THE ROTATIONAL ABILITY OF THE HUMAN BODY

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INTRODUCTION

In sports like gymnastics, trampolining and diving, rotation is the most fundamental part of the performance.

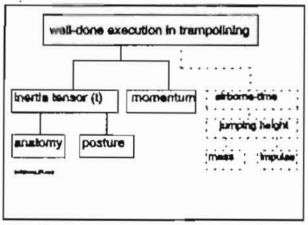

Figure 1: Determining factors for performance in trampolining

The proficiency of athletes in these sports is, therefore, highly dependant on their ability to rotate. To show this we examine the factors that determine the rotational ability of athletes in trampolining. We asked a vital question: "What is meant by good rotational ability, and thus an excellent performance in trampolining?" A brief overview of the important terms that determine high performance is given in Figure 1.

On the right-hand side (in doted lines) are the jumping height, the mass, and the impulse, all of which determine the airborne-time. On the left (in solid lines) are the significant parameters that contribute to the rotational ability of the athletes. The rotational ability is defined as the capability to rotate around the various axes of the body's center of gravity. In a performance we describe rotation by the rotational velocity $\vec{\Omega}(t)$ of the hip segment. This rotational velocity is determined by the inertia tensor $\Theta(t)$ together with the external momentum $\vec{L}$, and the internal momentum $\vec{H}(t)$ which is produced by the relative movements of the segments [see (1)].

$$(1) \qquad \vec{L} = \Theta(t) \cdot \vec{\Omega}(t) + \vec{H}(t) \quad \Rightarrow \quad \vec{\Omega}(t) = \Theta^{-1}(t) \cdot [\vec{L} - \vec{H}(t)]$$

The essential question for an athlete is therefore: "How can he/she generate the right external momentum, and how to control the posture and thereby the inertia tensor and the internal momentum?"

The inertia tensor, as a function of time, depends on anatomy and posture. In the case of a rigid body, the inertia tensor (written in terms of the coordinate system fixed within the body) is a simple constant. However, the inertia tensor of a human body depends on the mass distribution, and it can change drastically during the movement of the segments relative to each other. Since it is not possible to measure the mass distribution of a human body in all postures, we use one of the mathematical models to obtain the approximate density. Such models include those of SIMONS et. al. (1960), KULWICKI et. al. (1962), WHITSETT (1964), HANAVAN (1964), HATZE (1980), YEADON (1990). The purpose of this paper is to demonstrate, by using the mathematical model, how strongly body structure, dynamics, timing and coordination contribute to the ability of the human body to rotate.

METHODOLOGY

We have selected the best known model - the HANAVAN model (HANAVAN, 1964). Accordingly, we take 37 measurements (length and circumference) of segments, and the mass of the whole body for each person. Using the measurements, we calculate the sizes of the 15 segments as required by the model. By using the segment density data published by DEMPSTER and GAUGHRAN (1967), and with the aid of a computer program, we calculate the segment masses. By adding up these masses, we derive the mass of the whole body, and found a relative deviation,

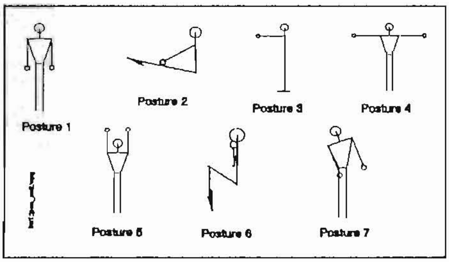

Figure 2: Seven postures

$$(2) \quad rel.\ deviation = \frac{(m_{mes} - m_{calc})}{m_{mes}}$$

when compared with the actual mass. The average deviation is 0.09 with a standard error of 0.011. A minor disadvantage of the HANAVAN model is its tendency to underestimate the mass of muscular people. However, to approximate the inertia tensor more accurately, we adjusted the segment density linearly to determine the actual mass of the body.

How then, does the normalized inertia tensor differ, when all bodies are in identical postures? With the aid of the computer software CONSIL (CONstance SImuLation Software for Human Body Movement) we calculated 7 postures (see Figure 2) for 6 top trampolinists, and for a group of 18 semi-trained adults.

To find the **momentum** and **timing**, we took videos of top trampolinists during the international DTB-Cup in Dillenburg (Germany). We used two HI 8 cameras at different fixed standpoints (see Figure 3) for the whole filming. Thereafter, we filmed a gauge cube in order to calculate the coordinates of the camera positions.

With the aid of the computer we measured the coordinates of 18 points of the human body as filmed. Our system has a monitor of 1100 mm x 880 mm , and a principle scanning resolution of 0.1 mm. However, we are restricted by the resolution of the video, which is 625 by 400 lines. The 18 points are shown in Figure 4; for the right and left side of the body together, there are two points each at the head (ears), the shoulders (acromion), the elbows, the wrists, the hands, the hip-joints, the knees, the ankle-joints, and the feet. The calculation of the 3-dimensional coordinates, based on the doctoral dissertation of Walton (1981), is done by a PDP 11/23 computer, using the program written in FORTRAN.

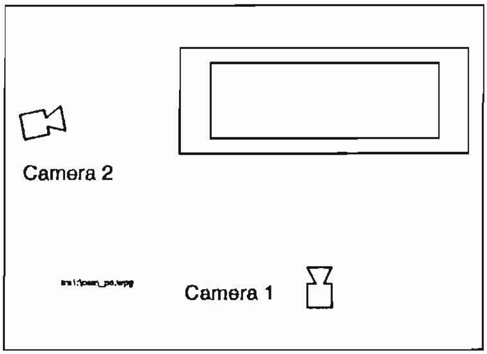

Figure 3: Position of video cameras

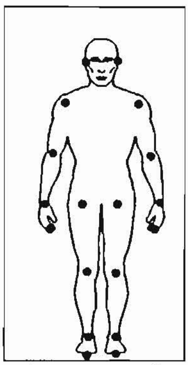

Figure 4: Scanned points on the human body

The result of this calculation is fed into an IBM compatible PC, which uses the CONSIL software system to analyze the required parameters.

The whole Measure-Analysis System, from filming, scanning, to analyzing, including the approximation by the Hanavan model, offers an important test parameter - the **center of gravity**. During the airborne-time of the performance, the center of gravity has to follow the path of a parabola. We found a difference for the z component [see (3)] between the actual and the theoretical data of σ = 0.057m for a single data point (derived from a data set of 6 trampoline jumps with a total of 244 frames).

$$(3) \quad \begin{aligned} \delta_z &= z_{CoG} - z_{theory} \\ \overline{\delta_z} &= (0 \pm 0.057)m \end{aligned}$$

We used one method to prove the accuracy of the scanning itself. Two people scanned independently one jump. We compared the normalized inertia tensor $(\Theta_{11})_N$ of scan a and b (the subtraction of which, showing the maximum deviation) as a function of time and found

$$\text{(4)} \qquad \overline{(\Theta^{a}_{11})_N - (\Theta^{b}_{11})_N} = 0.027 \pm 0.086$$

for single data points.

RESULTS

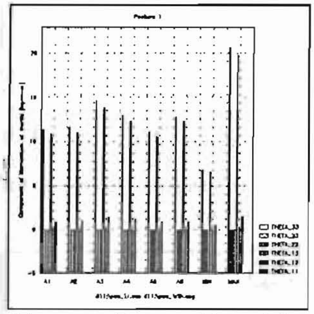

Figure 5: Inertia tensor for 6 top trampolinists compared to the minimal (MIN) and maximal (MAX) value of a sample of 18 semi-trained adults

Figure 5 gives the **inertia tensor** of the 6 top trampolinists, compared to the minimum (MIN) and the maximum (MAX) data of our group of semi-trained adults, all in posture 1. The differences in the inertia tensor components are caused by the mass density σ and the segment size τ, as seen in (5) [$\vec{\rho}$ denotes the coordinate vector].

$$\text{(5)} \qquad \Theta = \int_{\tau} d\tau\, \sigma [\rho^2 \cdot 1 - \vec{\rho} \otimes \vec{\rho}]$$

Therefore, the taller the person, the heavier the mass, the greater is his/her inertia tensor. If there are no great differences in the tensor components, relative to each other, then the rotational ability does not differ if the momentum is adjusted. It is, therefore, possible to separate the anatomical and the dynamical aspect of the rotational ability. We normalize the inertia tensor of each individual by dividing all components by his/her personal Θ_{11} of posture 1.

$$\text{(6)} \qquad \vec{\Omega}(t) = \Theta_N^{-1}(t) \cdot \frac{[\vec{L} - \vec{H}(t)]}{\Theta_{11}}$$

The results of our studies are shown in the graphs of Figure 6.
The normalized inertia tensor components of the 6 top trampolinists are shown for 2 of the 7 different postures (posture 2 shows the biggest deviation). The 95%-level at the right of each graph shows the summary of the results of the semi-trained group. This 95%-level lies within the marked part of the bars.

The Θ_{11}-component of the inertia tensor of a double-somersault with 1.5 twists is shown in Figure 7. The solid line is the average of the 5 different curves. For different athletes, we found differences in timing of up to 0.2 sec.

The momentum for such a performance is in the range of 100 Js (with actual measurements of 96 Js to 116 Js for the somersault axis). The other two axes are close to 0 Js with maximal value of up to a few Js.

DISCUSSION

For the 7 different postures we discovered, that the inertia tensor for trained or semi-trained persons differ only in the **absolute magnitude**. The relative inertia tensor Θ_N as defined above, shows only insignificant changes for all individuals. The standard deviation is < 0.024 for the top trampolinists and < 0.031 for the semi-trained adults. This is valid for all 7 postures and for all tensor components. It is therefore, always possible to get almost identical rotational ability for different athletes if the momentum can be produced in the right magnitude.

A combination of somersault and twists is govern by the inertia tensor together with the momentum. A well-done performance calls for a controlled inertia tensor throughout the execution. The momentum has to be chosen according to the actual body structure (weight and size) and the actual performance.

Trainers can use this finding to plan the training of the individual athletes. First of all, the body structure of an athlete is of marginal importance for a successful career in sports like trampolining. More important is the coordination (through the correct posture) and the timing, which has to be within the range of 0.01 sec. With the aid of our computer system we are able to calculate the optimal combination of the postures as a function of time, as well as the momentum necessary to produce high performance among athletes!

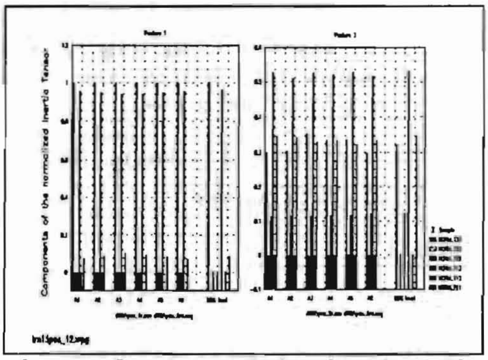

Figure 6: Normalized inertia tensor of 6 top trampolinists compared to the 95%-level of a sample of 18 semi-trained adults in posture 1 and 2.

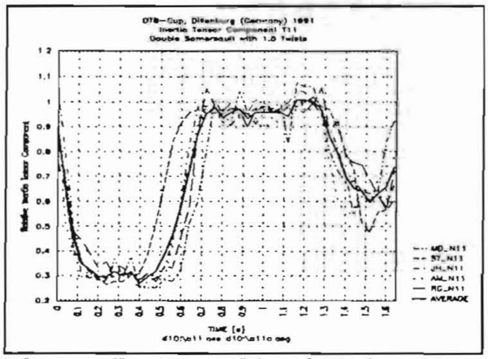

Figure 7: Normalized 1-1-component of the inertia tensor as a function of time for 5 athletes performing a DOUBLE SOMERSAULT WITH 1.5 TWISTS.

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