FORWARD DYNAMICS FOR THE EVALUATION OF PRACTICAL PROBLEMS IN SPORTS

Ulrich Göhner, Frank Schiebl, Joachim Dengler, Jörg Subke,
Eberhard-Karls-Universität, Tübingen, Germany

INTRODUCTION: In athletic movements there are often situations where one cannot rate varying executions, because the effects of single actions are unknown. At a tennis stroke for example, the movement of the ball after hitting is well visible as an effect of the action. However, the conditions at hitting the ball and the actions that lead to the torque of hitting are not reliably visible. Their interpretation is only subjective. Nevertheless, the trainer and the player have to give statements of the muscular activity like "hold the racket loosely or firmly "or"relax or stiffen your wrist." This paper focuses on a controversial problem: the use of the wrist in tennis. Some favor a firm wrist, others an actively moving wrist. The group which favors the active wrist based their idea on the higher velocities of the racket head. For this idea biomechanical considerations are only based on kinematic data and on analysis in muscular physiology (see KLEINÖDER 1997, ELLIOT 1991, HUIJING 1994, KOMI 1994) and not on kinetic analysis. With this work we try to fill these gaps with computer simulation.
In a similar way we worked on a problem in gymnastics: the increase of swings on the horizontal bar, which is necessary for all swing elements. Little work has been done in this area (see BAUER 1976, BÖHM1997 and WIEMANN 1993). Nevertheless, the research that allows a development of a general theory of the swing increase is lacking (except for the efforts of WIEMANN). The goal of this paper is to show that computer simulation can be a first step towards the development of such a theory.

METHODS: The tool used for computer simulation is the object-oriented model language Dymola (see OTTER 1995). Dymola is a multi-body modeling software system which is suitable for the calculation of inverse dynamics, as well as forward dynamics. In this case Dymola is used to calculate forward dynamics, which is the calculation of the trajectories of the body segments from a defined starting position and the calculation of the acting forces and torques over time.
For the modulation of the biomechanical structures, Dymola offers different tools. In accordance with the principle of Dymola to represent physical objects directly as model objects, there has been a coupling of 60 submodels for the model "tennis-stroke." Submodels combine the structural elements joints, masses and torques. The basis for the submodels are provided by an own model group in each case. Model classes, which have to be understood as patterns, cover different physical properties. The simulation of the forehand drive in tennis was realized on the basis of a multi-segment model. The body segments trunk, upper arm, forearm, hand and wrist as well as the racket were modeled. The joints consisted of a combination of several hinge joints. Thus the following movements are possible: upper arm horizontal flexion/extension, upper arm vertical flexion/extension, upper arm internal/external rotation, forearm flexion/extension, forearm pronation/supination, hand radial/ulnar flexion and hand flexion/extension. The submodels, which represent the joints, are coupled with a torque producing

submodel and thus have to be seen as non-mass motors. The maximal possible range of motion of the joints was taken from the literature. For the submodels, which were used for the modulation of the masses and their spatial expansion, the model class *BoxBody* was taken. NASA data were used as references for realistic masses and proportions of the segments. Different stroke principles were tried by systematic variation of the torque course.
For the modulation of the forward grand circle a three segment model was built. The model is based upon 18 coupled submodels. With the help of an inertial system, three body segments (upper extremities, trunk, lower extremities) are combined via hinge joints (connection hand -horizontal bar, shoulder joint, hip joint). Those segments were built with the submodels *Segment* and *Bar*. The submodel *Segment* allows the definition of the inertial properties of a rigid body. The midpoint of the mass of the rigid body can thus be modeled realistically. The submodel *Bar* is used for the determination of the distance of the joints to each other. Thereby the modulation of segment length becomes possible. NASA data were used as references for realistic masses and proportions of the segments. The maximal possible ranges of motion of the joints were taken from the literature. The systematic variations of the torque course is oriented to movement instructions from the literature.

RESULTS: The modeled stroke shows a movement pattern from proximal to distal. Typical for the forehand drive in tennis is that the action starts in the legs and is continued by the trunk. Subsequently, there is always a horizontal flexion in the shoulder joint. The action immediately before hitting the ball is a palmar and ulnar flexion through the wrist. After hitting the ball a flexion in the elbow joint follows simultanously with an internal rotation in the shoulder joint. Two different simulations on the basis of the above-described models were carried out. The first simulation is based upon the idea of blocking the shoulder out of a counter rotation at the beginning of the stroke right at the time after breaking up the counter rotation. This blocking of the shoulder should lead to an increase in the angular velocity of the distal segments. During the movement, torques for the maximum range of motion of the joints are modeled for the shoulder joint, the elbow joint and the wrist. The movement possibilities ulnar/radial flexion, shoulder rotation, vertical flexion/extension in the shoulder joint and the flexion/extension in the elbow were blocked for these simulations. The parameter ω(inertial system – upper arm) was systematically varied, which led to the following results:

ω(Inertialsystem–upperarm) (rad/ sec)	ω(trunk-upperarm) (rad/ sec)	ω(forearm-hand) (rad/ sec) - time (sec)
3.5	8	17 - 0.3
6.5	12	28 - 0.25
7	15	37 - 0.2

The upper arm stays back in all the trials and in the wrist there is a palmar flexion in the beginning of the movement. This palmer flexion can be avoided by a torque of about 10 Nm. A faster rotation of the shoulder causes higher angular velocities in the wrist. Those angular velocities are achieved without active generation of torques in the shoulder joint and the wrist.

The second simulation tests those situations where the shoulder was not blocked. The torque acting on the trunk was produced longer than the position of the dissolution of the counter rotation. The parameters ω(inertial system – upper arm) and M (shoulder horizontal flexion) were systematically varied, which led to the following results:

ω(Inertialsystem-upperarm) (rad/ sec)	M(Schulter horiz.flex) (Nm)	ω(trunk-upperarm) (rad/ sec)	ω(forearm-hand) (rad/ sec) - time(sec)
4	0	9	23/ 0.2
6	0	12	27/ 0.25
7	0	15	33/ 0.2
6	20	12	26/ 0.25
7	50	2.5	14/ 0.14

The longer acceleration of the shoulder joint over the position of the dissolution of the counter rotation does not lead to a further increase in the angular velocities in the wrist. The angular velocity even decreases when a flexion-causing torque in the shoulder joint is produced from the beginning of the movement.
This approach of systematic modulation of basic movement patterns for the forehand drive in tennis shows, that the preservation of rotatory impulses in multi-body systems can be used as a basic principle for the acceleration of distal segments. The active blocking of proximal segments leads to an angular acceleration in distal joints. Hereby it is possible to get higher velocities of the head of the racket.
Swings from hang like the giant circle are mainly controlled through actions in the hip and shoulder joint. In the simulation two alternatives to control the movement are tested: control of the movement through actions in the hip joint, control of the movement through actions in the shoulder joint. The following results can be shown: the model with a hip action of a flexion torque of 300 Nm swings into a vertical position in relation to the horizontal bar in 2.28 seconds. The generating torque works at the moment where the flexing joint is underneath the suspension. The model with the action in the shoulder takes 2.5 seconds to reach the vertical position in relation to the horizontal bar. If one compares the angles of the joints in this position, one can see that the model with action in the shoulder joint has an angle of about 90°. This final position is rather positive for further situations in gymnastics like elements which need an approximation of the hip towards the horizontal bar. The flexion torque could therefore be decreased, if only an elongated position in relation to the horizontal bar were necessary. In comparison with it, the model with the hip action shows a position in relation to the horizontal bar, which is characterized by an over-elongation in the hip. A gymnast would have to produce additional torque, which would prevent him from having an over-elongated position in the hip joint.

The results show, that it is possible to create giant circles with both actions. The action which should be preferred by the gymnast will depend on the connecting elements that will follow. Nevertheless, before the decision it should be clarified whether the gymnast is able to produce the corresponding torques in the shoulder joint. The "rotatory moment reaction" described by KASSAT (1993, 119ff) can be easily studied with the help of our three segment model. If the giant circle is practiced with action in the hip joint, one can see the "rotatory moment reaction" in the passive over-elongation in the shoulder joint. This means that the gymnast has to build up a lexion torque in the shoulder joint in this situation to reach the optimal position for a following swing movement.
The first steps of a systematic modulation of principal executions of the giant circle that are shown in this paper can lead to a general theory of swing increase with further work. Such a theory could be a very helpful instrument for the methodology of gymnastics.

REFERENCES:

Bauer, W. L. (1976). Mathematische Modellierung und Optimierung als Hilfsmittel zur Aufklärung des Lernvorgangs bei der Turnübung "Riesenfelge am Reck". Mehrkörpersystemen. Unveröffentlichte Diplomarbeit. Tübingen: Eberhard-Karls-Universität.

Elliot, B. (1991). The Role of Biomechanics in Power Strokes. *Tennis - The Australian Way Manual* **1**, 1-8.

Huijing, P. (1994). Das elastische Potential des Muskels. In P. V. Komi (Ed.), *Schnellkraft im Sport* (pp. 155-172). Köln: Deutscher Ärzte-Verlag.

Kleinöder, H. (1997). Quantitative Analysen von Schlagtechniken im Tennis. Unveröffentlichte Dissertationsschrift. Köln: Deutsche *Regelungstechnik* **10**, 334-341.

Böhm, H. (1997). Dynamik der Riesenfelge am Reck im Rahmen von Sporthochschule.

Komi, P. V. (1994). Der Dehnungs-Verkürzungszyklus. In P. V. Komi (Ed.), *Schnellkraft im Sport* (pp. 173-182). Köln: Deutscher Ärzte-Verlag.

Otter, M. (1995). Objektorientierte Modellierung mechatronischer Systeme am Beispiel geregelter Roboter. **VDI**, 20.

Wiemann, K. (1993). Biomechanik des Schwingens. Erfahren und Interpretieren. *Sportunterricht* **4**, 161-170.