The Changes in Mechanical Energy During the Giant Swing Backward on the Horizontal Bar

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INTRODUCTION

In the giant swing backward, mechanical energy of the whole body is decreased due to friction between gymnast hands and the bar, and to air resistance. To complete the rotation, the gymnast has to do muscular work to offset these energy losses. Total mechanical energy changes with the relationship between energy loss and muscular work. Therefore, for biomechanical investigation of the giant swing backward, it is important to have an accurate measure of the mechanical energy changes of the whole body. Although there are many studies of energetics of the human fundamental movement such as walking and running, the mechanical energy changes of the whole body have not been reported during the giant swing backward on the horizontal bar.

The purpose of this study is to report the mechanical energy changes of the whole body, and to identify the muscular work done by the gymnast during the giant swing backward on the horizontal bar.

METHODS

The subjects in this study were five male gymnasts, aged 19 to 21 yrs. Their body weight and height were 60.8 ± 3.2 kg (mean ± SD) and 1.64 ± 0.02 m, respectively. The body landmarks were attached to the gymnasts. The motions were filmed from the side with a high-speed camera (Photo Sonics 16-1PL) of 33 frames a second. Analysis was started from the handstand position and one rotation was divided into four phases every 90 deg of angular displacement of center of mass of the whole body (C.M.) (Fig. 1).

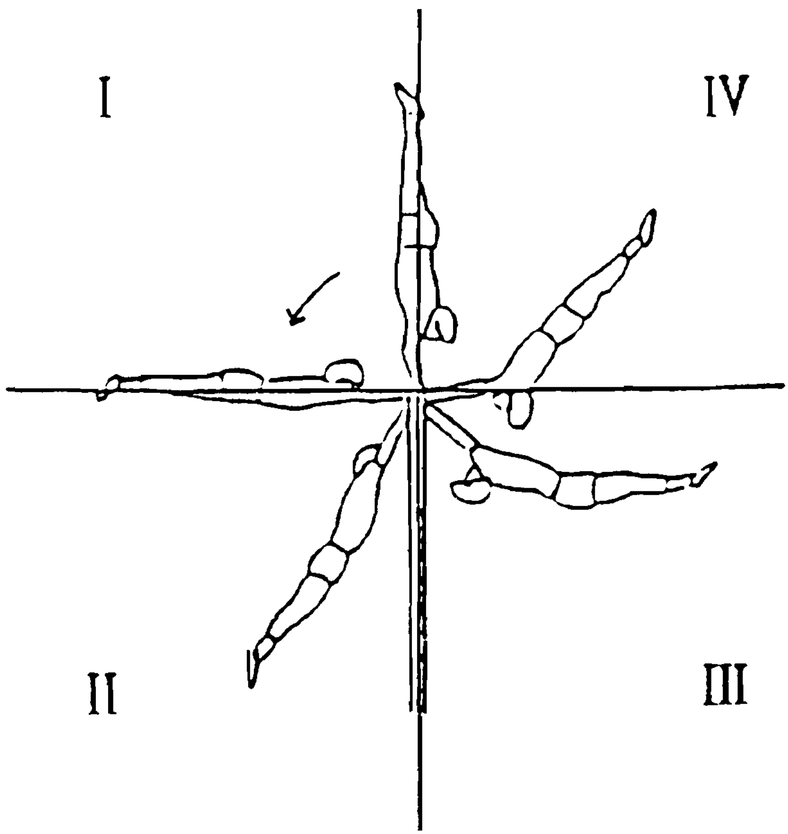

Fig. 1 Analytical phases in the giant swing backward on the horizontal bar.

An eight-segment mathematical model of the body was used for mechanical analysis representing individual body segments, such as the head (included neck), trunk, upper arm, forearm, hand, thigh, shank and foot segment. The body landmarks digitized from the films represented the endpoints of each of the segments. Segment masses and center of mass were calculated from the data of Dempster (1955) and segment moments of inertia were obtained from the data of Widule (1966).

The segment endpoint data were smoothed using a digital filter with a cutoff frequency of 3.2 Hz. The resulting filtered displacement-time curves were differentiated by first order finite differences, to determine the velocity-time relationships.

The mechanical energy of the body was calculated:

$$PE_{cm} = MgH$$

$$KE_{cm} = \frac{1}{2}MV^2$$

$$KE_{int} = \sum_{i=1}^{8} \left(\frac{1}{2} m_i v_i^2 + \frac{1}{2} I_i w_i^2 \right)$$

where PE_{cm} = potential energy of the C.M., KE_{cm} = kinetic energy of the C.M., KE_{int} = internal kinetic energy, M = body mass (kg), g = gravitational acceleration (9.8 m/s^2), H = height of the C.M. (m), V = velocity of the C.M. (m/s), m_i = mass of i-th segment (kg), v_i = relative velocity of mass center of i-th segment to the C.M. (m/s), I_i = moment of inertia of i-th segment about its mass center (kg m^2), and w_i = angular velocity of i-th segment (rad/s). Each mechanical energy was represented as relative value to total mechanical energy of the whole body at the first handstand position.

The period of one rotation of the giant swing backward for each subject's record was normalized to 100%. Then average curve of joint angle and mechanical energy were calculated at each 0.25% interval of the one rotation period. The standard deviation at each of these intervals was also calculated.

RESULTS AND DISCUSSION

Figure 2 shows changes in the shoulder (upper panel) and hip (lower) angle. Shoulder joint extended in the third phase, and flexed in the first half of the fourth phase. Hip joint slightly extended in the end half of the second phase, and flexed in the third phase. In the first half of the fourth phase, hip joint extended again.

Figure 3 shows changes in potential energy of the C.M. (upper panel), kinetic energy of the C.M. (middle) and internal kinetic energy (lower). Potential energy of the C.M. was 96% of total mechanical energy at the

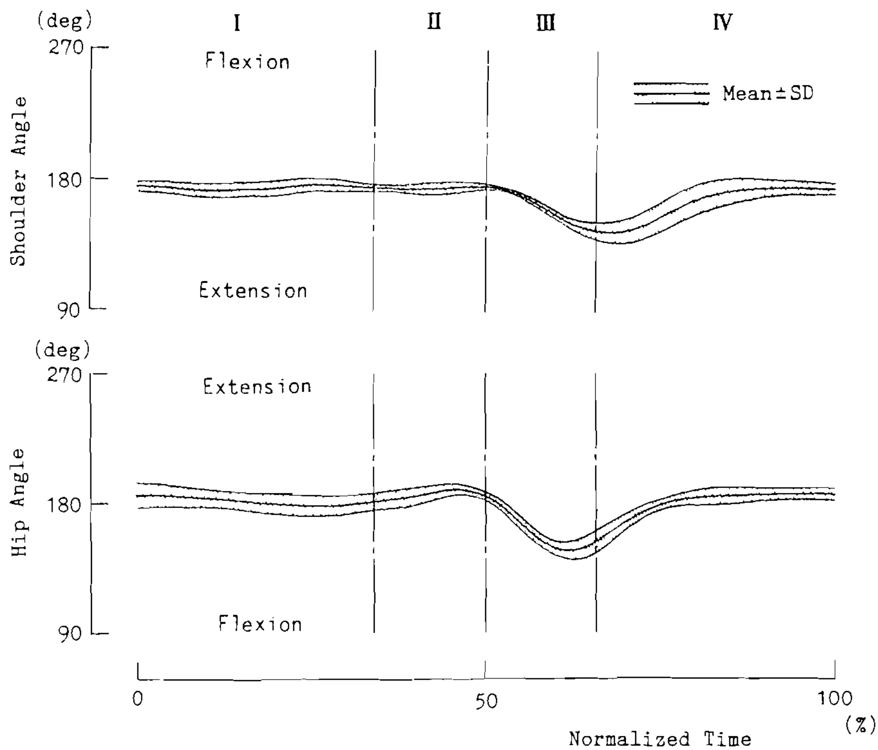

Fig. 2 Changes in shoulder (upper panel) and hip (lower) angle during the giant swing backward on the horizontal bar.

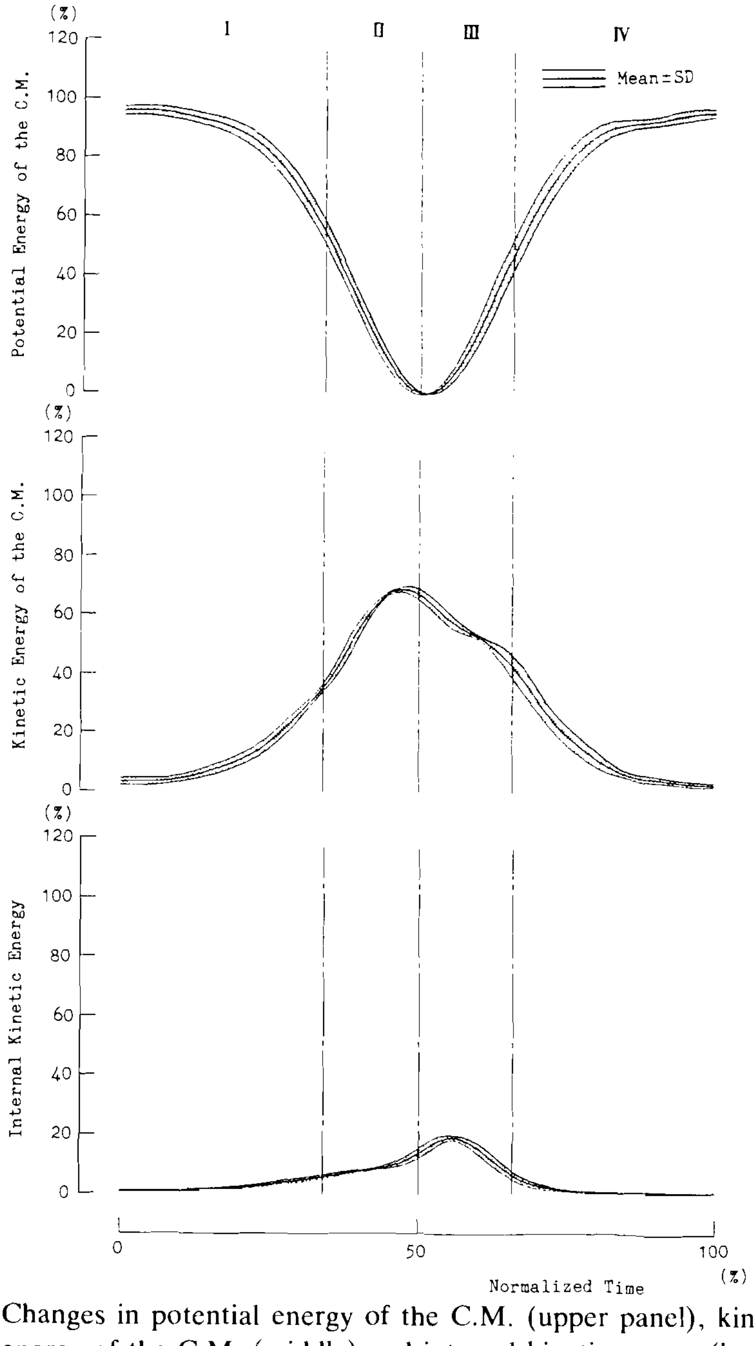

Fig. 3 Changes in potential energy of the C.M. (upper panel), kinetic energy of the C.M. (middle) and internal kinetic energy (lower) relative to total energy of the whole body at the first handstand position during the giant swing backward on the horizontal bar.

first handstand position. It was decreased in the first and second phases, and increased in the third and fourth phases. Potential energy of the C.M. was almost recovered to the level of the first handstand position in the end half of the fourth phase. On the other hand, kinetic energy of the C.M. was increased in the first and second phase, and it was showed maximal value of 65% of total mechanical energy at the first handstand position. Then it was decreased in the third and fourth phases. Internal kinetic energy was increased rapidly in the end half of the second phase. Maximal value of internal kinetic energy was appeared in the first half of the third phase, and it was decreased in the end half of the third phase and first half of the fourth phase. Figure 4 shows changes in total energy during the giant swing backward. Total energy was decreased in the end half of the first phase and second phase. Minimal value of total energy was 75.7% of total energy at the first handstand position, and it was appeared at 52% of normalized time. Therefore, the loss of mechanical energy of the whole body was 24.3% of total energy at the first handstand position. Then total energy was increased in the third phase and it was almost recovered to the level of the first handstand position.

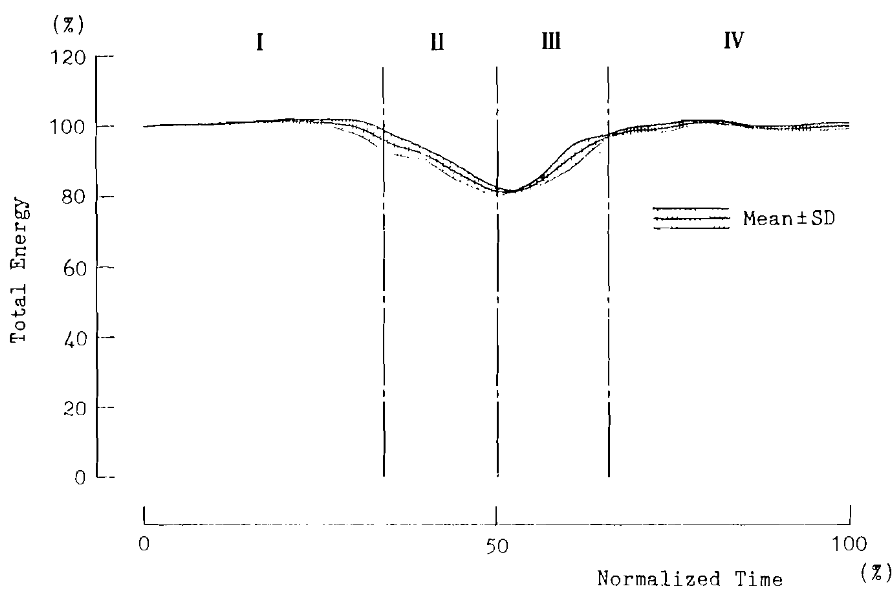

Fig. 4 Changes in total energy relative to total energy of the whole body at the first handstand position during the giant swing backward on the horizontal bar.

Figure 5 shows summary of the mechanical energy changes during the giant swing backward on the horizontal bar. Potential energy was transformed into kinetic energy of the C.M. and internal kinetic energy. However, not all the potential energy was converted into kinetic form, because of the friction between gymnast's hand and the bar, and of air resistance. Some of decreased mechanical energy was stored as elastic energy of the bar. Kinetic energy of the C.M. and internal kinetic energy was converted back to potential energy of the C.M. in the third and fourth phases. In the third phase, total energy was almost recovered to initial level of the first handstand position. This increased mechanical energy was due to muscular work done by the gymnast and conversion of the elastic energy of the bar into mechanical energy of the gymnast body.

The results of the changes in joint angles and in total energy indicated that muscular work was done by extension of the shoulder joint and flexion of the hip joint in the third phase.

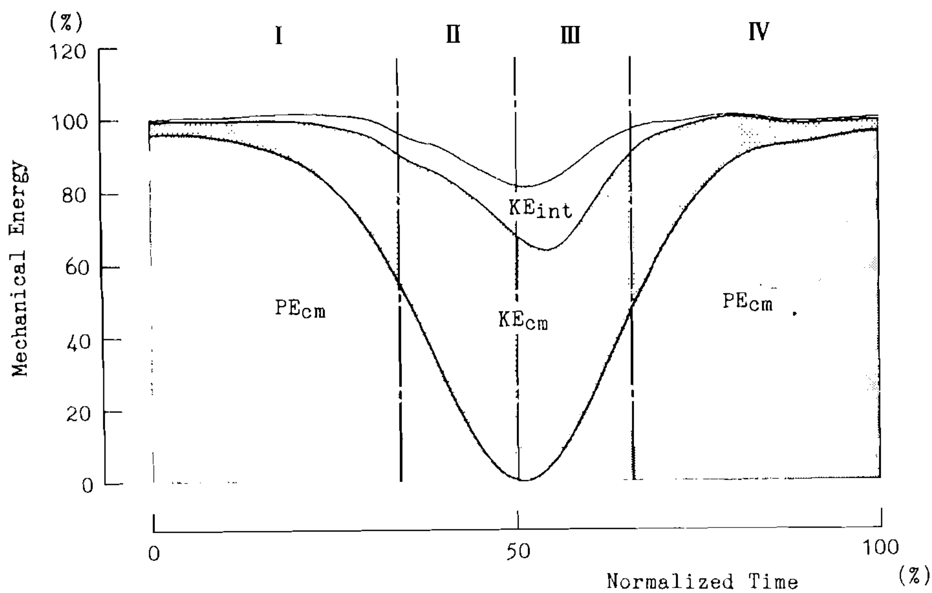

Fig. 5 Summary of the mechanical energy changes during the giant swing backward on the horizontal bar. PE_{cm} = potential energy of the C.M.; KE_{cm} = kinetic energy of the C.M.; KE_{int} = internal kinetic energy.

CONCLUSION

Mechanical energy was measured during the giant swing backward on the horizontal bar by means of cinematography. Total mechanical energy of the whole body was decreased in the end half of the downswing and the loss of mechanical energy was due to friction between gymnast's hand and the bar, and to air resistance. However, total mechanical energy of the whole body was recovered to the initial level. The results from this investigation suggested that muscular work was done to offset the loss of mechanical energy by flexion of the hip joint and extension of the shoulder joint in the first half of the upswing.

REFERENCES

Dempster, W. T., Space requirements of the seated operator, WADC Technical Report 55-199, Wright Patterson Air Force Base, Ohio, 1955.

Widule, C. J., Segmental moment of inertia scaling procedure, Res. Quart. Exercise Sport, 47, 143-147, 1966.