INTRODUCTION

The most important purpose of the takeoff phase is to obtain a large initial vertical velocity as much as possible. There have been many studies on the takeoff of high jump kinematics. Since, the vertical impulse is results from the joint torque of the muscles of the takeoff leg, investigating the joint torque production and the function of the takeoff leg muscles is useful to get insight into the takeoff motion and improve the performance of high jump. Joint torque and power have been computed in the biomechanics researches on a running (Ae, M. et al, 1986), a standing vertical jump (Fukasiro, S. et al, 1987), or a running long jump (Ae, M. et al, 1989). However, the motion of Fosbury-flop technique with the curved run-up is three dimensional in nature and very complex. This may be one of the reasons why there is few kinematic studies on the joint torque during the takeoff of Fosbury-flop.

The purpose of this study was to investigate three-dimensional joint torque and the function of the takeoff leg in the Fosbury flop style.

METHODS

Ten male Fosbury flop jumpers were participated in this study as the subjects. Their personal best records were ranging from 2.31m to 1.80m (Table 1). The takeoff motion of the subjects was videotaped with two high-speed VTR cameras (250Hz). The ground reaction forces during the takeoff phase were collected with two force platforms (Kistler AG, 500 or 1000 Hz). Three-dimensional coordinates of the segment endpoints were obtained by digitizing the VTR images from at least ten frames before touchdown (TD) of the takeoff foot to ten frames after takeoff (TO), with a DLT technique and were smoothed with a Butterworth digital filter (Wells, R.P. and Winter, D.A. 1980) of optimum cutoff frequencies (2.5~22.5Hz). Body segment parameters after Ae (1996) were used to estimate the location of the CG, mass and moment of inertia of the body segments. The following joint torques of takeoff leg joints (JT) was calculated by an inverse dynamic approach, abduction/adduction (abd/add), extension/flexion (ext/flex) and external/internal (ext/int) rotation torques for the hip and knee joints, and abduction/adduction (abd/add), plantar/dorsi flexion (pla/dor) and supination/pronation (sup/pro) torques for the ankle joint. Joint torque power (JTP) was calculated as an inner product of the joint torque and the joint angular velocity. JTs and JTPs were divided by the subject’s body mass and normalized by the time of the takeoff phase which was defined as the period from the touchdown to the toe off of the takeoff foot.

RESULTS AND DISCUSSION

Figure 1 shows the averaged patterns of joint torques of the hip, the knee and the ankle. The ext/flex and abd/add torques of the hip and the knee, and the pla/dor flexion torque of the ankle were dominant to other torques in each joint. The knee abduction torque was large in the second half of the takeoff phase. Since no muscles about the knee joint can abduct and adduct the knee joint because of the anatomical limitation, the large abduction torque of the knee will be caused by the internal rotation and abduction torques of the hip. Therefore, we focused our discussion on four joint torques: abd/add and ext/flex torque of the hip, ext/flex torque of the knee, and pla/dor flexion torque of the ankle.

Table 1 The characteristic of subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Record (m)</th>
<th>Best (m)</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YT</td>
<td>2.05</td>
<td>2.31</td>
<td>1.80</td>
<td>70</td>
</tr>
<tr>
<td>HH</td>
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<td>HJ</td>
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<td>2.12</td>
<td>1.74</td>
<td>60</td>
</tr>
<tr>
<td>KK</td>
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<td>2.16</td>
<td>1.87</td>
<td>68</td>
</tr>
<tr>
<td>ES</td>
<td>2.00</td>
<td>2.10</td>
<td>1.91</td>
<td>72</td>
</tr>
<tr>
<td>YD</td>
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<td>2.08</td>
<td>1.79</td>
<td>75</td>
</tr>
<tr>
<td>SK</td>
<td>1.85</td>
<td>1.96</td>
<td>1.76</td>
<td>62</td>
</tr>
<tr>
<td>OK</td>
<td>1.85</td>
<td>1.97</td>
<td>1.81</td>
<td>70</td>
</tr>
<tr>
<td>ST</td>
<td>1.75</td>
<td>1.81</td>
<td>1.80</td>
<td>63</td>
</tr>
<tr>
<td>WT</td>
<td>1.80</td>
<td>1.95</td>
<td>1.72</td>
<td>56</td>
</tr>
</tbody>
</table>

MEAN±SD 1.92±0.10 2.07±0.14 1.81±0.06 67.1±6.19
Figure 1: Three-dimensional joint torques of the hip, knee and ankle.

Figure 2 shows the averaged patterns of the joint torque (upper), joint angular velocity (middle) and joint torque power (bottom) of the hip joint of the takeoff leg. Thick line indicates average, and thin lines indicate standard deviation. The positive power indicates mechanical energy generation, and negative power is mechanical energy absorption.

The hip abduction torque was dominant in the whole takeoff phase. And the hip abd/add power was negative in the first half and positive in the second half. These indicate the hip abduction muscles exerted the power in eccentric contraction in the first half and in concentric contraction in the second half. We can roughly estimate how the external force, i.e. the ground reaction force, affects joint torque. Figure 3 showed stick pictures of the jumper and the ground reaction force. We can observe that in the back view the body leaned toward the center of the curve and the ground reaction force vector passed in the medial side of the hip joint of the takeoff. It implies that the hip abduction torque will be exerted to resist the large ground reaction force not to collapse the takeoff leg. In other words, if he had been able to and exert large hip abduction torque, the ground reaction force would have been larger.

Figure 3 Stick pictures of the takeoff motion and ground reaction force vector

Figure 2: Joint torque (upper), joint angular velocity (middle) and joint torque power (bottom) about the hip abduction / adduction and extension / flexion.

Figure 4 showed the relationship between the peak value of the hip abduction torque and the inward lean angle of the body, and Figure 5 showed the relationship between the peak value of the hip abduction torque and the run-up velocity. These significant relationships suggest that large run-up velocity and inward lean angle will require the hip abductor muscles exerting large force. This large abduction torque will be one of the characteristics of Fosbury-flop style because the remarkable inward lean of the body will not in the takeoff of straddle style and long jump.
The hip extension torque was dominant in the whole takeoff phase, with large variations in the first half. The first peak of extension torque (6.30±5.52 Nm/kg) appeared at 10% time and the second peak (6.08±2.72 Nm/kg) was shown at 20% time. Similar to the hip extensors the hip extensor muscles exerted positive power in the second half. The hip abd/add and ext/flex angular velocities were small in the first half. While the hip abduction and extension torques were very large. We can infer from this fact that one of the functions of the muscles around the hip joint may be stabilizing the hip joint of the takeoff leg in the first half against the large moment which is resulted from the impact force after touchdown, and generating large mechanical energy in the second half. And we can suggest that Fosbury-flop high jumpers should develop the abductors strength in the training.

Figure 6 shows averaged patterns of joint torque (upper), joint angular velocity (middle) and joint torque power (bottom) about the knee extension / flexion and ankle plantar / dorsi flexion.

The hip abduction torque was largest of all joint torques of the takeoff leg. The hip abduction torque of the takeoff leg in the long jump or the straddle technique should be much smaller than in the Fosbury-flop. As compared with the knee extensor muscles absorbed large mechanical energy after TD.

As shown in the side view of Figure 3, the vertical ground reaction force vector passed far away from the knee joint. This fact implies that the knee extension torque must be large to prevent collapsing of takeoff leg. Therefore, the function of the muscles about the knee joint, especially extensors will be absorbing impact force at TD and mechanical energy in most of takeoff phase. The knee extensor muscles have another important function will be exerting the vertical ground reaction force in the whole takeoff phase.

The ankle plantar flexion torque was as large as that of the other leg joints in the whole takeoff phase (peak value was 5.37±1.01 Nm/kg at 60% time). The ankle plantar flexors absorbed the mechanical energy in the first half and generated mechanical energy in the second half. The ankle plantar flexors absorbed impact force at TD and mechanical energy in the first half, which was similar to the knee extensors. In addition the large positive power in the second half contributed to raising the whole body. Therefore, it is said that the function of the ankle (plantar flexors) is absorbing mechanical energy in the first half and generating mechanical energy in the second half.

The hip abduction torque was largest of all joint torques of the takeoff leg. The hip abduction torque of the takeoff leg in the long jump or the straddle technique should be much smaller than in the Fosbury-flop. As compared with the
takeoff motion of the long jump or the straddle technique. Fosbury-flop technique with the curved run-up tends the jumper to lean laterally toward the center of the curve, which the ground reaction force vector will result in large hip adduction moment. This will be one of the reasons why the hip abduction torque was large in the Fosbury-flop technique. Although the important of the hip abduction muscles is not emphasized, the development of the hip abductor muscles will be important for flop jumpers to prevent collapsing the takeoff leg and hip injury.

The knee extension torque was smaller than the abduction and extension torques of the hip. But the knee joint angular velocity was larger than the hip abd/add and ext/flex angular velocities, and knee extensors had to absorb much of the mechanical energy and prevent collapsing of the takeoff leg. This will be a major function of the knee extensors in the takeoff phase.

It is easy to say from the joint torque power of the ankle that the function of the ankle plantar flexors will be absorbing the mechanical energy in the first half and generating the mechanical energy in the second half.

REFERENCES