

BIOMECHANICAL MODELING APPLIED TO HUMAN MOVEMENT ANALYSIS

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Biomechanical modelling can be a helpful instrument in human movement analysis. Here, the focus will be set on analyzing human movement using inverse dynamics. Dealing with inverse problems, one important issue is the transfer of a real motion to the model and how to find an optimal description of the movement. Furthermore, joint models, the description of joint kinematics, as well as the individual adaptability of those models will influence the results of human movement analysis.

KEYWORDS: inverse dynamics, biomechanical modelling, motion analysis

INTRODUCTION: One aim of sport biomechanics is to analyze movement techniques during competition or training exercises. This results in knowledge about efficiency of certain techniques and provides a basis for future recommendations for training exercises. This paper presents applications of biomechanical modelling for human movement analysis.

ANALYSIS OF VOLLEYBALL SPIKES: In order to understand how specific movements are performed, it is important to describe the specific movement under consideration with high accuracy. Assets and drawbacks of these movements can only be understood, if it is possible to describe movements with close-to-reality and artefact-poor time histories for the inner co-ordinates.

Roemer et al. 2007 used a 3D man model to reconstruct volleyball spikes performed during European League Games in 2006. Boundary conditions for the analysis were: diagonal performed spikes from position four, flight angle of the ball after impact from 110° to 145° to the net, and the step close technique (Coutts, 1982). Four digital cameras (3x Basler, 1x Vosskühler) with a frame rate of 100 Hz were used. This setup was calibrated by 16 landmarks with known coordinates. Seventeen body points were digitized per frame and the multi body system (MBS) man model DYNAMICUS was used to quantify the time histories of these joint angles. Thirteen joints were considered and the total degrees of freedom for this model was 22. Using the Dynamic Tracking method (Roemer et al., 2001), model-fixed points were defined corresponding to the digitized body points of the subject. In these points the man model was connected viscoelastically to the reference points. This leads to dynamic adjustments of the man model with the moving reference point cloud. Due to the linear elasticity used to connect the markers, this approach is equivalent to linear filtering. Thus, the movement of the real volleyball spiker was transferred to the man model and the time histories of all major joints were quantified.



Figure 1: Man model in marker cloud

The investigated movements occurred in different game situations and different sets, but individual coordination techniques within the shoulder joint could be identified for this movement (Roemer et al. 2007).

Roemer et al (2008) analyzed more players and the shoulder kinematics were described in greater detail; therefore the kinematic description of the shoulder movement applied quaternions and the axis-angle approach to avoid the gimbal lock. The orientation of the resulting axis of rotation in the shoulder joint and the rotational angle were calculated. Additionally the 3D coordinates of the elbow movement around the shoulder and the internal and external rotation were investigated. The results show that specific movement strategies for the humerus could be detected using these methods.

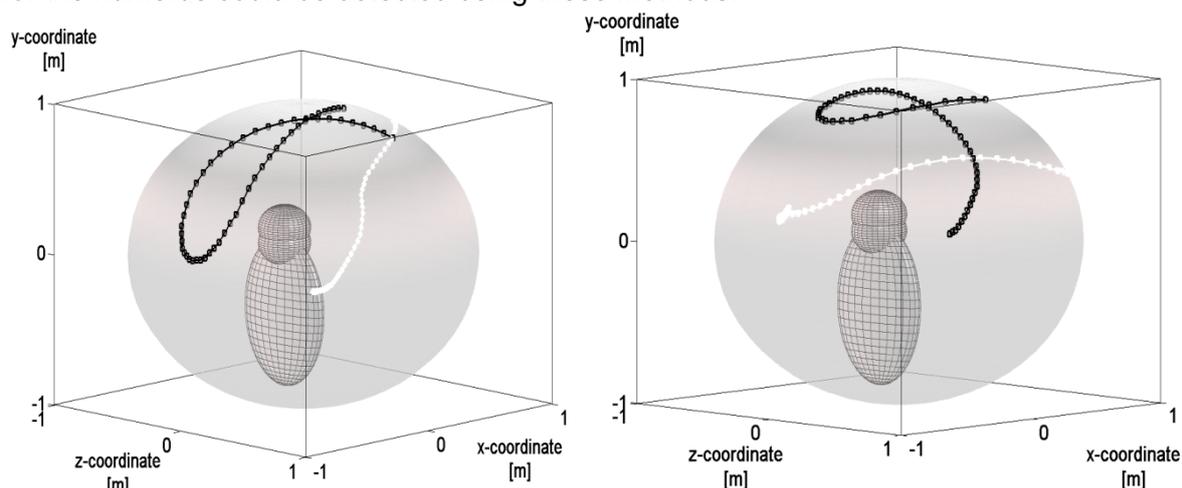


Figure 2: Trajectories of hand (black) and elbow (white) with respect to the shoulder joint, normalized and projected to a sphere

In conclusion: The advantage of applying the modelling method is to avoid the problem of gimbal lock while describing complex shoulder kinematics. This allowed for a detailed analysis of shoulder kinematics which revealed interdependencies of internal and external rotation with abduction and adduction movements during volleyball spikes

ANALYSIS OF LEG EXTENSION MOVEMENTS: The quantification of not directly-measurable attributes for muscle contractions in sport movements may lead to further information for strength training (Hatze 1998, Wank 2000). One area of interest is the comparability of internal versus external loads. Thus a neuromuscular multi body system model was developed for analyzing movements within the lower extremities (Roemer 2004).

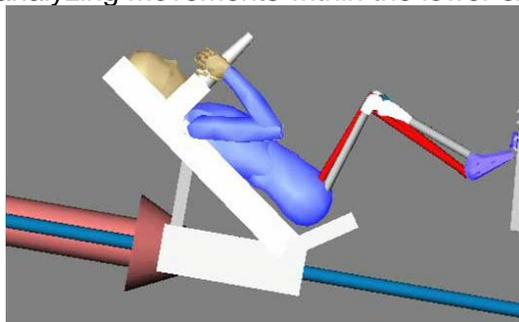


Figure 3: Simulation of leg extension movements in a leg press machine

While using inverse kinematics and inverse dynamics with a focus on the lower extremities, the knee model type is of major interest. To determine the accuracy of different knee joint model types and their influence on calculated muscle forces the model was evaluated as follows:

- accuracy of an magnetic resonance imaging (MRI) based knee joint model with respect to the coordinates of the moving joint axis.

- influence of individualized versus simplified model types on calculated muscle forces of a specific movement with respect to the patellofemoral joint.
- influence of individualized versus simplified model types on calculated muscle forces with respect to the knee joint.

The results indicated that it is necessary to use an individualized model that takes the moving joint axes of the knee joint and the patellofemoral joint respectively into account for the calculation of muscle forces for the Quadriceps. The consideration of the changing leverages within these joints during knee motion leads to more realistic results for calculated muscle forces. Otherwise it was not possible to calculate muscle stimulation functions that were comparable with measured EMG data (Roemer et al. 2010).

In order to simplify the process of gaining input data for the above described knee joint models, a new approach to estimate the moving joint axis within the knee joint using motion analysis data was evaluated. Therefore, a single case study was performed and data for the knee model were collected via MRI scans and motion analysis using a 12 camera VICON system (240Hz). MRI scans in 13 different knee positions were used to collect data representing the relative movement between tibia and femur for knee flexion movements.

Furthermore, the coordinates of 40 markers placed around the thigh and 40 markers placed on the shank were used to reconstruct the relative motion of these two segments. An optimization method described by Andriacchi et al. (1998) was used to minimize the influence of the skin movement on the marker coordinates. However, the results of this case study revealed that the approach to calculate the moving joint axis out of motion analysis data was insufficient. A combination of inaccuracies of the motion analysis data due to skin movements and numerical problems related to the kinematic theory approach caused this result. In conclusion: It is essential to use individually parameterized models for the knee joint as well as for the patellofemoral joint while analyzing the correlations between external and internal loads and the efficiency of specific training exercises for the lower extremities.

ANALYSIS OF ROWING MOVEMENTS (PILOT STUDY): Movement biomechanics of overweight and obese individuals are not well understood. One factor that has been linked to obesity and the disability to perform activities of daily living is osteoarthritis as well as other musculoskeletal diseases. It is well known, that a reduction in body weight will decrease the risk and/or severity of such diseases (Messier, Gutekunst, Davis, & DeVita, 2005). Caloric control and moderate exercise are crucial for reducing body weight in obese individuals. In general, non weight bearing exercises are recommended because it is assumed that they are more beneficial than weight bearing exercises. However, so far the literature reveals no clear evidence with respect to this assumption and there is little research available investigating the influence of obesity on joint mechanics. For this study the non weight bearing exercise of rowing on a Concept 2 (Model E) rowing ergometer was chosen. Ten normal weight and ten overweight volunteers with no or minor previous rowing experience took part in this study. The subjects were asked to row at three different resistance levels for two minutes each with two minutes of rest in between. Anthropometric measurements were taken, such as body weight, body height, and body composition. Three dimensional coordinates of the whole body movement were measured using a Vicon Motion Analysis System with 6 cameras. It was hypothesized, that obese subjects will show different results in leg joint angles than normal weight subjects. This two tailed hypothesis was chosen, because no previous data existed indicating a relationship with obesity and joint kinematics.

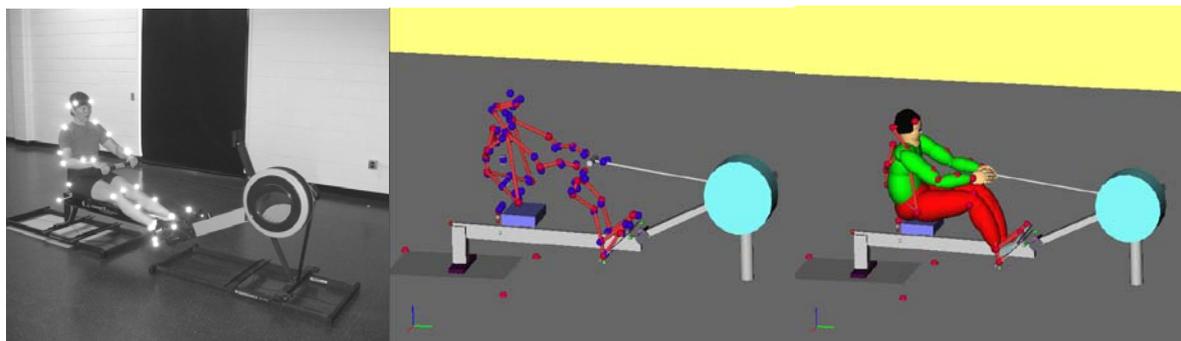


Figure 4: Process of data acquisition, transferring the movement data to the multi body system model, and reconstruction of the movement performing inverse kinematics.

The results of the flexion angles in hip and knee joints indicate that there is a relationship of body weight and movement kinematics. Both, the hip and the knee joints show differences with respect to maximum flexion angle. Obese subjects tend to have less hip and knee flexion in the catch phase. A follow-up study with 40 subjects was performed and first results will be presented by Richter et al. 2010.

CONCLUSION: The presented studies demonstrated how modelling methods can be applied to human movement analysis. It was shown how different joint models may influence results of calculated muscle forces and how different modelling methods can help describing complex shoulder movements.

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