. Whereas that text mostly covers first and second year undergraduate material, this one focuses on third and fourth year undergraduate and postgraduate topics. The book is organised into two halves, which deal respectively with the two key issues of sports biomechanics: why injuries occur and how performance can be improved. Wherever possible, these topics are approached from a practical sport viewpoint. The mathematical element in biomechanics often deters students without a mathematical background. Where we consider that basic mathematical equations add to the clarity of the material, then these have been included, particularly in Chapter 4. However, we have otherwise avoided extensive mathematical development of the topics, so that the non-mathematical reader should find most of the material easily accessible.

The production of any textbook relies on the cooperation of many people other than the authors. We acknowledge the helpful contributions of several colleagues at our university, the University of Otago. In particular, the book could not have been produced without the backing of the Dean of the School of Physical Education, Professor Doug Booth. Neither would it have been possible without the inspiration provided by our many undergraduate and postgraduate students over the years. Roger Bartlett would like to thank his former honours student Anna Skelton for proof reading the drafts of his chapters and for suggesting the topics for the glossaries in those chapters, and to acknowledge the encouragement and psychological support provided by Jo Trezise and Jo Stuthridge during the gestation period of this book. Roger would also like to thank Professor Mike Hughes for permission to use and adapt some of the material from one of their joint chapters on performance analysis, and for inspiring much of his interest in that discipline. Melanie Bussey would like to thank graduate students Rhys Thorp and Neil Anderson for their aid in chasing down lost references and tedious file formatting. Most importantly, she would like to thank her family, husband Mike Sam and children Sophie and Jackson, for their patience, support and encouragement.

Roger Bartlett and Melanie Bussey

Introduction

Sports biomechanics has been described as having two aims that, at times, seem incompatible: the reduction of injury risk and the improvement of sports performance. The first four chapters of this book focus on the first of these aspects, the reduction of injury risk, while the last four chapters focus on the improvement of sports performance. At the end of the last chapter, the book comes full circle with a consideration of intervention strategies to reduce the risk of injury to fast bowlers in cricket.

The reduction of injury risk may involve a sequence of stages that begins with a description of the incidence and types of sports injury. The next stage is to identify the factors and mechanisms that affect the occurrence of sports injury. This relates to the properties of biological materials (Chapter 1), the mechanisms of injury occurrence (Chapter 2), the identifiable risk factors (Chapter 3) and the estimation of forces in biological structures (Chapter 4). Where deemed necessary, mathematical equations have been introduced, although extensive mathematical development of topics covered has been avoided.

Biomechanists use the principles and theories of physics and mechanical engineering to describe the forces and force-related factors that lead to injury. In a biomechanical model, it is the relationship between applied force and specific tissue tolerance to the applied force that determines the outcome of an inciting event.

In Chapter 1, we consider important mechanical concepts in the study of injury such as energy, external forces or load and the effects of loading on biological tissue along with an introduction to the important epidemiological concepts that support the biomechanical study of injury risk. The most important mechanical properties of biological and non-biological materials are explained. In particular, we outline the composition and biomechanical properties of bone, cartilage, ligament and tendon and their behaviour under various forms of loading. Muscle elasticity, contractility, the generation of maximal force in a muscle, muscle activation, muscle stiffness and the importance of the stretch–shortening cycle are all described.

To understand how sport participation may affect biological tissue and tissue tolerance to loads applied during sport participation, it is necessary to understand how biological tissue adapts to mechanical stress. In Chapter 2, we consider aspects of tissue adaptation and the effect of mechanical stress on bone, cartilage, muscle, ligament and tendons. Furthermore, we cover the biomechanical reasons why injuries occur in sport, and we distinguish between acute and overuse injury. An understanding is provided of the various injuries that occur to bone and soft tissues, including cartilage, ligaments and the muscle–tendon unit, and how these depend on the load characteristics. The sports injuries that affect the major joints of the lower and upper extremities, and the back and neck, are also covered.

Chapter 3 includes a consideration of some of the most general and common intrinsic and extrinsic risk factors in sport. Intrinsic risk factors are those factors that affect the load tolerance of the tissues within the athlete. Intrinsic factors considered in Chapter 3 are age, sex, anatomy, previous injury history, and movement technique. Extrinsic risk factors are those factors that influence the load characteristics applied to the tissues within the athlete while participating in sport. Under extrinsic risk factors, we consider the important characteristics of sports surfaces and how specific surfaces behave. The methods used to assess sports surfaces biomechanically and the injury aspects of sports surfaces are also covered. Attention is then given to the injury-moderating role of protective equipment. In addition to protective equipment, we consider various forms of athletic footwear, including running shoes, court shoes and field shoes, and important aspects of each in reducing injury and enhancing the relationship between the athlete and the surface on which they play. We look at various faults in movement technique across a range of individual and team sports and evaluate the effect of such faults on musculoskeletal injury.

In Chapter 4 the difficulties of calculating the forces in muscles and ligaments are considered, including typical simplifications made in inverse dynamics modelling. The equations for planar force and moment calculations from inverse dynamics for single segments and for a segment chain are explained, along with how the procedures can be extended to multi-link systems. The various approaches to overcoming the redundancy or indeterminacy problem are described. The method of inverse optimisation is covered, and attention is given to an evaluation of the various cost functions used. Finally, the uses and limitations of electromyography (EMG) in estimating muscle force are outlined.

The second aim of sports biomechanics, as we observed above, is the improvement of performance. This can involve certain aspects of sports equipment design and engineering, which can also help reduce the risk of injury; this is a major concern of the new discipline of Sports Engineering. In Chapter 5, we focus on Performance Analysis, a 'discipline' of sports science that has truly emerged and prospered since the first edition of this book. In the following two chapters, we look at the contribution sports biomechanics has made, and can make, to the improvement of sports performance – by improving the movement technique of the performer, through both qualitative (Chapter 6) and quantitative biomechanical modelling and analysis (Chapter 7). In Chapter 8, we conclude by looking at aspects of intervention strategies to improve performance.

Performance analysis can be considered to bring together various disciplines which are concerned with the analysis and improvement of sports performance. It is used extensively by sports movement analysts working 'in the field' with coaches and athletes. It can be seen, primarily, as an amalgam of sports biomechanics, notational analysis, and motor learning and control, with important contributions from sports technology and, when related to the analysis of performance, inputs from physiology, coaching science and, occasionally, psychology. In Chapter 5, we focus on the notational analysis and biomechanical analysis components of performance analysis, which are the aspects most directly involved with the analysis of sports performance, and we touch on the four-stage approach to structured performance analysis. The qualitative, semi-quantitative and quantitative approaches are outlined and contrasted. We then consider what notational analysis involves and how it is used to try to understand and improve performance of teams and individuals, and consider both hand notation systems and computerised notational analysis. We also outline some of the components of biomechanical analysis, such as analysis of phases of a sports technique, and movement principles as they relate to movement phase analysis and sports performance.

To improve sports performance, we effectively need some 'model' to which we can compare the current movement technique and performance of our athlete. In Chapter 6, we focus on the use of qualitative biomechanical analysis (in which we include semi-quantitative analysis) in the improvement of sports performance. Qualitative analysis is often used more directly than quantitative analysis in seeking to improve sports performance, as it is the approach most often used by coaches, teachers and performance analysts working with individual athletes and sports teams. We consider in more detail the four-stage structured analysis approach. A strong focus in this chapter is the use of deterministic models of sports performance to identify observable 'critical features' of the movement; we also look at alternative ways of identifying critical features. The use of qualitative biomechanical analysis software packages is overviewed. Qualitative analysis is not, however, only about observational analysis of video. It also involves the qualitative (and semi-quantitative) analysis of movement patterns and coordination patterns. We look at both of these types of pattern and see how they can enhance observational analysis of video footage. The coordination patterns we consider are angle–angle diagrams, phase planes and relative phase, and cross-correlation functions.

In Chapter 7, we consider the fundamentals underlying the quantitative biomechanical optimisation of sports movements, and focus on those approaches that have a strong emphasis on improving performance, albeit often more indirectly that the qualitative methods of the previous chapter. The relationships that can exist between a performance criterion and various performance variables are explained. The cross-sectional, longitudinal and contrast approaches to statistical modelling are described and the limitations of statistical modelling in sports biomechanics are evaluated. The advantages and limitations of computer simulation modelling, when seeking to evaluate and improve sports movements, are covered; brief explanations of modelling, simulation, simulation evaluation and optimisation are also provided. The differences between static and dynamic optimisation and global and local optimums are outlined. The interpretation and explanation of graphical representations of optimisation and the use of contour maps to identify likely ways to performance improvement are emphasised, in the context of studies of javelin throwing. We touch on models of human skeletal muscle and their use in both general computer simulation models of the sports performer and establishing optimal sports movements. The chapter concludes with the consideration of a more recent approach to modelling sports movements through the use of artificial intelligence, particularly artificial neural networks.

Chapter 8 considers how the results of performance analysis and of biomechanical studies of sports movements can be communicated and fed back to the athlete and coach to improve performance; this is the crucial intervention stage of the four-stage analysis process discussed in Chapter 6. The fundamental points that must be satisfied for feedback to the coach and athlete to be relevant are covered. The different forms of feedback that are now available are critically assessed. The strengths and weaknesses of the various models of performance covered in Chapters 6 and 7 and their limitations as intervention 'tools' are evaluated. The issues that must be addressed in seeking to optimise the provision of biomechanical information to the coach and athlete are discussed, with reference to some relevant motor learning literature. An overview and evaluation is provided of several forms of computer-based feedback. Finally, several intervention case studies are considered, mostly dealing with reducing injury risk in cricket fast bowlers.

Contents

Figures