PERSPECTIVES IN METHODOLOGY IN BIOMECHANICS OF SPORT

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INTRODUCTION

Biomechanics of human movements is mechanics applied to the human locomotor system. It deals with the forces acting on and within the human body and the produced effects, the mechanical behaviour and the biological response. In fundamental research the understanding of the laws and principles underlying the structure and the function of the movement apparatus are of basic interest. The application of biomechanics covers a rather broad field including biomedical engineering, ergonomics and the study of everyday and sports activities. The conceptual brace of these applications is the common task: to improve the motor performance of a system with limited capacity and to reduce the risk of excessive mechanical loading during this transfer process and when performing maximal.

Biomechanics of sports is predominantly directed towards practical applications. The main objectives are: 1. the identification of factors influencing performance and 2. the identification of factors influencing load on the movement apparatus. The complex categories related to these parameters are sports techniques, the physical properties of the body and the external conditions. This paper deals with the methodological problems and approaches of sports biomechanics.

METHODOLOGY IN BIOMECHANICS OF SPORT.

The methodology is of basic importance for a science. It can be classified into three parts: 1. the measuring methods (instruments), 2. the modelling theory and 3. the research strategy/design in practical applications. These aspects will be discussed in the following and with the aid of a few examples the actual state as well as some perspectives will be illustrated.

1. MEASURING METHODS.

According to the categories of the primary quantities to be measured the measuring methods can be subdivided into four different areas: kinemetry, dynamometry, biomechanical anthropometry and electromyography. In fig. 1 an overview on the measuring methods and on'the commonly measured or calculated mechanical parameters is given. The most interesting quantities are the net moments as representatives of the internal forces acting in muscles, ligaments and joints. The normal procedure called "inverse dynamics" is the following: displacement data related to the movement of body segments are measured and by applying two times numerical differentiation velocities and accelerations are calculated. Than the equations of motion can be solved.

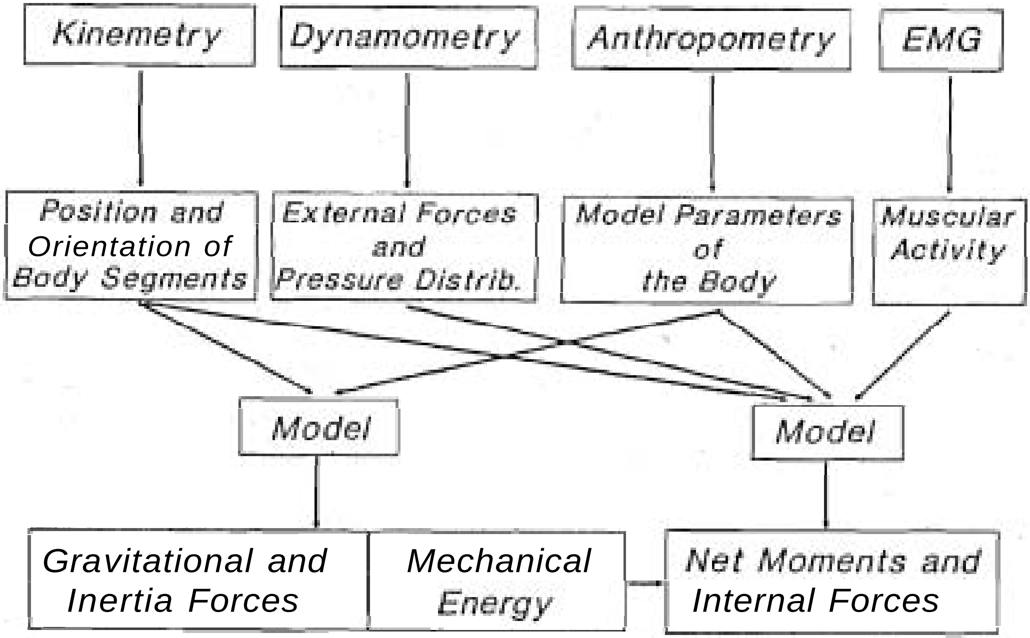

Figure 1: Measuring methods used in the process of determination of internal forces,

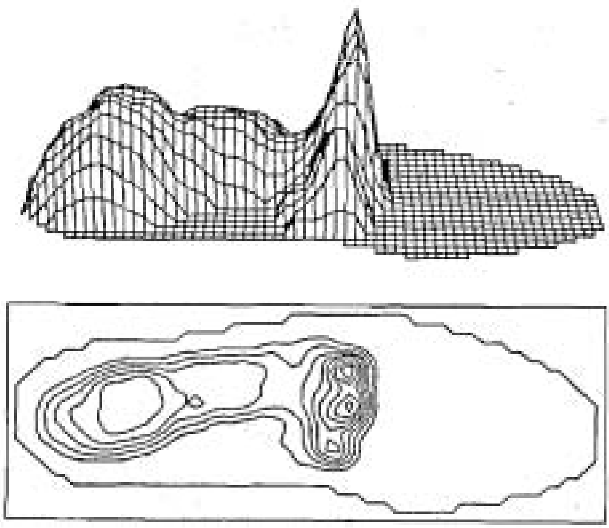

Figure 2: Summation of pressure under the foot during a stance phase in walking (Subject with toe amputation).

Besides the considerable development of low-cost computer power, the instruments for data acquisition and processing have been improved further in the last ten years.

In kinemetry the main progress was the nearly total replacement of conventional cine cameras by video recording. The advantages of the new technique are: fast available presentation, remote controlled camera positioning, setting and operation, noiseless operation, applicability in competition and readiness of the electronically stored images for automatic data evaluation. At the same time a number of different very sophisticated systems for semi or fully automatic data acquisition came onto the market, drastically reducing the expenditure of work for the numerical data evaluation. Some of them are using the video-technique, others are based on various opto-electronic techniques. Mathematical procedures are enabling easy and flexible camera setup and calibration, the use of non-metric cameras and a rather acccurate computation of 3-dimensional object coordinates. Three-dimensional studies thus could be standard now.

In dynamometry measuring systems for normal pressure distribution with high sensor density and time resolution even for in-shoe measurements have been developed. They are offering a new category of parameters (Fig.2). Like an X-ray under the foot sole the individual pressure pattern during real activities can be recorded or just monitored online. Frame rates of up to 100 fps with nearly 1000 single sensors are possible. These measurements will be of great importance in the design and evaluation of shoes, inlays and therapeutic treatments of foot problems. The bi-pedal recording of the path of pressure centres will provide extremely helpful informations in all questions related to equilibrium regulations, technique and symmetry of motor activities. These data will also stimulate a more differentiated modelling of the foot. It is very likely that transducer arrays sensitive for horizontal shear forces will be available in the near future.

The construction of the conventional force platforms has not been changed substantially. But the users are now more critical with respect to measuring accuracy particularly concerning the frequency response and the point of application of the force vector. Despite the fact that hardware and software improvements can be defined, it seems that corresponding measures as for example specific calibration procedures are not being used frequently.

Biomechanical anthropometry provides the input data for the models of the human body. Conventional tools of anthropometry are now being replaced by new techniques like computer tomography (CT) and magnetic resonance imaging (MRI). These methods allow a 3-dimensional reconstruction of hard and soft tissues of the complete body with an accuracy never thought of before. The most powerful systems are able to make 20 fps with exposure times less than 50 ms. They will revolutionize the modelling of the macroscopic structures of the individual body: the real joint geometry, shape and topography of muscles and ligaments will be inplemented in the models. The methods will also offer new possibilities for a better definition of the relations between external landmarks and the anatomical frame. The importance of this development can hardly be overestimated: besides the anatomical structures themselves also assessments of functional properties closely related to those structures will be possible.

As distinguished From the above mentioned methods, which deliver mechanical properties and the net outputs of the musculo-skeletal system, the electromyography provides information about the neural input to the muscle system. As a control parameter the EMG is of eminent importance for modelling of the dynamic neuro-musculo-skeletal system. However there is one important point to consider: the electrical signal connected with the muscles' activity is an indirect indicator of muscle tension or force. and the external torque or net moment is also an indirect measure of muscular force. So both cannot be used as mutual validation criteria. In order to enable comparisons of EMG signals, a further standardization of processing procedures is needed.

2. MODELLING.

Scientific methods are characterized by the use of models which represent the theoretical basis. Models are physical or mathematical systems, which reflect essential characteristics of the original object so that the study of the model provides new informations about the object. At the very beginning it has to be stated that in biomechanics no accepted theory is existing, which really explains in a scientific sense the phenomena under study. There are two reasons for that: 1. the biological system "human body" is too complex to be described correctly with the very limited approaches available up to now, and 2. the science "biomechanics" is too young to have been able to develop appropriate tools to study this system. Consequently the effectivity of models used in biomechanics cannot be compared with that of models used in physics, in chemistry or in engineering.

There are different types of models, the selection of which largely depends on the purpose of the model and the available information about the original. In a simplifying way two types of models be discussed here: 1. the empirical-statistical model and 2. the theoretical model.

EMPIRICAL-STATISTICAL MODEL.

This type of model of the human body and its movement is used in order to identify and to evaluate biomechanical parameters, that are factors influencing the performance. Based on empirical data (kinematic, kinetic, anthropometric measurements) and using different statistical procedures it can be tried to figure out the possible relations between the selected parameters and the performance. A typical feature of this approach is the supression of functional relationships between the variables for the benefit of single numerical values, extreme values of parameters, to a certain extent selected arbitrarily. Thus the dynamic nature of the movement gets lost. This loss of information can be tolerated in some cases, when additional a priori information, e.g. empirical knowledge about the problem is available. Further the model cannot assure that the entering variables are independent from each other. Nevertheless it can be applied as a pragmatic approach to filter out important factors by means of statistical relations and for many reasons this model is widely used.

THEORETICAL MODEL.

This type of model is based on the theoretical knowledge of the mechanical structure and function of the human body. A hierarchy of models of different levels of complexity can be established (1): mechanical model (single point or multi-link system), musculo-mechanical model, neuro-musculo-skeletal model. As originals for all these models may serve the whole body or any subsystem, including environmental conditions.

A key factor in biomechanical analyses of gross body motions is the determination of internal forces acting in muscles, tendons, ligaments and bones. These components of the biomechanical structure of the movement are of utmost importance in the application in training. A simple model is commonly used to determine net joint moments and global internal forces in the lower extremity. It is the first step reflecting the "bio" parameters: it takes into account the lever arms of the musculature, which are an important structural characteristic of the body.

There are many examples demonstrating the usefulnes of joint moments in the judgement of movement techniques, showing that neither the kinematics nor the force platform data alone give enough information about the structure of the movement.

In running the movement of the foot related to the shank during the contact phase serves as an indicator of somehow pathological loading of the achilles tendon and the medial/lateral ligaments of the ankle joint. Excessive pronation in the beginning of the stance phase is regarded to be responsible for several trouble. A simple consideration may be that pathological loads can only be present when the structures are under a certain tension. In this case predominantly tensions in the achilles tendon and the medial ligaments/muscle components come into question. Figs. 3a and 3b show the result of an analysis of runners for one single subject. From the net moment in the sagittal plane it becomes clear, that it concerns a rearfoot runner, since in the very beginning the foot flexor muscles are active, thus controlling the extension of the foot. What is is more important: In the phase of maximum pronation (30 - 40 ms after heel strike) neither the moments in the sagittal plane nor in the frontal plane are indicating evident loading of the corresponding structures. This is not a general pattern, it is individually different and most probably depends on the flexibility of the foot joints. However, the result underlines that it is not advisible to judge a movement alone on the basis of kinematic informations.

Despite the usefulnes of this "net moment model", due to a number of reasons it can yield more or less erroneous results: uncontrolled antagonistic muscular activity, unknown force distribution between two-joint muscles or muscles acting in the same function, loading of ligaments and - very important - a rather rough estimation of the macroscopic anatomical structures of the body. Appropriate parameter variations using the same model tell us something about the wide range of numerical results. In order to overcome the indeterminacy of the biomechanical system, mathematical optimization procedures have been used. These methods are useful tools for the analysis of complex systems, which are functioning according to certain principles. The crucial question hereby is which criteria should be selected as objective functions. A literature review shows that predominantly the following criteria have been used: minimization of energy expenditure, net muscular power output, net muscular and joint forces and muscular tensions. These criteria are not neccessarily of biological relevance. They rather meet the

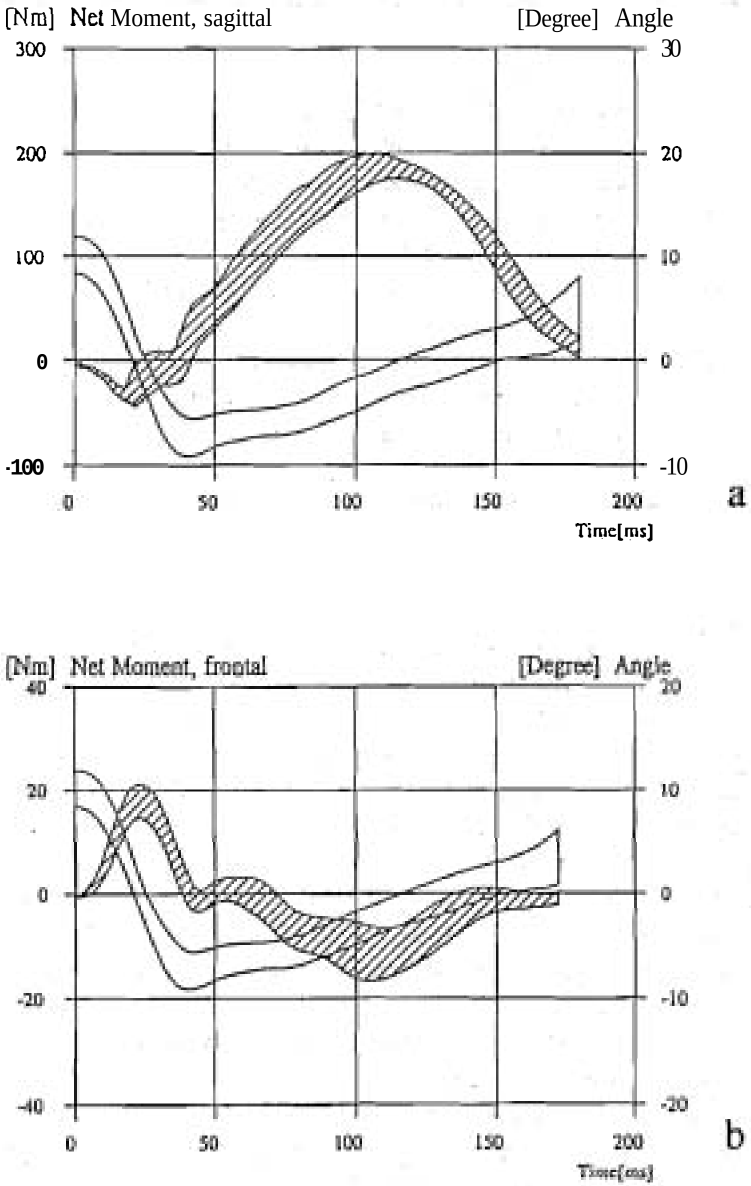

Figure 3a/3b: Net moments and pronation/supination angle of the foot during the stance phase of running (Average from 7 trials of the same subject, 3-dim. analysis). Running velocity approx. 5 m/s. Shaded areas: Moments with respect to the ankle joint, empty areas: angles. Positive angles indicate supination, negative angles pronation. 3a: sagittal plane, moments positive when loading the foot extensors, negative when loading the flexors. 3b: frontal plane, moments positive when loading the medial, negative when loading the lateral structures (muscles and ligaments).

requirements of the optimization calculus. Although one might find supporting arguments these functions can be regarded as to some extent arbitrarily chosen abstract mathematical functions.

Objective functions of biological relevance can be derived from the work of Pauwels (2), who studied the construction principles of the human body from an engineering standpoint. His work represents a major contribution to biomechanics and would deserve much more attention than it received up to now. The main results of his theoretical and experimental studies concerning the mechanical properties of bones and the effects of muscular forces can be summarized as follows: The human skeleton is an ideal light construction. Shape, density and structure of the bones are reducing the bending stresses. The geometrical configuration of muscles and their coordination are reducing bending stresses of the bones and reducing peak stresses in the joints.

It seems obvious that these constructional principles yield a sound basis to deduce biologically meaningful optimization criteria: the minimization of total stresses in active and passive structures of the locomotor system in a time average. he relation between structure and function is so close that just from the structure the functional requirements can be deduced. This approach offers a new conception: it is no more the force playing the decisive role but the stresses and their equal distribution on surfaces and cross sections resp. All proprioceptive sensors are sensitive against stress and strain, not against force. The realization of this approach of course requires more precise informations about the external kinematics and kinetics of the movement and in particular about the 3-dimensional form and topology of the individual body segments. The new methods for body structure measurements mentioned in the previous paragraph will give wnsiderable support to this approach.

In wnclusion it must be stated, however, that there is no generally accepted procedure to build up a model, neither for the empirical-statistical type nor for the theoretical models.

3. PRACTICAL APPLICATIONS AND RESEARCH STRATEGY.

The effective application of the results in the practical field is an important objective. As stated before there are some serious difficulties to apply a strictly scientific approach. Models partly reflecting the complexity of the human body are very complicated, hardly to control and to verify. Moreover they are not very well suited for communication purposes outside the special scientific area.

If effective application is of primary importance, a more pragmatic approach has to be considered. This means that not only scientific methods and results and technical instruments can be used (of course in a much more professional manner than today) but also the empirical knowledge from practical coaching and training, from physiology and psychology, from other fields of biomechanics have to be exploited. In this way the empirical knowledge is guiding the research methodology and setup, on the other hand scientific theories and experimental findings influence the strategy and observation priorities in practise.

The analysis of a movement technique and its physical conditions may give a clear description of the relations within a set of variables. This may be available for different levels of performance. However, this is not sufficient, when an athlete has to be "transformed" from a given state into another one. If the adaptation processes, the biological reactions of the locomotor system to certain training measures are not known, it is not possible to perform what is called "controle of the training process". The study of these adaptive processes (quantification of the input-output relations) and again the use of empirical knowledge is inavoidable. **A** useful tool to merge all these informations from various sources and of different levels of quantification could certainly be the expert system.

In biomechanics of sport the measuring methods and the modelling approaches are not the most critical aspects. This is true under the assumption that these tools are correctly used and their capacity being fully exploited. Then it seems that the strategies have to be reconsidered, even when some parts of the work is rather a technical service than sophisticated science.

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