BIOMECHANICAL STUDY ON THE MUSCLES' SPECIFIC ABILITIES OF TAKEOFF IN LONG JUMP

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Through using the method of biomechanical theory and experimental research, the paper studied the specific ability characteristics of takeoff leg muscles in long jump. Seven male long jumpers were required to complete running long jump. Kinematics and dynamics data were from biomechanical investigation. The 'Inverse Dynamics' method was used to calculate the muscles moment of hip, knee and ankle of the takeoff leg. The result showed that the ability of quick eccentric contraction of hip was important in takeoff. The knee was shown the characteristics of 'fore-support push' in take off. The ability of concentric contraction of knee's extensors played a very important part in getting vertical velocity, the larger peak of knee flexion moment emerged in earlier takeoff phase that indicated the knee flexion muscles actively contracted in this period.

KEY WORDS: long jump, takeoff, muscle, biomechanics

INTRODUCTION: A long jump is composed of four parts: the run up phase, the takeoff phase, the flight phase and the landing phase, among which the takeoff is regarded as the most important one, because the body gains most of its vertical velocity in this phase. Long jumpers need high velocity in the takeoff. The time for elite athletes for this is about 0.1 s - 0.13 s, and the velocity of body's center of gravity (COG) is about 9-11m.s^{-1} in this period (James et.al. 1986, 1990; Lees et al. 1994; Coh et al. 1997). The specific characteristics of long jump determine the contraction type and characteristics of lower extremity muscles in takeoff. So muscles' specific abilities during takeoff is very important for long jumpers' performance.
The purposes of this study using the methods of biomechanical theory and experimental research is to study the specific ability characteristics of takeoff leg muscles in long jump, to determine the varied characteristics of the muscles' moments of hip, knee, ankle and the relations between them and joints angle, to analyze muscles contraction type, and to approach the muscles' specific ability characteristics, so as to provide some beneficial proposals for long jumpers' training.

METHODS: Seven male college student long jumpers (ages: 20.57 ± 0.53 y, heights: 1.73±0.02 m, weights: 66.61 ± 1.78 kg, best achievements: 7.02 ± 0.32 m, present achievements: 6.83 ± 0.34 m) as research subjects were required to complete running long jump take-off. One camera (JVC9800, 100 Hz) was used to record the take-off, and ground reaction force (GRF) data was recorded by a floor-mounted force platform (500 Hz, Kistler 9281B). The kinematic and kinetic data were synchronized using an LED interfaced to the vertical output of the force plate. Seven valid samples were recorded.
Analysis methods: 2D kinematics data of body were analyzed and processed using SIMI MOTION software. The data were smoothed (cubic spline, standard error = 0.001), and 3D GRF and center of pressure were obtained from the force platform software. The lower extremity was simplified to three rigid segments: thigh, shank and foot. The segment mechanical parameters were assumed constant, joints were frictionless hinges, and the net actions of muscles were represented across each joint individually. According to dynamical laws and experimental results, the inverse dynamics method (Winter 1979) was used to calculate the muscles moment of hip, knee and ankle of the takeoff leg. Dempster's (1955) data were used for inertia parameters. The kinematic data and the ground reaction force data were interpolated (cubic spline) to 1000Hz in order to match with them each other. The calculation was programmed by Quick Basic 4.5 language in PC586.
SPSS 10.0 for Windows Software was used to analyze and process the data, while Microsoft Excel 2000 was used to draw the curves. The data presented in the text were mean ±

standard deviation ($\bar{x} \pm SD$), and in the figures were mean ($\bar{x}$). The sample size was seven. The unit of moment was N·m per-kilogram body weight (N·m/kg), and the take-off time was normalized time (%).

RESULTS: The Figure 1, 2 and 3 showed the joint angle changes of hip, knee and ankle in the takeoff, respectively. The Figure 4 was the results of joint moment of hip, knee and ankle.

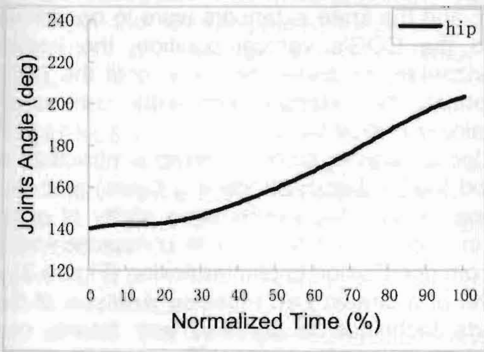

Figure1 The angle of hip in the takeoff.

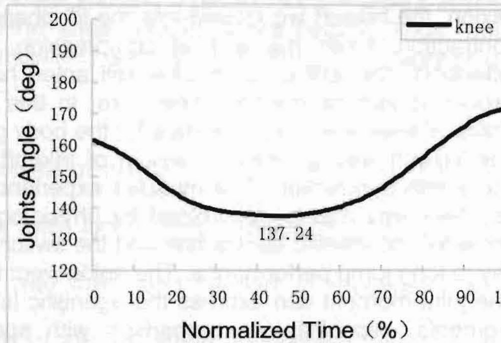

Figure 2 The angle of knee in the takeoff.

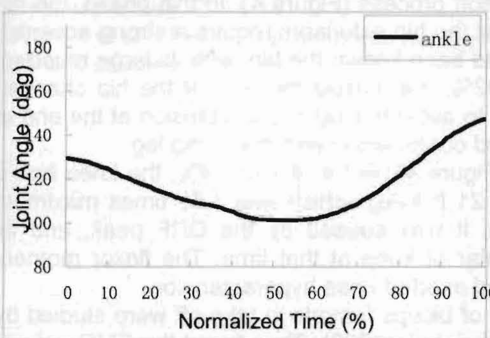

Figure 3 The angle of ankle in the takeoff.

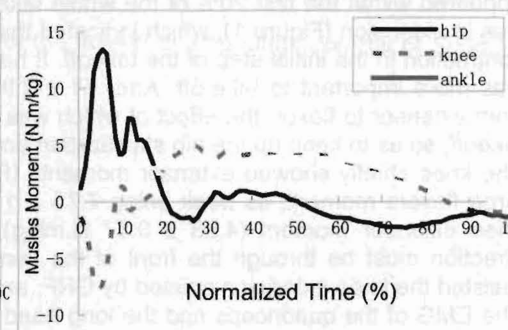

Figure 4 The moment of hip, knee, ankle in the takeoff.

DISCUSSION: The joint angle of hip was continuously increased during the takeoff (Figure 1). It indicated the hip hardly participated in compression, which meant the extensors of hip must have strong eccentric contraction ability, especially in earlier the takeoff phase, so as to resist the GRF. Comparatively, the compression process was mainly completed by knee (Figure 2). Many researchers regarded the magnitude of change in knee angle as a symbol of good or bad ability of the lower extremity in compression (James et.al. 1986, 1990; Lees et.al. 1994; Coh et.al. 1997). Lees et.al. (1994) reported the results of 27 elite male long jumpers: the angle of maximum flexion of knee was 144.1° ± 5.14°, range of knee angle was 21.8° ± 1.24°. Our results were 137.24° ± 6.19° and 24.26° ± 1.26°, respectively. Our subjects' compression abilities were lower. If the maximum knee compression was regarded as a criterion of the ability of take off leg, the extensors' eccentric contraction of the knee was very important within 40% earlier takeoff time (Figure 2).

If the instant of knee maximum flexion is considered as a line of demarcation between compression and lift in takeoff, we found this time emerged before the COG reached vertical position (the line between COG and press center under feet of the take off leg is vertical with ground) (Table 1).

Table 1 The time of knee angle and COG vertical position.

Max knee flexion (%)	COG vertical position (%)
49.39±5.61	62.53±5.23

Compression of the takeoff leg had ended before the COG reached the vertical position, namely, presented the characteristics of 'fore-support push'. After the end of maximum knee flexion, the takeoff leg moved into the lift phase, and the knee extensors were in concentric contraction. From the end of compression to the COG's vertical position, the knee's extensors' concentric contraction still acted horizontally to brake the body, until the COG exceeded vertical position. Therefore, in this phase, the extensors concentric contraction ability of knee was very important for the body gaining vertical velocity.

The takeoff was a typical example of takeoff leg's muscles from eccentric contraction to concentric contraction. The muscles experienced SSC (Stretch-Shortening Cycle) process; its effect was mainly determined by physiological factors. So, the muscles ability of quick eccentric, concentric contraction and the switch in velocity from eccentric to concentric was a key to long jump performance. The ankle went from dorsiflexion to plantar flexion (Figure 3).

The joint moment can express the agonistic level of a certain joint muscles. Analysis of the moments, especially in comparison with sports technique in success and failure, can quantitatively reflect the active condition and characteristics of muscles (Mihajlov et al., 1982). When the takeoff foot landed, the hip first displayed large extensor moments, which appeared within the first 20% of the whole takeoff process (Figure 4). In this phase, the hip was in extension (Figure 1), which indicated that the hip extensors require a strong eccentric contraction in the initial step of the takeoff. It had been known the hip, with its large muscles, was more important to take-off. After 51 ± 3.92%, the muscle moment of the hip changed from extensor to flexor, the effect of which was to avoid the hip hyperextension at the end of takeoff, so as to keep up the hip stabilization and coordination with the swing leg.

The knee chiefly showed extensor moments (Figure 4). But in the first 8%, the knee had a large flexors moment, its peak being 7.75 ± 1.21 N.m/kg, which was 1.58 times maximum knee extensor moment (4.88 ± 0.87 N.m/kg), It was caused by the GRF peak, and its direction must be through the front of the center of knee at that time. The flexor moment resisted the knee extension caused by GRF, and averted knee hyperextension.

The EMG of the quadriceps and the long head of biceps femoris in take-off were studied by Seluyanov et al. (1983). They found the EMG actions of the opistho-femur muscles were enhanced in the first phase of take-off, meanwhile the quadriceps, its antagonist, was attenuated (Figure 5). When the take-off leg had to resist the GRF impact in landing, the opistho-femur muscles were highly active, which suggested that the knee was in active flexion at that instant. The large flexor moment (Figure 4) is important to long jumpers. Long jumpers' injuries (and sprinters) resulting from take-off were mostly caused by limited opistho-femur muscle strength, which has implications for training.

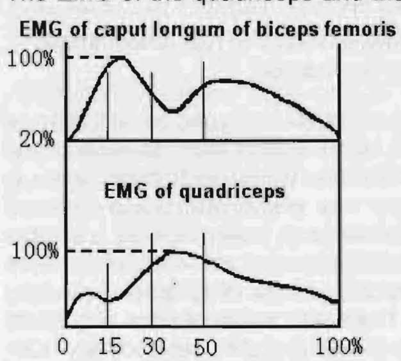

Figure 5 The EMG of the quadriceps and the caput longum of biceps femoris in take-off (from Seluyanov et al. 1983)

The ankle chiefly presented extensors moment (Figure 4).

The joint muscle moment is a comprehensive representation for all muscles that cross the joint. It can directly reflect the active characteristic and function in takeoff so that help the development of technique and strength training.

CONCLUSION: In the takeoff of long jump, the hip hardly participated in compression. It was mainly completed by knee. The magnitude of its angle can show a good or bad ability of the knee muscles in compression. The knee was shown the characteristics of 'fore-support push' in take off. In this phase, the concentric contraction ability of knee extensors was very important for generating vertical velocity. The extensor moment of hip plays a very important part. The hip had large extensor moments in the first 20% of the takeoff phase. Its ability in eccentric contraction was more important. The knee showed a larger flexor moment in the first 8% of the takeoff phase, which means the knee was in active flexion. Thus, the development of knee flexors (opistho-femur muscles) strength contributed to decreased injuries.

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