INTRODUCTION

When body size increases due to growth, it is the interplay between greater whole body inertia and the concomitant improvement in strength and power that determine an athlete’s ability to perform. In order to adapt to a larger moment of inertia, the young athlete must develop greater angular momentum and/or greater linear momentum so as to allow sufficient time for the required movement. For example, in a backward somersault (salto), a larger gymnast may develop greater take-off impulse, so as to increase angular momentum in the flight phase. She may also increase vertical impulse, so as to give herself greater vertical momentum at take-off and thus a longer time of flight in which to complete the required body rotations.

Jensen (1981) reported that as the moment of inertia of individual segments of the human body increased, due to growth, there was an increased compensation in the force patterns in order to maintain or improve the performance of rotational movements. In women’s gymnastics these mechanical interrelationships produce a selection bias toward light, though relatively powerful athletes. Through adolescent development we often note a substantial performance decrement because increases in segment moment of inertia values are not matched by concomitant increases in strength and power (Jensen, 1981). These changes in inertia represent constraints to which the body must adapt (via improved technique and power), if the level of motor performance is to be maintained. The aim of this paper was to quantify the influence of physical size, strength and power among young female gymnasts on their ability to create maximum rotation and height in front and back saltos.

METHODS

Female gymnasts (n = 37) aged 10 to 13.5 years, who trained 15 hours per week or more in elite or club programs, were tested on a battery of anthropometric (height, mass and sum of 8 skinfolds), and gymnastic ability (front and back saltos, v-sit action, and vertical jump) tests. Repeat testing occurred at four monthly intervals over 3.3 years using an identical protocol (Richards et al., 1999). The same anthropometrists, were generally used throughout the study. They had established measurement precision levels within the accepted limits for the technical error of measurement (1% for segment lengths and 5% for skinfolds (Carter and Ackland, 1994).

Gymnasts were photographed by two cameras while standing in the anatomical position for the purpose of identifying individual body segment moment of inertia parameters using the elliptical zone modelling technique (Jensen, 1978; Jensen and Fletcher, 1994). Elastic bands and markers were placed over previously marked segment endpoints so they were visible from the anterior and lateral camera positions. To ensure maximal visibility of the trunk segment the subject stood with the left arm in the anatomical position and the right arm folded behind the trunk. Two 35 mm single lens reflex cameras allowed simultaneous photographs of the body to be taken. One camera had its optical axis aligned so that an anterior view of the body was visible and the other had its optical axis aligned at 90° to provide a photograph of the body from a lateral perspective (symmetry was assumed in this filming). In addition, two scales with 10.0 cm graduations were included in the field of view of each camera to permit the conversion of image to real lengths.

Individual data series were smoothed using a cubic spline algorithm (Reinsch, 1967), differentiated and interpolated to provided growth values at one month intervals over the period of the study.

Flexion and extension peak torque values (gravity corrected) were measured for the lower leg (90°/s) and upper arm (210°/s) segments, while trunk flexion and extension strength was determined using an isometric protocol (Richards et al., 1999). Whole body angular momentum was derived using kinematic data collected from high speed motion analysis and the technique proposed by Hay et al. (1978).

Subjects were landmarked (most distal and lateral point of the fifth metatarsal; lateral malleolus of the fibula; lateral junction of the femur and tibia; superior surface of the greater trochanter of the femur; dorso-lateral portion of the acromion process; humero-radial junction; ulna styloid process) prior to performing three trials of the following gymnastics skills.

- A vertical jump for maximum height provided a measure of leg power. In this test the subject was assisted into the ready position with knees flexed to 90°, the right arm positioned behind the back and the left arm extended above the head.
- A v-sit action at maximum speed to indicate the ability to achieve a rapid pike position in flight. In this test subjects were required to lie supine on a gymnastics mat at 90° to the camera with arms extended overhead. The gymnast then performed a v-sit action as fast as possible. That is, from a back lying position the upper and lower limbs were rotated toward each other so that the hands touched the feet in the shortest possible time.
- Maximum rotations in front and back saltos were performed from a 1m high padded bench into a portable pit consisting of 1m deep, solid foam segments. This
provided sufficient cushioning on impact to prevent injury from a poor landing.

Body segment velocities and temporal parameters were recorded using a Photosonics high speed camera operating at 100 Hz (saltos) and 50 Hz (v-sit). A 1 m rule with 10 cm graduations (to provide a scaling factor), a high speed clock (for film speed calibration) and a board with the subject number and testing session were included within the field of view of the camera. The trial with the greatest number of rotations in the front and back saltos, as identified from the film, was chosen for analysis.

Following low pass filtering (Butterworth-recursive-5Hz), peak torque, maximum trunk angular velocity, centre of mass vertical displacement, angular momentum, and take-off angles were derived.

Four stepwise linear regression analyses were used to predict maximum angular velocity and jump height (elevation of the body’s centre of mass) for the front and back saltos from the anthropometric, strength and performance variables. Only variables that were significantly correlated with the dependent variable were entered into the initial model. Successive iterations of the analyses removed predictor variables. The eventually chosen model provided near maximum prediction capability with the least number of predictor variables.

Data were included for each subject at ages 11.5, 12.5 and 13.5 years.

THEORETICAL PERFORMANCE MODEL

The following theoretical performance model (Figure 1) was structured to explain the influence of body size, strength and leg power on the ability to generate maximum rotation in a front and back salto, whilst minimising the influence of gymnastic skill. The dependent variable ‘jump height’ was indicative of the ‘flight time’ parameter shown below, whereas ‘angular velocity’ was measured directly during the performance tests.

RESULTS AND DISCUSSION

Back salto height (BSH) is predicted \((F=33.67; \ p<0.0001; \ R^2 = .600)\) by independent variables – body mass, leg strength, leg power, and take-off angle.

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BSH = -39.7 - (0.45 \text{ mass}) + (0.034 \text{ leg strength}) + (0.01 \text{ power}) + (0.77 \text{ take-off angle})
\]

Time of flight, which is obviously important in all rotational gymnastic manoeuvres is negatively affected by the mass of the gymnast. However, performance is enhanced through a combination of leg strength and power together with a more vertical take-off angle.

Constraining moment of inertia is a key factor in attaining rotation in a back salto. The importance of the ability to tuck or pike quickly (Figure 2) to off-set the effect of whole body moment of inertia, is evident from the importance of v-sit time in the equation.

Front salto height (FSH) is predicted \((F=8.70; \ p<0.0001; \ R^2 = .223)\) by independent variables – body mass, leg power, and take-off angle.

\[
FSH = -10.2 - (0.003 \text{ power}) + (0.2 \text{ take-off angle}) - (0.04 \text{ mass})
\]

While the numbers in the equations may vary, the positive and negative influences on achieving height in the forward salto are the same as were previously reported for the back salto.

Front salto velocity (FSV) is predicted \((F=15.66; \ p<0.0001; \ R^2 = .410)\) by independent variables – body mass, v-sit time, angular momentum, and take-off angle

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FSV = 16.7 - (0.13 \text{ mass}) + (0.13 \text{ angular momentum}) + (0.03 \text{ take-off angle}) - (8.1 \text{ v-sit time})
\]
The important positive and negative influences on the ability to achieve rapid rotations are again very similar to that reported for the back salto. The gymnast must be able to rapidly rotate to a piked (v-sit time) or tucked position to reduce the negative influence of whole body moment of inertia.

**SUMMARY**

The degree to which the body’s centre of mass is raised during performance is important for maximising body rotation. In accord with the theoretical model, the interplay of body mass, strength and leg power appears vital to a successful outcome (particularly with the back salto). With respect to rotational velocity, the ability to constrain whole body moment of inertia is crucial. Richards et al. (1999) reported that gymnasts who trained greater than 20 hours/week were significantly smaller, but markedly stronger than those club level gymnasts who trained about 15 hours /week, despite the size disadvantage. The gymnasts with the smaller moment of inertia values were able to produce higher velocities for front and backward salto rotations and a faster v-sit action. Therefore, as observed in this study one’s ability to achieve a tight tuck position rapidly is important to offset the negative effects of increased body size. When body size increases due to growth, it is the interplay between greater inertia and the concomitant improvement in strength/power in combination with skill that determine an athlete’s ability to perform.

**REFERENCES**