AN ESTIMATE OF FORCES AND TORQUES AT THE JOINTS DURING TRAMPOLINE PERFORMANCES

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INTRODUCTION

The analysis and simulation of aerial movements of the human body by using mathematical body models and computer software has achieved significant progress in the last 10 years. This is evident from the series of articles published by Yeadon (1990) which gives the determination of the orientation angles, an inertia model of the human body, the determination of the angular momentum, and the simulation of aerial movement. However, to date, no method exists that helps to indicate the active muscle groups, nor estimate the strength essential for movement. This is vital in the case of trampolining, whereby aerial movement is largely controlled by the use of the appropriate muscles. In the training of trampolinists, most coaches are guided by their own experience. As each individual athlete has his unique set of anthropometric qualities, it is not clear if this method of training helps to strengthen the right muscle groups to the right degree, and if the capability of the trampolinist is utilized to the utmost. In view of this, we developed a method which uses inverse dynamics to calculate the forces and torques at the joints. From the anatomists' point of view, these forces and torques are connected to specific muscle activity. Consequently an expert can tell from the results, the muscle activity, which muscle groups have to be strengthen and to what extend.

METHODOLOGY

The basic tool required to calculate the forces and torques of the joints is the SDS software - an analyzing and simulation program produced by the french company SOLID DYNAMICS. This software uses algorithms, based on Newtonian mechanics, as described in Walker and Orin (1982). Originally invented for the simulation of dynamical behavior of industrial products, SDS is now used for the first time in the field of biomechanics. Due to its open programming structure, a broad spectrum of mathematical body model can be applied. As model, we selected the 15-segment Hanavan model (Hanavan, 1964).

The first step to provide SDS with the right set of anthropometric data of each individual. This is done by taking 39 anthropometric measurements of each athlete and processing it using the program ANT, which we invented for general use. ANT calculates the 15 segments of the Hanavan model by using the mass density given by Dempster et. al. (1967). The outcome of this program provides all the necessary parameters to project the athletes segmental data namely, segment length, radii, mass, center of gravity, inertia tensor, and the location of the joints with respect to the other segments.

The next step is to obtain coordinates of 18 landmarks of the human body as functions of time: the ears, the shoulders, the elbows, the wrists, the hands, the hip joints, the knees, the ankles, and the feet. In order to do this we film the trampoline performance using three video cameras (PAL, 50 Hz), and thereafter digitized it manually using the 3D Peak Performance system. However, the product of Peak in the form of coordinates of landmarks cannot be read by SDS which requires the data input in another form, namely the body's center of gravity coordinate, the orientation of the basis-segment (we selected the lower trunk), and the body posture via Euler angles for each segment relative to the connected one. In order to make the output of Peak

Performance applicable for SDS, we created a program which converts the Peak output to readable files for SDS.

With the SDS internal programming, language routines are established which calculate the necessary data as input for inverse dynamics. This produces coordinate, linear velocity, linear acceleration of the basis segment, and angular coordinates, angular velocity, angular acceleration for all 15 segments. As the calculation of the linear and angular coordinates as functions of time produces smooth curves, so linear and angular velocity can be calculated with an acceptable noise to signal relation (< 3%). However, angular accelerations exhibit huge artifacts caused by digitizing errors. The linear acceleration of the basis-segment as approximated by the equation:

$$\vec{a} = - w^2 * \vec{r}$$

give results with a noise to signal relation < 2%. A further analysis (least square method) of the angular acceleration terms suggests that the contribution to the forces at the joints is insignificant and can be neglected. We thus set the angular accelerations of all segments to zero.

RESULTS AND DISCUSSION

The coordinate system is orientated according to figure 1: the x-axis is defined by the intersection of the sagittal plane and the transverse plane; the y-axis (the twist axis) is taken at the intersection of the frontal and the sagittal plane; and the z-axis (the somersault axis) is defined by the intersection of the frontal and the transverse plane. Figure 2 shows the angular velocity of the basis-segment during "a triple somersault and half twist". Shortly after the take-off, the angular velocity increases to 15 1/s for the z component, while the others remain close to zero. The angular velocity is relatively constant for the first two somersaults. After 1.1 sec the twist is initiated; the z component drops to 4 1/s and the y component increases to 7 1/s. After the twist the z component increases to 9 1/s while the y component decreases to zero. The forces and torques at the joints depend on this angular velocity as well as on the anthropometry and posture of the athlete. For this purpose we use the anthropometric data of a well-trained trampolinist with a body mass of 75 kg and a'height of 1.78m. The forces and torques of his right hip, right knee, and neck are given in figure 3. The maximum force is up to 700 N for the right hip, 550 N for the right knee, and 600 N for the neck. The resulting maximum torque is 200 Nm for the right hip - which is four times as much as the resulting torque during a lever on the parallel bars; 40 Nm for the right knee, and 80 Nm for the neck. The torque at the neck is equivalent to a force of 270 N pushing on to the forehead (of an adult).

CONCLUSION

From the results it is clear that forces and torques indicates the active muscle groups. Our method enables the analysis and comparison of trampoline performances of the same routine. Possible differences can be defined in terms of inertia and angular momentum, where inertia is dependent on anthropometry, and posture (inertia tensor) is controlled by muscle activity. This concept of calculation and simulation is a highly desirable tool to construct and realize techniques for each trampolinist based on strength and coordination. It thus provides coaches a means to create strength-building programs. Future projects call for a more detailed study of anthropometric qualities, and the possibility to distinguish different body types relative to abilities. Ultimately, the capability of trampolinists can be realized to the utmost.

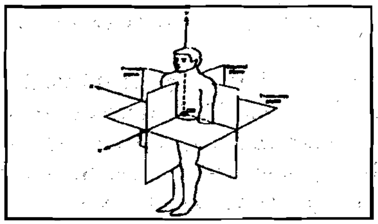

Figure 1: Coordinate system

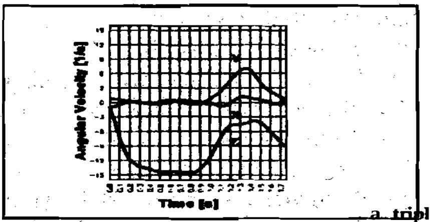

Figure 2: Angular velocity during a triple **somersault** with **1/2 twist**

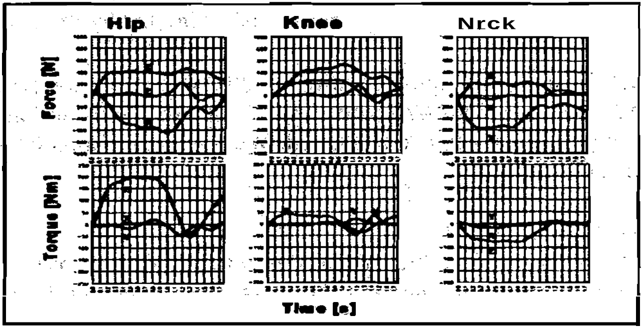

Figure 3: Force and torque at hip. knee, **and neck**

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