Sports and Athletics Preparation, Performance, and Psychology

World Book of Swimming

From Science to Performance

Ludovic Seifert
Didier Chollet
Inigo Mujika
Editors

NOVA

SPORTS AND ATHLETICS PREPARATION, PERFORMANCE AND PSYCHOLOGY

WORLD BOOK OF SWIMMING: FROM SCIENCE TO PERFORMANCE

LUDOVIC SEIFERT
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EDITORS

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PREFACE

Before 1970, scientific research in swimming was poor and anecdotal, and the improvements of performance were linked firstly to the swimmer's experience and, secondly, as a result of permanent research for speed. Before and after the Second World War, scientific studies were conducted by pioneers and marked the beginning of research in stroke mechanics and swimming physiology exercise. This book reviews research on the body of knowledge available for the improvement of sports coaching and training practice in swimming, which seems to be relevant, numerous, and diversified enough to help swimming coaches bridge the gap between theory and practice.

Chapter 1 - Swimming performance depends on the interaction of propulsive and resistive forces. A swimmer can improve by reducing resistive forces, or drag, that act on the swimming body at a given velocity or by increasing the propulsive forces. It is thus interesting to have knowledge of the backgrounds of both propulsion and drag. Especially when improvement of performance is at stake, it is interesting for the coach to know in what way it is possible to evaluate a swimmer's ability to minimize resistance and maximize propulsion. Therefore, measurement tools will be discussed that are currently used to evaluate for example the effect of suits on resistance followed by a discussion of propulsion of arms and legs in front crawl swimming.

Chapter 2 - A swimmer needs solutions of propulsive actions to cover a given distance in least amount of time in aquatic space which is referred to as self-produced propulsion. In aquatic space - in contrast to locomotion on land - the cyclic interaction between the body (and its parts) and water mass is essential to achieve propulsion. The water mass is displaced "irregularly" creating unsteady flow conditions. Since water mass is accelerated and decelerated, unsteady flow conditions are coming onto play, e.g. another force, called Acceleration-Reaction (AR) and vortex induced momentum. Momentum is propelling the body while forces are changing the propelling effects. AR can slow either down the swimmer or thrust the swimmer depending on the timing of body motion and motion of water. Vortex induced momentum in unsteady flow is based on fast turning actions of the body parts. This is best explained referring to aquatic animals: the trunk is displacing water and the tail and fin are accelerating the water mass resulting in vortex forms. Some vortex forms when accompanied by a jet-flow may result in additional thrust effects. PIV-methods [16, 22] or CFD-methods [9, 21, 24] allow for unsteady flow visualization and calculation of the momentum and forces due to self-propelling actions.

Chapter 3 - "The swimming muscle" refers to a collection of papers and ad hoc research projects dealing with the electromyographic (EMG) data acquisition in an aquatic environment. The detection of the electricity potentials in human muscle, is probably amongst the oldest, if not "the oldest" scientific experiments. This chapter will inform the reader about the essential knowledge of historical facts in order to understand the evolution of EMG and its methodological development. The basic methodological description combined with neuromuscular basics is specified and is related to the complexity of measuring human dynamic muscle activity in an aquatic environment and to the complexity of stroke techniques, training aids and systems e.g. data acquisition approaches, signal processing and EMG force relations. The EMG allows for the description of motion of swimming techniques in terms of muscle participations, synchronisation and intensity. Muscular activity descriptions permit the development of applied and related aspects e.g. training, technique improvement and performance enhancement. Remodelling the front crawl with EMG is considered in combination with a selective approach of shoulder problems and solutions. Many studies of swimming and EMG are known since many decennia but back-, breast stroke and butterfly research and related feedback remain limited.

Chapter 4 - The swimming velocity resulted from the combination of the propulsive and drag forces. The biomechanics evaluation was strongly improved during the 30 last years. Results underlined the main contribution of the hand in the swimming propulsion. The in-sweep-pull phase appeared the most important phase of the stroke either for kinematics (hand, elbow paths, velocity and acceleration) or kinetics (forces) and muscular activations. Fatigue state lead to a decrease of the in-sweep efficiency, the swimmer not be able to maintain the forces, muscles contributions and path during this constraining phase. The strength capacity seems to be a necessary but not sufficient parameter of the performance which is more related to the swimming force and power. Kinematics, kinetics and electromygraphic measurements confirmed the complementarity of the dry land and the water training process, the first allowing control of different parameters (muscles, imbalance, velocity, load), the second one more reproducing the race condition.

Large individual variations were observed either in fresh or fatigue states, either for local or international swimmers. Consequently, biomechanical approaches could be useful tool in the swimmer evaluation to adapt specifically the training process.

Future researches will increase the knowledge on swimming propulsion and their applications in the improvement of performance.

Chapter 5 - This chapter deals with intra-cyclic velocity variations within a swimming stroke cycle (dv), and its variation with technique, exercise intensity, energy expenditure and fatigue, as a relevant parameter to assess biomechanical and coordinative development of swimming technique. The text starts through the theoretical foundations of the assumption, relating variable movement with increased energy demands and biomechanical proficiency. Then it progresses to the definition of the actual state of the art of the practical solutions available for its assessment, with special emphasis on the discussion about the convenience of centre of mass or a fixed anatomical point assessment. The relationships between dv and other performance related/determinant factors, both biomechanical and coordinative or physiologic and energetic, will be also addressed. Finally, the chapter concludes with considerations related to the applications of the study of dv to performance and training evaluation and advice.

Chapter 6 - This chapter on breaststroke kinematics mostly presents the works of the Leuven Research and Evaluation Centre, under the direction of Professor Ulrik Persyn since 1970, and is dedicated to one of his pioneering researchers in breaststroke Dr Veronique Colman. The breaststroke has the greatest variation in intra-cyclic velocity of the four strokes and has the most variants in style. This chapter is therefore composed of four parts: the phases of a stroke cycle, the intra-cyclic velocity variations, the styles (undulating vs. flat), and the influence of body characteristics.

Chapter 7 - In swimming, as in several sports, the performance optimization relates to capacity of swimmers to coordinate their motor actions. In alternates strokes (front crawl and backstroke), the inter-arm coordination is evaluated. The method uses the Index of Coordination (IdC) to measure the coordination of arm stroking with precise quantification of the lag time between the start of propulsion by one arm and the end of propulsion by the other, and secondly to describe how this index varies as a function of the stroking parameters (speed, stroke rate, stroke length). In simultaneous strokes the assessment of arm-leg coordination, both in butterfly stroke and in breaststroke, consists to analyse the spatial-temporal relationships between the key points defining the start and the end of the arm and the leg stroke phases. Coordination changes are function of skill level, gender, and speed. The major objective of this chapter was to present the studies about the coordination, firstly of arm stroking in alternates strokes, secondly arm to leg coordination in simultaneous strokes, thirdly the effect of skill, gender and speed on inter-limb coordination and fourthly the coordination between propulsion and breathing: effect of preferential side of breathing, coordination asymmetry, force asymmetry and handedness.

Chapter 8 - The rolling actions of the shoulders and hips (bodyroll) in front-crawl and backstroke reflect the rhythmical contributions of the lower limbs, the actions of the upper limbs, and gravitational effects. The timing of the shoulder and hip rotations varies between and within swimmers, depending on speed, the stage of the race, and the nature of the kick (e.g. depth and frequency). A number of performance benefits have been attributed to bodyroll including reduced drag, increased stroke length, reduction in shoulder injury and increased propulsion.

Chapter 9 - This chapter addresses the role of rhythm in butterfly swimming. The underlying rhythms of the vertical undulations of the body parts and the motion of a ‘body wave’ have been quantified using Fourier analysis. In combination with advanced three dimensional analysis of kinematics, kinetics, and energetics, the analysis of rhythms and body wave motion provide insights into how skilled butterfly swimmers are able to re-use energy in the process of rotating and raising the trunk to swim economically. Three main conclusions can be drawn from the evidence and rationale provided. First skilled butterfly swimming is characterised by wave-like undulations of shoulders, hips, knees, and ankles with the vertical undulations consisting almost entirely of a waveform corresponding to the stroke frequency (H1) and a waveform of twice that frequency (H2). Second, the undulations are coordinated to yield travelling 'body waves' to optimise performance from both hydrodynamic and energy transmission and re-use perspectives. Third, the phase relationship between the one-beat H1 frequency and two-beat H2 is important to performance.

Chapter 10 - This chapter deals with the way morphology influences performance and mechanics of swimming. Performance in swimming is influenced by size. A taller swimmer will generally swim faster. Larger propelling sizes better the propelling efficiency and lower the stroke rate – creating a more energy efficient mode of swimming. Drag is influenced by size: a taller swimmer will create less wave resistance at the same speed, and the tall swimmer will have a greater potential for maximal velocity due to a higher hull speed. Pressure drag is directly influenced by the projected cross sectional area which increases drag. During a swimming race, a taller swimmer will have a shorter true race distance due to turning and finishing actions with their center of mass further away from the pool wall.

Sprinters are larger than long distance specialists, freestyle specialists are often larger than breaststrokers and the best swimmers are often taller and bigger that the rest. There is little to do with the genetics of one individual, however coaches should guide the young athletes to make the most out of ones pre determined morphology. The guiding towards specialization of strokes or distances should have the scientific evidences presented in this chapter in mind.

Chapter 11 - Swimming performance can be described as the result of the transformation of the swimmer's metabolic power into mechanical power with a given energetic efficiency. Most of the energy produced by the swimmer is utilized to overcome water resistance or drag, and the rate of energy expenditure theoretically increases with the cube of the velocity. This energy is generated by the sum of the immediate (phosphagen), short-term (anaerobic glycolysis) and long-term (oxidative phosphorilation or aerobic) energy delivery systems. The relative contribution of each system has been frequently determined on research developed in other types of exercise activities or from linear calculations. The modeling of the energy metabolism behavior using computer simulation, combined with physiological field measurements, offers new insights and improved estimations on the relative contribution of the energy delivery systems.

Chapter 12 - The primary purpose for training energy systems is to improve swimming performance by enhancing the ability to produce energy from anaerobic and aerobic processes. Endurance training which is performed at sub-maximal intensities, i.e. from around lactate threshold to $\dot{V}O_2max$, enhances lactate removal, and improves cardio-respiratory functions for oxygen delivery, as well as muscular oxidative capacity for oxygen utilization. Anaerobic training which produces a significant amount of lactic acid induces an increase in the enzymatic activity of the glycolytic system as well as the muscle's buffering capacity. Finally, sprint training lasting less than 10 seconds enhances the ATP-PCr system and glycolytic system, but could decrease some resting metabolites stores, such as ATP and PCr. Since the effect of training on each energy system depends strongly on training intensities, it is of major importance to understand why training intensities have to be carefully set to optimally stress and maximally potentiate each energy system.

Chapter 13 - In competitive swimming, as in other competitive sports, lactate tests are commonly applied not only to describe the current metabolic performance of the swimmer but also to define appropriate training goals, intensity and volume, to monitor metabolic adaptations to training and to adjust the training periodisation in order to increase the training efficiency. Mader ([42], [44]) argued in a mathematical model of metabolic energy supply that beside the aerobic activity the lactate production also strongly affects the lactate-speed relation. This finding can explain a lot of contradictory interpretations ([28]) and paradoxes between the evaluation of lactate tests and the performances in competition and/or in training, but it also stresses the importance of examining and considering both the aerobic and anaerobic metabolic components together in order to ensure a reliable implementation of lactate test results ([56]). In the last 20 years, more basic studies support this rather theoretical approach and provide better insight in different factors, other than O_2-limitation for contraction, that affect blood lactate concentrations during exercise ([19], [20]).

Beside its metabolic metamorphosis, being upgraded from a glycolitic waste product to an important intermediate that helps regulating the metabolic activity, lactate has newly been described as a signalling molecule ([62]) between respectively the metabolic and nervous system and the metabolic and gene expression system. However these finding certainly need more research before any evidence based application in training.

Chapter 14 - Lactate threshold, Maximal Lactate Steady State (MLSS), and Critical Swimming Speed (CSS) represent distinct measures of endurance fitness. Each parameter can be used to assess a discrete aspect of swimming endurance. The lactate threshold can be identified from changes in the capillary blood lactate concentrations during an incremental step test. Alternative and non-invasive methods using open indirect calorimetry have recently been applied in swimming. Several 30-min sub-maximal constant speed tests need to be performed to determine MLSS, seen by some physiologists as the criterion measure of aerobic endurance. However, CSS is perceived in swimming as a more practical method for assessing aerobic endurance as it only requires the performance of several shorter maximal efforts to exhaustion. For coaching purposes, the 60-min and 30-min time trial tests could be effective for estimating MLSS and CSS. For any of these methods, both validity and reliability have to be established before being applied in research or practical settings. Given the narrow spectrum of sub-maximal speeds in swimming, good precision in the estimation of endurance speeds is a priority.

Chapter 15 - The energy cost per unit distance (i. e. the economy of swimming, *C*) is given by the ratio $\dot{E} / v$ where $\dot{E}$ is the net (above resting) metabolic power and v is the swimming speed. The contribution of the aerobic and anaerobic energy sources to $\dot{E}$ in swimming competitions differs according to the distance covered; it is independent of swimming style, gender or skill and depends essentially upon the duration of the exercise. In swimming, *C* increases with the speed with a non linear function; for a given speed, *C* is the lowest for the front crawl, followed by the backstroke, the butterfly and the breaststroke. *C* is essentially determined by the hydrodynamic resistance (W_d): the higher W_d, the higher *C*; and by the propelling efficiency (η_P): the higher η_P the lower *C*. Hence, all factors influencing W_d and/or η_P will result in proportional changes in *C*. The concepts of economy and efficiency are strictly related; hence, this chapter is also devoted to an analysis of the efficiencies in swimming; a summary of the values reported in the literature is also presented from a "historical point of view". Last but not least, the factors setting performance ($\dot{E}_{max}$ and *C*) are briefly reviewed in view of a proper planning of swim training.

Chapter 16 - The primary goal of this chapter is to familiarize the readers with areas and results of research on strength training in swimming. Analysis of modern studies on relationship between different manifestations of strength and swimming performance demonstrates a high specificity of strength application in aquatic locomotion. This specificity requires adequate methods of strength training, which focus on utilization of strength developed in dry-land training in swimming motor patterns. Authors propose to use the values of pulling force and power recorded in tethered, semi-tethered swimming or acquired with the MAD-system as criteria of specific strength and reliable predictors of swimming performance. Materials of the chapter suggest that despite the growing value of aquatic strength training, dry-land training will remain an important form of supplementary preparation. At the same time the content and objectives of dry-land training are changing in accordance with demands of swimming sport. In this respect, contribution into competitive performance of the strength of stabilizing muscles and core body as well as efficiency of injury preventing strength training require further investigation. The chapter also contains recommendations on strength training for age group swimmers, methods of testing of strength and organization of research.

Chapter 17 - The taper forms the final part of the swimming training program prior to a major competition. The aim of the taper is to enhance competitive performance by reducing the degree of residual fatigue and optimizing physiological and psychological capacities. Various studies have reported cardiorespiratory, metabolic, hormonal, and neuromuscular changes during the taper. The expected mean improvement in competitive swimming performance with an effective taper is ~0.3-5% although individuals will respond differently. The three primary types of taper are the linear taper (systematic reduction in training volume and load), exponential taper (with either a fast or slow decay), and the step taper (substantial standardized reduction in training volume and load). Training frequency is maintained or only a modest reduction of one or two training sessions per week should be made by the end of the taper. The intensity of training in main sets is held relatively constant. The typical reduction in training volume is ~50-75% of the peak volume achieved during the training season. Tapers should be individualized according to the specific circumstances of swimmers (e.g. time required for elimination of residual fatigue and optimization of adaptations).

Chapter 18 - More than three quarters of all competitive swimming events are completed in less than two and a half minutes by athletes of at least national class. To prepare for these events, coaches manipulate training load (usually described as a combination of volume, intensity, frequency, and dry-land training) at various times of the season in an attempt to prepare their swimmers to peak just at the right time. Leading into competition, there is usually a phase of high load training followed by some kind of tapering (reduced load) program. Scientific data support bigger performance gains through a program based on high intensity and low volume prior to a high-load phase and taper phase leading into competition. Individual athletes will respond differently to such fluctuations in training load and will depend on parameters such as training status at the time and performance level. Individual responses can be monitored using simple observational or monitoring techniques, regression analysis, or with the help of a systems model. These analytical processes may be useful tools to establish individualized training programs.

Chapter 19 - The high volume nature of elite swim training can result in an increased susceptibility to overreaching and the overtraining syndrome. Appropriate use of recovery strategies during training and competition may result in reduced fatigue, enhanced adaptation to training and reduced risk of developing the overtraining syndrome. Appropriate monitoring of performance and mood state may provide early indications of excessive fatigue. Biochemical, hormonal and immune system indicators appear to be less promising as markers of overreaching and the overtraining syndrome. Both active and passive recovery can be beneficial to repeat performance when considering the duration of the effort and the amount of recovery time. Further, evidence regarding the effectiveness of various recovery strategies, including hydrotherapy and sleep quality and quantity, is increasing. Research is supporting the role of recovery in minimising fatigue associated with high intensity training. A careful balance of appropriate high volume training and recovery can ensure maximum performance gains are achieved by elite swimmers. Monitoring of the swimmers' performance and mood state and incorporating recovery strategies can play a role in ensuring this balance is maintained.

Chapter 20 - Altitude/hypoxic training is today a common practice among swimmers although its benefits are still controversial in scientific literature. Traditional altitude training ("live high-train high") is still the most frequently used method in swimming, even though from a physiological perspective the "live high-train low" strategy appears to be a more promising alternative. While acute hypoxia deteriorates swimming performance, chronic hypoxia may induce acclimatization effects, mainly through the acceleration of red blood cell production, which could improve aerobic capacity and therewith performance upon return to sea level. Other potential benefits such as improved exercise economy, enhanced muscle buffer capacity and pH regulation, and improved mitochondrial function have also been postulated. In order to get a better picture of the potential usefulness of altitude and hypoxic training in swimming this chapter will (i) briefly review the acute and chronic effects of hypoxia, (ii) describe traditional and current methods of altitude/hypoxic training, (iii) discuss the scientific evidence on the effects of altitude/hypoxic training on sea level swimming performance, and (iv) give some practical guidelines for altitude/hypoxic training.

Chapter 21 - Competition race analysis in swimming has evolved significantly over the past two decades. In the early 2000s FINA (swimming's international governing body) passed a resolution to make competition race analysis obligatory in all FINA International competitions. This was potentially a very progressive initiative; however it was not successfully implemented due to a lack of financial support from FINA. The following chapter investigates the history of international competition race analysis in swimming. It describes the function of race analysis and what it attempts to achieve. The chapter provides a description of how race analysis is performed and how race analysis results are presented to the swimmer and coach. Finally, it illustrates what the swimmer will gain from utilizing race analysis, as well as it investigated the possible future directions of competition race analysis in the sport.

Chapter 22 - Dive starts generate the fastest velocities in swimming races. With 50m events lasting for just over 20s, a starting gain of 0.1s could very likely mean the difference between winning and losing. As the length of races increases, any proportionate gain from the start diminishes, but remains important. Research remains ambivalent regarding the complex manoeuvres required for an effective start and, despite the introduction of several new techniques; none have demonstrated superiority.

Turning generates the second fastest velocities in swimming and can represent up to 30% of distance covered. Efficient turns increase in importance with the race distance; especially in short course pools. Changes have occurred with turn techniques but superiority is again equivocal. However, rules no longer requiring hand touches have altered freestyle and backstroke turns; and underwater kicking has altered turns for all four competitive strokes.

This chapter reviews sport science research of swim starts and turns to provide evidence based information that coaches could use with swimmers.

Chapter 23 - In cyclical activities, where the same motor structure is repeated, speed is the result of a contradictory relationship between the amplitude or stroke length (distance per cycle) and the frequency or stroke rate (a number of cycles per unit of time). In swimming, the swimmer must find the optimal combination of stroke rate and stroke length parameters to reach and maintain the highest possible speed according to the constraints of the task. The swimmers swim more and more quickly, using different combinations of stroke length and stroke rate, which relate to the type of race, the stroke, the gender, the training program and the anthropometric characteristics of the swimmer.

Chapter 24 - Classification is the distinguishing factor of Paralympic sports and a majority of the research done here on swimming has had this in mind. Competition for persons with loco-motor disabilities is organized under a functional classification system in which persons with various impairments compete against one another in several classes. Swimmers with visual impairment (3 classes) and intellectual disability are also discussed here. Mathematical comparisons of 100m freestyle world records for loco-motor disability digress over the 10 classes in a predicable manner. This is not the case in other events however. Paralympic 100m freestyle swimmers demonstrate on the mean similar stroking parameter changes to able-bodied Olympic swimmers between and within races. Paralympic swimmers with visual impairment do not differ in this respect in freestyle races. The greater variation in stroking models is reduced when specific impairment groups are isolated. Experienced and trained swimmers with intellectual disability are, however, not able to maintain stable race speed and stroking models over several freestyle races. In breaststroke both visually impaired and intellectually disabled have much more trouble turning than in their freestyle races with relatively slow breaststroke turns and more than 8% losses in swimming speed in the subsequent race sections. The physical capacity of Paralympic swimmers has seldom been examined. As expected passive drag increases with decreased function at a fixed towing speed. World championship participants with intellectual disability are smaller (38th percentile) and show extremely poor hand grip strength when compared to European national level able- bodied swimmers (*M* percentile score = 1.1 $\pm$3.2).

Chapter 25 - The purpose of the present chapter is to present five main specific characteristics of the swimming part of a triathlon event; *i.e.* different technical skills (coordination, efficiency); wearing a wetsuit; drafting another triathlete; specific pacing and preparing the subsequent parts (swim-to-cycle transition). Triathletes are obviously of a lower performance level in swimming-only than elite swimmers but are also less technically skilled: their stroke length, propelling efficiency, inter-limb coordination and economy are lower. The metabolic responses in swimming are influenced by the thermoregulatory responses (*i.e.* water and air temperature, type of wetsuit). Wearing a neoprene wetsuit has been shown to improve buoyancy and consequently swimming performance but the extent to which improvement occurs is influenced by the anthropometrical and technical features of the subject. Similarly, drafting another swimmer is commonly reported as an efficient way of reducing drag, decreasing energy cost and therefore improving swimming performance. However, drafting induces some technical and pacing adaptations and its advantages are influenced by many factors (position of and distance to the draftee, body composition and performance level of the drafter…). Olympic-distance (OD) and Ironman (IR) triathlons require different pacing strategies during their swimming portions. A very fast start during the 1500 m of an OD triathlon has been reported to be paramount for the overall final performance whereas in IR competition, an even pace is recommended for energy sparing. Finally, the swim section strongly influences the subsequent cycling and running sections. Each of the factors mentioned above (technical skills, wetsuit use, drafting, pacing) leads to modification of the metabolic responses to swimming that then influences the physiological responses underlying efficiency/economy, and, consequently, performance (power output/ velocity) within the subsequent cycle and run.

Chapter 26 - Attention to the preservation and promotion of health in the aquatic athlete maximizes performance. Knowledge of the common injuries directs attention towards injury prevention and minimizes time lost from training. Early identification of and appropriate intervention for medical issues is essential for the well being of the swimmer. The promotion of healthy nutritional habits serves to maintain health and enhance performance. As with all sports, attention should be paid to the ethics of fair play; an understanding of the doping control requirements as they pertain to aquatic athletes is important for all members of the athletes' entourage. Each of the five aquatic disciplines has unique health concerns common to that particular aquatic sport. Understanding the unique demands of the aquatic discipline and the specific injuries and illnesses is important for the development of a training program. Maximizing performance through the application of sport science and attention to medical issues is essential in the development of the aquatic athlete.

Chapter 27 - The nutritional concerns of swimmers involve an amalgam of challenges. During the training phase, swimmers share the priorities of endurance athletes, whereas issues in the competition setting are more related to brief duration events. Swimmers often begin a competitive career at a young age, adding their sports nutrition needs to the dietary challenge of adolescence and early adulthood. Achieving the ideal physique is a key challenge for many swimmers. Issues include meeting the high energy needs for growth and training in young male swimmers, adapting energy intake to the reduced energy requirements of the taper or off-season, or dealing with the gain of body fat in female swimmers as they progress through puberty. Strategic eating around key workouts and races is important to enhance training outcomes and competition performance. Swimmers are fascinated by the array of sports foods and supplements that promise improved performances. Among the many products on the market, a few offer legitimate benefits – either helping the swimmer meet their daily nutritional goals (e.g. sports drinks, liquid meal supplements, and sports bars), or by directly enhancing performance and recovery (e.g. creatine, bicarbonate, caffeine). The decision to use such products needs to be balanced against the expense and the risk that they may cause an inadvertent doping outcome.

CONTENTS

SECTION I
BIOMECHANICS