A BIOMECHANICAL ANALYSIS OF THE ESKIMO ROLL IN KAYAKING.

M.J.L. ALEXANDER, G.G. GIESBRECHT, R. NICKEL
UNIVERSITY OF MANITOBA,
FACULTY OF PHYSICAL EDUCATION

Introduction

The purpose of the present study was to develop a mechanical model of the Eskimo roll in kayaking, in order to eventually develop a land-based Eskimo roll simulator. The Eskimo roll consists of a 360" rotation of the subject and the kayak, from an upright position, to an upside down position underwater, and back to an upright position. The Eskimo roll is a necessary skill in kayaking, as rough water will often overturn the kayak, which is then stable in an upside down position. The kayaker must be able to apply torques to the water from this upside down position to right the kayak. The Eskimo roll is a very difficult skill to master, as the starting position is a stable position upside down in the water which is potentially dangerous for beginners. A land-based simulator would assist the teaching and learning of this skill in a safe environment, but accurate simulation of the skill is difficult due to the unique characteristics of moving against the water.

Methods and Procedures

The subjects used in the present study were four skilled kayakers (one female and three males), two of whom teach the Eskimo roll and all subjects perform the skill on a regular basis. The subjects were filmed in three separate filming sessions, in which the camera placement and camera views were slightly altered for each session, in an attempt to improve filming accuracy. The Peak calibration frame was filmed in two positions; above the water while suspended on top of a kayak; and underwater while held afloat while tied to an inner tube.

Several trials of the Eskimo roll were filmed on three occasions while being performed in an indoor pool; using three video cameras and four different camera views. In the initial filming session two cameras were Gen-locked together to film the sagittal and frontal views of the skill from the pool deck, and the digitized video data from these cameras was used to produce three dimensional coordinates. In a subsequent filming session one underwater camera filmed the skill from underwater below the kayak; and one overhead camera filmed the skill from the end of the three-meter diving board. A later filming session used two Gen-locked video cameras filming from the underwater window of the pool, but due to the small size of the window the cameras were too close together to produce accurate three-dimensional coordinates. One of the cameras was then moved to the pool deck, and placed in a transparent plastic box which was partially submerged at the edge of the pool. This camera remained Gen-locked to a second camera filming from the underwater window. The video cameras and video film analysis equipment were provided by Peak Performance Technologies.

Film Data Analysis

The film from each Panasonic camera was subsequently analyzed using the Peak Performance Analysis System, in which points of interest on the kayak and the subject were digitized for each frame of film from each camera and the locations of each point were recorded throughout the performance of the skill. Only the best two trials of the skill were digitized, as all trials were very similar and only representative data was required for this preliminary study. The following points were digitized and recorded from each view: top of the head, sternal notch, hips, knees, ankles, shoulders, elbows, wrists, fingers, bow and stern of the kayak, and the top and bottom of each paddle blade. The data from the two synchronized cameras were used to calculate three dimensional coordinates, using the DLT (Direct Linear Transformation) techniques programmed into the Peak system. The origin of the three dimensional coordinates was located at the bow of the kayak, with the X-axis coinciding with the long axis of the kayak (a line from bow to stern), the Y-axis was a line vertical to the kayak, and the Z axis horizontal (sideways) to the kayak.

The video film data was then digitized from each of the camera views, and the two views were combined using the DLT procedure to produce three-dimensional coordinates. The digitized film data was smoothed using a second order Butterworth filter at a cut off frequency of 6 Hz. The smoothed data was used to produce frame-by-frame tracings of the steps in performing the Eskimo roll. These tracings included views from the front, rear, overhead, and underneath the kayak. The digitized points were used to determine the smoothed displacement, velocity and acceleration data of the important points in the skill. As well, the angular displacement, velocity and accelerations were calculated from the film data. These calculated values were used in the equations developed to estimate the torques produced by the paddle to perform the roll.

This film data was used to input actual values into an equation developed to estimate the torques required to right the kayak. A computer program was written to produce the torques from the equation, with estimates for each of the terms. The Eskimo roll was modelled as an irregular cylinder, rotating around the longitudinal axis of the system consisting of the kayak plus kayaker. The kayaker used the paddle to apply torques to the water, to overcome his inertia and move the kayak to the upright position. The inertia of the kayak was due to the mass of the kayak, the mass of the kayaker, the drag force of the water against the system, and the torque due to gravity which had to be overcome during the righting movements.

Calculation of Paddle Torques

The computer program developed to calculate the torques produced by the kayaker to return the kayak to the upright position was programmed in PASCAL on the IBM 486 microcomputer. The necessary kinematic data was read in from the Peak data files, and the constants were read into the program prior to calculation of torques. The moment of inertia of the system (I) was estimated from tabled values of the subject, plus estimates from the shape and weight of the kayak. The angular acceleration (a) of the system was estimated from the film data, which has provided a temporal record of the kayak during the roll. The cross sectional area (A_1) of the athlete was estimated from their individual body dimensions. The area of the paddle (A_2) was measured directly from the paddle used in the filming session.

The equation which was used to estimate the torque required from the paddler to rotate the system to an upright position is listed below. The values which were read into the equation are included with each term.

$t = I_a a + F_d d_1 - F_l d_2 + mg d_3 - b_f d_4$ **(Equation 1)** and

$F_d = (A_1 V r v_1^2 / 2)$; $F_l = (A_2 C_l r v_2^2 / 2)$

where t = Torque (N.m): calculated from the PASCAL program

Ia = moment of inertia of the athlete + kayak around x-axis of system;

Ia = $I_{cg} + md_3^2 + M_k d^2$ where I_{cg} is the moment of inertia of the athlete about A-P axis through CG, m is the mass of the athlete (70 kg) and d_3^2 is the distance from the CG of the athlete to the axis of rotation, M is mass of kayak times distance to axis squared

I_{cg}= moment of inertia of athlete (kg.m^2) = 7.072 kg.m^2: from tabled value reported by Kreighbaum (1990)

a = angular acceleration of kayak (rad / sec^2): calculated from film data

$F_d = (A_1 V r v_1^2 / 2)$ = drag force due to water resistance (N) (Sprigings & Koehler, 1990)

$F_l = (A2 C_l r v_2^2 / 2)$ = lift force due to paddle movement (N)

A_1 = cross sectional area of the athlete = .238 m^2: from tabled values reported by Humanscale (Diffrient, Tilley & Bardagjy, 1978)

A2 = area of the paddle = .08 m^2, measured from paddle

V = coefficient of drag; k = .4

C_l = coefficient of lift of the paddle for a given angle of attack = .6 if angle less than 10". and .1 if greater than 10"

r = density of water 998 kg/m^3

v_1^2 = linear velocity of shoulder of athlete squared (m/s)^2: calculated from digitized film data

v_2^2= linear velocity of paddle squared (m/s)^2; calculated from film data

d1 = distance from axis to center of pressure of drag force (m): estimated to be at midpoint from hips to top of head of kayaker

d2 = distance from axis to point of application of lift force (m): estimated to be at end of active paddle blade

m = subject mass = 80 kg or 68 kg, depending on subject

g = acceleration due to gravity = 9.81 m/s^2

d3 = horizontal distance from CM to axis of rotation (m)

b_f = buoyant force acting on center of buoyancy of system; weight of the displaced water = 785 N.

d_4 = horizontal distance from center of buoyancy to axis of rotation (m); estimated to be at midpoint from hips to shoulders of kayaker

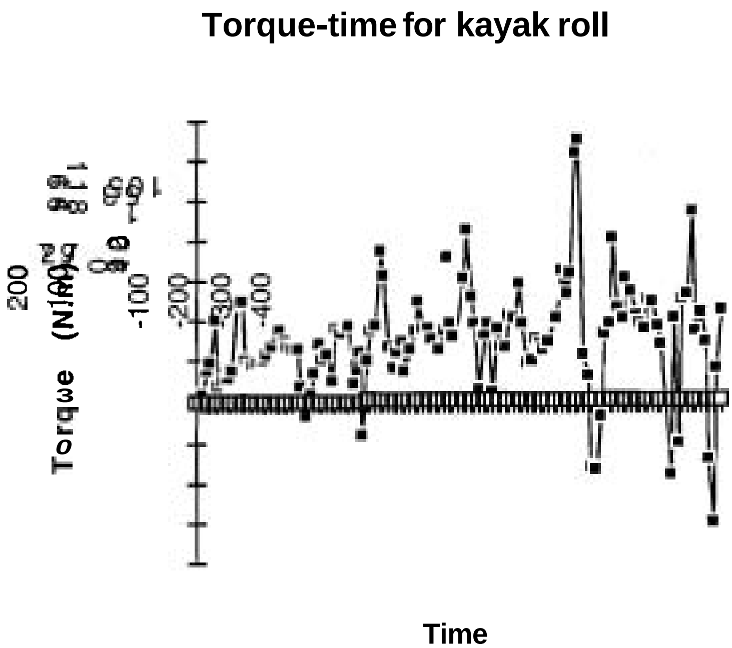
Results

The equation developed for the analysis of the Eskimo roll, and described previously, was used to develop a computer program to calculate the torques and forces necessary to perform the Eskimo roll. It must be noted that the values calculated here are first approximations of these values, as there are several terms in the equation which were estimated and not measured.

Torque Needed to Right Kayak

In this study, the torque necessary to right the kayak was assumed to be produced by the actions of the paddle applying forces to the water. However, this assumption may not be completely accurate, since it is possible to perform the Eskimo roll without the paddle, by using the hip flick alone. This finding suggests that the hip flick may be the major source of torques to right the kayak, but it is very difficult to model this movement, and how the torques are produced by hip lateral motion. The torques calculated in this model may be too large to be produced only by the paddle, but it is not clear how the torques produced by the hip flick can be resisted in this system.

The torque (t) necessary to right the kayak from the stable, upside down position was calculated from the film data described previously, and is reported in Figure 1. The torque value fluctuated slightly, as it was dependent on the fluctuations in the moment of inertia and the angular acceleration of the kayaker during the skill. The initial torque value is approximately 200 N.m, and it increases to almost 400 Nm during the initial phase of the skill. The peak torque output of over 600 N.m occurred at 1.5 second into the skill, likely at the point where the paddle switched from lift to drag forces. From this peak value the torques decreased to 300 N.m for the remainder of the motion of the paddle.



References

Diffrient, N., Tilley, A.R. & Bardagjy, J. (1978). Humanscale 1/2/3. Cambridge, Mass: MIT Press.

Kreighbaum, E. & Barthels, K.M. (1990). Biomechanics: a qualitative approach for studying human movement. Third edition. New York: Macmillan Publishing Company.

Sprigings, E.J. & Koehler, J.A. (1990). 'The choice between Bernoulli's or Newton's Model in predicting dynamic lift'. International Journal of Sport Biomechanics, 6, 235-245.