Kinetic Analysis of Backward Giant Swing on Parallel Bars

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The purpose of this study was to investigate the kinetic characteristics of backward giant swing on parallel bars (PB) compared with those of backward giant swing on horizontal bar (HB). The subjects were six male skillful university gymnasts. Their performances of PB and HB were videotaped with a digital video camera to calculate the knee, shoulder, and hip joint angle, joint torque, joint power, and mechanical work from two-dimensional coordination of the body landmarks. The mechanical negative work done by hip extension torque leading to hang phase of PB were larger than those of HB. During upward phase from hang, the shoulder extension torque of PB was exerted longer period of time than HB, with the result that mechanical positive work done by shoulder extension torque of PB was larger than that of HB. For effective training of backward giant swing on parallel bars, the coach has to recognize their characteristic differences from those of horizontal bar.

Keywords: Gymnastics, parallel bars, backward giant swing, joint torque, joint power

1. Introduction

The backward giant swing on parallel bars in men's artistic gymnastics was demonstrated for the first time in the world by a Japanese gymnast, Eizo Kenmotsu, at the World Gymnastic Championship in Strasbourg, 1979. Whereas a backward giant swing on the horizontal bar is performed in rotating on the bar grasped with an overhand grip, the backward giant swing on parallel bars is "an element" characterized by the course of rotation between two parallel bars grasped from inside, with knees bent at a hang position forced from the height limitation of the apparatus and then changing grip upon reaching a handstand. Although the performance was highly appraised at first, recently many gymnasts have performed this with a twist or a somersault. Thus at present, as in the case with a backward giant swing on the horizontal bar, a backward giant swing on parallel bars has been positioned as a basic skill for achieving more technically difficult elements (Fujiwara, K., & Mizuguchi, H., 2001).
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clarifying its movement technique to be utilized in efficient coaching.

This study therefore aims to clarify the change in torque and power exerted at the joint while performing a backward giant swing on parallel bars in particular, and to examine the movement technique of a backward giant swing on parallel bars comparing the obtained data on parallel bars with that on the horizontal bar.

2. Methodology

2.1. Subjects and filming method

The subjects of this study were 6 male university gymnasts who have achieved mastery of a backward giant swing on both parallel bars and horizontal bar (age: 19.7 ± 1.0, height: 1.66 ± 0.02 m, weight: 60.3 ± 3.2 kg, gymnastic experience: 13.2 ± 1.8 years).

The purpose and method of this study were explained to all the participants before experiments commenced. The participants consented to participate in the experiments.

Firstly, the subjects were instructed to perform a backward giant swing on parallel bars (PB hereafter), to "start the downswing from a handstand and finish in a handstand again" specifically. They were asked to perform PB several times after voluntary exercise.

The attempt was filmed by using a digital video camera (SONY, DCR-VX 1000) placed at 16 m right beside the horizontal bar and at the same height of the bar, at 60 fields per second, 1/250 second exposure time. Calibrating equipment was filmed before the attempt of both PB and HB. Vinyl tape and reflex markers were attached to the Subjects at the wrists, elbow joints, top of the head, greater trochanters, knee joints, ankles and toes in order to facilitate the later digitizing of the data.

2.2. Digitization and reconstruction

Analysis was conducted on the attempt of both PB and HB executed by each subject and judged most satisfying both in the self report of each subject and in the observation report of experimenters. Films were digitized with X (horizontal) – Y (vertical) coordinate values on 9 measured points of the body (finger tip, wrist, elbow joint, shoulder joint, top of head, greater trochanter, knee joint, ankle joint, toe) during one rotation from a handstand to the next handstand on both parallel bars and horizontal bar at every 2 fields (30 Hz) using a video motion analysis system (DKH, Frame-DIAS II).

After digitizing, each coordinate value at measured points of the body, which had been converted to life size, was determined of its cutoff frequency (X-coordinate 1.5~3.9 Hz, Y-coordinate 1.8~3.9 Hz) using the residual analysis method of Winter (1990) on X-Y coordinate at each measured point and smoothed by the Butterworth digital filter.

2.3. Data analysis

The body was replaced by a rigid link model of 8 segments composed of head, trunk, upper arm, forearm, hand, thigh, lower leg and foot. The gravity center of the whole body and the gravity center of each segment of the body, inertia moment, flexion and extension angles of knee joints, hip joints and shoulder joints, rotation angle of the body (RA hereafter) (Figure 1) were calculated using smoothed coordinate values of each measured point of the body and inertia coefficient of Ae, M., (1996). In addition, velocity,
acceleration, angular velocity and angular acceleration were calculated by differentiating measured points of the body, gravity center position of each body segment and each joint angle with respect to time.

Based on this data, the equation of motion (Winter, 1900) on each body segment was formulated to calculate the torque at knee, hip and shoulder joints by solving the equation in order from the foot. Respecting direction, extension of each joint torque was determined to be positive and flexion to be negative. Each joint torque was the total of right and left, and the value was divided by the body mass of the subject to be standardized. Then joint power was determined from the product of joint torque and joint angular velocity, and the mechanical work done by each joint was calculated by integrating joint power generated at RA 10–350° with respect to time of every RA 5°.

Since each subject moved with temporal difference, the cubic spline function was used to calculate the value at every RA 5° of determined data on joint torque and power in order to facilitate the comparison. The Wilcoxon signed rank test was used to test the difference between PB and HB. The significant level was set to below 5% and the significant tendency below 10%.

3. Results

3.1. Joint Angle

Figure 2 gives the transition of each joint angle in PB and HB listing the average value and standard deviation of subjects. It is required to bend the
knee joints around the hang at RA 180° in PB as mentioned above, because the height of parallel bars is defined to 1.80 m, while the horizontal bar is placed at 2.55 m above the landing mat. Given this condition, the knee joint angle was kept nearly 180° during the whole course of movement in HB, while the knee joint angle of PB started to decline after passing around RA 90°, became 71.6°~82.5° at RA 195~300° and then increased again. Difference of significant tendency ($p < 0.10$) and significant difference ($p < 0.05$) were observed at RA 90° and at RA 105~345° respectively between PB and HB.

Hip joint angles of both PB and HB declined slightly after the downswing from a handstand, then increased until the hang at RA 135~165°. After that it declined again, and then started to increase at RA 255°. This pattern was roughly identical for both PB and HB. However, the hip joint angle was smaller after the downswing from a handstand to RA 15~60° in PB than in HB and difference of significant tendency ($p < 0.10$) or significant difference ($p < 0.05$) was observed. Thereafter, the hip joint angle was smaller after the downswing from a handstand to RA 15~60° in PB than in HB and difference of significant tendency ($p < 0.10$) or significant difference ($p < 0.05$) was observed. Thereafter, the hip joint angle of PB started to decline after showing the maximal value (188.5 ± 10.9°) at RA 135°. The minimal values (PB: 138.1 ± 3.8°, HB: 159.8 ± 7.1°) were seen at RA 255° for both PB and HB, whereas the hip joint angle in PB was always significantly smaller ($p < 0.05$) than in HB at RA 135~255°. After that, the hip joint angle increased both in PB and in HB, whereas it was always significantly greater ($p < 0.05$) in PB than in HB at RA 285~330°.

The shoulder joint angle slightly reduced after the downswing from a handstand in HB. It increased after becoming 162.7 ± 5.4° at RA 60° and showed the maximal value of 178.7 ± 5.8° at RA 165°. Then it reduced to the minimal value of 144.8 ± 5.6° at RA 270° and started to increase again. The shoulder joint angle in PB also slightly declined for a moment after the downswing from a handstand to show 157.3 ± 7.0° at RA 30°. Since then, it increased slightly to show 167.3 ± 5.5° at RA 75°, and continued unchanged until RA 180°. Then it reduced to show the minimal value (128.2 ± 6.5°) at RA 285° and increased again. The shoulder joint angle was always smaller in PB than in HB, and difference of significant tendency ($p < 0.10$) or significant difference ($p < 0.05$) was observed after RA 90° until RA 345°.

3.2. Joint Torque

Figure 4 shows the transition of joint torque in both PB and HB by listing the average value and the standard deviation of subjects.

Knee joint torque in HB was nearly zero during the whole course of movement. In contrast, flexion torque at RA 30~45°, extension torque at RA 75~90°, flexion torque at RA 105~270° and extension torque at RA 285~300° were acknowledged in
Changes in Joint Powers

3.3. Joint power

Figure 5 shows the transition in joint power in PB and HB, listing the average value and the standard deviation of subjects.

Knee joint power was rarely exerted during the whole course of movement in HB. In contrast, positive power was exerted at RA 105°–210° and RA 165° to reach its peak (6.87 ± 1.64 W/kg) in PB. The value in PB was significantly larger (p < 0.05) than in HB at RA 120°–195°.

Hip joint power showed a negative value at RA 75°–90° where flexion torque was exerted in PB and significant difference between PB and HB was observed (p < 0.05). Although extension torque was exerted at RA 135°–165° both in PB and in HB, the power showed positive values in HB and negative values in PB. Significant difference was
observed at this phase ($p < 0.05$). In consequence, negative values were observed both in PB and in HB, and then positive peak values appeared at RA 225° (PB: 3.59 ± 0.64 W/kg, HB: 3.01 ± 1.94 W/kg). No significant difference or difference of significant tendency was observed among them. However, positive power started to be exerted earlier at RA 195° in PB in contrast to at RA 210° in HB. After the peak, it declined rapidly in HB, while the degree of reduction was slower in PB. Significantly larger values ($p < 0.05$) appeared in PB (2.20 ± 1.20 W/kg) than in HB (0.83 ± 0.71 W/kg) at RA 240°. The value continued to decline until RA 255° and then positive power was exerted again at RA 270° in PB. The value was significantly greater ($p < 0.05$) in PB (2.23 ± 1.18 W/kg) than in HB (0.03 ± 0.31 W/kg) at RA 270°.

The changing patterns of shoulder joint power were consistent both in PB and in HB, showing a great peak at RA 240°. The increase before reaching at the peak of RA 240° started earlier in PB than in HB. The power was greater in PB (0.39 ± 0.35 W/kg) than in HB (-0.01 ± 0.23 W/kg) at RA 165° and difference of significant tendency was observed ($p < 0.10$). After the peak, the degree of decline was smaller again in PB, and the power was significantly greater ($p < 0.05$) at RA 270° in PB (2.22 ± 1.82 W/kg) than in HB (0.33 ± 0.39 W/kg).

### 3.4. Mechanical work

Mechanical work done by joint torque during performance of PB and HB is shown in Table 1, listing the average value and the standard deviation of subjects.

Work done by knee joint torque was significantly greater ($p < 0.05$) in PB (PB: 1.04 ± 0.14 J/kg) at RA 90~180° than in HB (HB: 0.02 ± 0.02 J/kg). At RA 180~270°, the value also showed significantly greater tendency ($p < 0.10$) in PB (0.39 ± 0.28 J/kg) than in HB (0.01 ± 0.03 J/kg). Furthermore, the value was significantly greater ($p < 0.05$) in PB (0.15 ± 0.06 J/kg) at RA 270~350° than in HB (0.00 ± 0.01 J/kg). The total value of the whole course of movement at RA 10~350° was significantly greater ($p < 0.05$) in PB (1.59 ± 0.19 J/kg) than in HB (0.03 ± 0.04 J/kg).

Work done by hip joint torque was rarely observed in HP (-0.01 ± 0.02 J/kg) at RA 10~90°, while negative work was exerted in PB (-0.11 ± 0.07 J/kg). Significant difference was observed between them ($p < 0.05$). Positive work was seen at RA 90~180° in HB (0.19 ± 0.17 J/kg) and negative work was seen in PB (-0.12 ± 0.06 J/kg) in contrast, showing significant difference between PB and HB ($p < 0.05$). Positive work was observed both in PB and HB at RA 180~270° where the value was significantly greater ($p < 0.05$) in PB (0.49 ± 0.17 J/kg) than in HB (0.19 ± 0.15 J/kg). The dynamics of hip joint angle velocity, hip joint torque and hip joint power of each subject at this phase are

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<tr>
<th>Table 1: Mechanical works done by joint torques</th>
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<tr>
<td>Normalized joint torque work (J/kg)</td>
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<td>RA10~90°</td>
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Mean ± SD
PB: Parallel bars HB: Horizontal bar
†: Difference between PB and HB ($p<0.10$)
*: Significant difference between PB and HB ($p<0.05$)
Negative power caused by extension torque of the hip joint was exerted earlier at this phase in HB, and then positive power caused by flexion torque of the hip joint was observed. In contrast, positive power caused by flexion torque of the hip joint was exerted earlier at this phase in PB, and then later positive power by extension torque of the hip joint was seen.

Table 2 shows the magnitude of work done by extension/flexion torque of the hip joint at this phase. The magnitude of work done by hip joint flexion torque was identical both in HB and PB. In contrast, a negative value (-0.12 ± 0.11 J/kg) appeared in HB, while a positive value (0.09 ± 0.10 J/kg) was seen in PB in respect to extension torque of the hip joint. Significant difference ($p < 0.05$) was observed between them. At RA 270°–350°, positive work was done in HB (0.04 ± 0.04 J/kg), while slightly negative work was done in PB (-0.07 ± 0.12 J/kg). Significant tendency ($p < 0.10$) that the value was greater in HB than in PB was observed. No difference was seen between PB and HB in the total work during the whole course of movement at RA 10°–350°.

Work done by shoulder joint torque was rarely observed at RA 10°–90° and RA 90°–180° both in PB and HB. Positive work of
certain magnitude was conducted at RA 180–270° both in PB and HB. Significant tendency ($p < 0.10$) that the work was greater in PB $(1.64 \pm 0.43 \text{ J/kg})$ than in HB $(1.06 \pm 0.29 \text{ J/kg})$ was observed. At RA 270–350°, negative work was done both in PB and HB and the values were almost identical. The total value of the whole course of movement at RA 10–350° showed no difference of significant tendency or significant difference between PB and HB.

The total amount of work done by each joint torque at each movement phase is shown at the bottom of Table 1. At the phase of RA 10–90°, significant tendency ($p < 0.10$) was observed whose amount was smaller in PB $(-0.16 \pm 0.17 \text{ J/kg})$ than in HB $(-0.02 \pm 0.07 \text{ J/kg})$. At the phase of RA 90–180°, the value was significantly greater in PB ($p<0.05$) $(0.96 \pm 0.20 \text{ J/kg})$ than in HB $(0.20 \pm 0.23 \text{ J/kg})$. At RA 180–270°, the value of PB $(2.52 \pm 0.47 \text{ J/kg})$ was significantly greater ($p < 0.05$) than HB $(1.26 \pm 0.41 \text{ J/kg})$. No difference was observed at RA 270–350° between PB and HB. In respect to the total work done by each joint torque during the whole course of movement, the value was significantly greater ($p < 0.05$) in PB $(3.29 \pm 0.51 \text{ J/kg})$ than in HB $(1.38 \pm 0.42 \text{ J/kg})$.

4. Discussion

Yabe, K. et al (1987) clarified that kinetic energy lost by friction resistance at a grip point and air resistance when performing a backward giant swing on the horizontal bar is compensated by the power exerted in hip joint flexion and shoulder joint extension at the phase when the gravity center of the body passes under the horizontal bar and then is elevated. This argument is confirmed here in this study both in HB and PB. More specifically, flexion torque of the hip joint, extension torque of the shoulder joint and the power of both were demonstrated both in HB and in PB at the phase when the gravity center of the body passed under the horizontal bar or parallel bars and then was elevated. Extension power of the shoulder joint was larger than flexion power of the hip joint commonly both in HB and PB, which is also consistent with the report of Yabe, K. et al (1987) on HB. However, some different aspects were observed between HB and PB concerning the pattern of these power exertions.

The knee joint is required to bend at the hang because of the height limitation of the apparatus in PB, which clearly affects angle shift, flexion torque and power of the knee joint. Movement to bend the knee joint at a hang is not seen in HB. In PB it causes the turning radius of the rotating body to decrease. Moreover, changing grip is necessary when performing a handstand at the last phase of a backward giant swing, which requires the body to be elevated over the bar. This circumstance is considered to cause the difference between HB and PB in the magnitude of torque and mechanical work at the hip and shoulder joint to elevate the body after the hang.

The total work of each joint during the whole course of movement was significantly greater in PB than in HB. It is estimated to result mainly from the difference in work done by flexion torque of the knee joint. A fully detailed examination on each joint at each rotation phase follows.

In respect to the hip joint, great difference in the pattern of torque exertion and its magnitude was observed at RA 90° and at around RA 270° between PB and HB. No great difference was observed from the phase to reach the hang position to the phase when the body started to be elevated. It was commonly observed that negative joint power was exerted around the hanging phase both in PB and HB in relation to the dynamics of joint power demonstration. However, the exerted time is earlier in PB, and mechanical work at RA 90–180° when reaching a hang was positive in HB but negative in PB in contrast. At this phase, extension torque of the hip joint has been continually exerted both in PB and HB, which explains that concentric activity of extension muscles of the hip joint appeared at RA 90–165° in HB and the activity was eccentric at RA 135–180° in PB. It is considered that extension torque of the hip joint is also exerted in HB and the eccentric muscle activity of the hip joint extension muscles is conducted at RA 180–195° where joint power shows negative values. When the upper body rotates at the phase reaching a hang, the toes stay at the rear of rotation due to the inertia of the lower body and exertion of extension torque of the hip joint. Then at around the phase when the upper body passes under the horizontal bar or parallel bars, the lower body is starting to rotate in the same direction as the upper body due to the force of gravity. Consequently, the
hip joint bends. The eccentric muscle activity of the hip joint extension muscles at around the phase of a hang, which was observed both in PB and in HB in this study, suggests that it requires effort to keep hip joint extension against external force to bend the hip joint. If flexion torque of the hip joint is exerted in accordance with external force to bend the hip joint instead of keeping hip joint extension, the exertion of hip joint flexion torque comes at the early stage of a backward giant swing rotation and consequently it becomes difficult to elevate the body. Therefore, the effort to keep hip joint extension by the eccentric muscle activity of the hip joint extension muscles at the phase leading to a hang can be positioned as an important operation to prepare for the next exertion of hip joint flexion torque at the desirable phase. Since studies on backward giant swing on the horizontal bar have not mentioned this fact so far, this is knowledge obtained for the first time in this study.

As described above, the important eccentric muscle activity of the hip joint extension muscles at the phase leading to a hang started earlier in PB than in HB. In PB, it is considered that external force to bend the hip joint appears earlier than in HB because the inertia moment of the lower body becomes smaller by bending the knee joint. In order to exert flexion torque of the hip joint to elevate the body effectively at the desirable phase, it is necessary to keep hip joint extension by eccentric muscle activity of the hip joint extension muscles early at the phase leading to a hang in PB, which is suggested to be an important technical point in PB.

The magnitude of mechanical work done by the hip joint at RA 180°–270° was larger in PB. The result shown in Figure 6 and Table 2 indicates that the total work is consequently smaller in HB because negative work is done by extension torque of the hip joint to keep hip joint extension after the gravity center of the body passes under the horizontal bar and then positive work is done by flexion torque of the hip joint. On the contrary, positive work is done at the early point of this phase by flexion torque of the hip joint in PB, which causes the total work to be larger. The fact that mechanical work of the hip joint becomes large at this phase in PB is considered not because the work of flexion torque of the hip joint is large but negative work is not performed by extension torque of the hip joint early at this phase and, in addition, positive work is performed by extension torque of the hip joint at the final stage of this phase.

Hip joint flexion after a hang is called "tap" at the scene of training. It is instructed to conduct this "tap" powerfully after a hang in order to perform work to elevate the body. In order to perform the "tap" at the desirable moment, it is required to keep the hip joint angle wide until the hang phase, and it is suggested that a tap should be performed earlier in PB than in HB. Moreover, the body should be elevated over the bar to change the grip before reaching a handstand at the last phase of the backward giant swing in PB. The positive work done by extension torque of the hip joint following at around RA 250° in PB, which is not observed in HB, is speculated to be a result of the bodily operation to utilize the force of backward giant swing rotation to elevate the body, so called an "open chest" or "body stretch". Exertion of negative work done by flexing torque of the hip joint immediately after RA 270° can be assumed to prevent the hip joint from extending too far after the "open chest".

Relating to the shoulder joint, even though particular difference was not observed between PB and HB in the peak of exerted extension torque and the fact that it starts at the phase when the body passes under the horizontal bar or parallel bars to be elevated, large extension torque appeared earlier in PB than in HB. Joint power showed no difference either, in being exerted after the hang phase both in HB and PB, while the power appeared earlier and remained longer after the peak in PB than in HB. The magnitude of mechanical work in the shoulder joint was three times larger than the work done by flexing torque of the hip joint both in PB and HB. Almost all the work appeared during exertion of extension torque of the shoulder joints both in PB and in HB. The magnitude tended to be significantly larger in PB than in HB. These facts indicate that it requires longer exertion of shoulder joint extension torque and the work done by this from earlier moment after a hang position in PB than in HB.

As mentioned above, in PB it is required to elevate the body over the bar while increasing rotating radius at the last phase of a backward giant
swing, in order to hang with the knee joint bent and to reach a handstand extending the knee joint. The joint should do the mechanical work for that purpose and this seems to be the cause of larger exertion of extension torque of the shoulder joint in PB than in HB.

This extending motion of the shoulder joint after the hang phase is described among trainers as "pulling the bar". It seems to imply that performing this motion powerfully early at the hang phase and for a long period is essential to succeed in performing a backward giant swing in parallel bars.

Considering these, it is suggested that hip joint extension torque is required to do negative mechanical work at the phase leading to a hang, and flexion torque of the hip joint and extension torque of the shoulder joint must be exerted earlier at the upward phase after the hang in PB. It seems necessary for PB coaches to understand this and to encourage gymnasts to keep extension so that the hip joint would not bend early at the phase leading to a hang, and to extend the shoulder joint ("pull the bar") early at the same time with hip joint flexion (tap) after a hang.

5. Conclusion

This study compared and analyzed kinetic characteristics of a backward giant swing on parallel bars with those on the horizontal bar. The results are as follows.

(1) When performing a backward giant swing on the parallel bars, the knee joint is required to bend because of the height limitation of the apparatus, which was reflected clearly in the values of the shifting knee joint angle, flexion torque, power and mechanical work at the joint. This was not seen in the performance of a backward giant swing on the horizontal bar.

(2) Extension torque of the hip joint was exerted and negative mechanical work was done at the phase leading to a hang both on parallel bars and the horizontal bar, while the starting point of exertion was earlier in a backward giant swing on the parallel bars than on the horizontal bar.

(3) Mechanical work was done by flexion torque of the hip joint and extension torque of the shoulder joint at the upward phase after a hang both in a backward giant swing on the parallel bars and on the horizontal bar. The magnitude of work done by extension torque of the shoulder joint was three times as large as the work done by flexion torque of the hip joint at the same phase.

(4) Mechanical work done by extension torque of the shoulder joint was larger in performing a backward giant swing on the parallel bars compared to the horizontal bar at the upward phase after a hang. This is caused by the time of torque exertion but not the difference in the peak value of torque.

From these it is suggested that hip joint extension at the phase leading to a hang, hip joint flexion and earlier and longer shoulder joint extension at the upward phase after a hang are needed more in performing a backward giant swing on the parallel bars than on the horizontal bar. When coaching a backward giant swing on the parallel bars, a coach should understand the characteristics which are different from those on the horizontal bar, and comprehend technical points including keeping the hip joint angle wide until the hang phase, then performing the hip joint "tap" powerfully and conducting extension motion of the shoulder joint described as "pulling the bar" powerfully and for a long time from early phase at the hang, which will lead to effective training.

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Backward Giant Swing on Parallel Bars


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