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2-8

The running motion analysis by the angular momentum and the driving power

○ Kyo Sato (Nihon University), Kazuhito Misaji (Nihon University)

1. Introduction

It is very important that we analyze a burden for the human musculoskeletal. It is for performance improvement at the time of the motion and the prevention of the injury. Actually, the motion analysis by the motion capture for top athletes is carried out. In addition, the civic interest in sports is increasing because the Tokyo Olympics are held in 2020. And the running citizen's runners run for a hobby and healthy intention is increasing year by year [(1)]. With it, it is increasing to the lower limbs disorder by the excessive running of the citizen runner [(2)]. On the other hand, the injury at the time of the running of the athlete greatly influences the sports life of the person. Logical effective training is necessary for the running performance gain in various sports and the record improvement in track and field. It is similar about the prevention of the injury.

Specifically, it is that we quantify a burden degree and the fatigue degree of each muscle of the lower leg joint rotation to participate in running motion. We can think that it is essential for a running performance gain and an effective training method. Therefore, we use the driving power to evaluate motion performance of cars and the angular momentum to express intensity of the motion. We consider a burden degree and the fatigue degree of each muscle of around the lower limbs joint in the running motion of person. We inspect value and usefulness of the method to evaluate the exercise that we showed this time from a consideration result.

2. Analysis method

2・1 Calculation of muscle activation

We used lower limbs musculoskeletal model of SCOT L.DELP and others show to figure 1 [(3)], to estimate muscle activation of around each muscle of each joint. There were a lot of models based on the model of Hill about the muscle model. We used that F.E.Zajac suggested the muscle model that we showed to figure 2,3 in this subject that I showed to figure two or three by the main subject suggested [(4)]. We are using the value of SCOT L.DELP and others about the parameter below. The maximum isometric contraction of the muscle of the number i is F_0^i. The length of the muscle of the number i is l_i. The angle with the muscle to attach to the tendon is ϕ. The muscle activation estimate calculation was used SIMM that the musculoskeletal model motion analysis software [(5)].

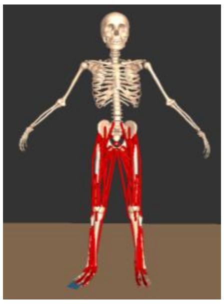


Fig.1 Lower limbs musculoskeletal model

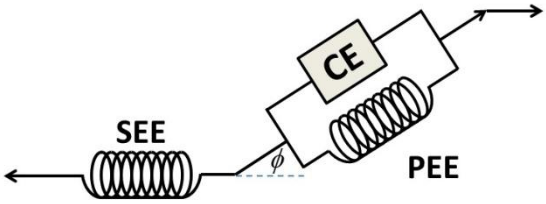


Fig.2 Hill type model

We input a joint position and posture data at the time of the running. Each joint angle is calculated by inverse kinematics. The driving torque of around each joint is calculated by inverse dynamics. The muscle activation of each muscle is calculated using a three dimensional musculoskeletal model of that we showed before. We show a process to calculate below.

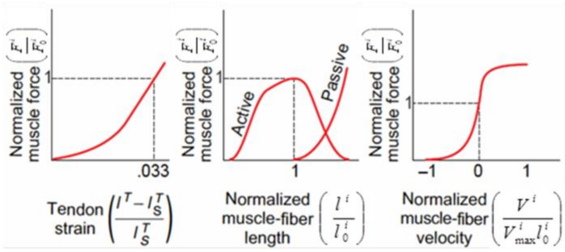


Fig.3 Mechanical properties of muscle

角運動量と駆動パワーを用いたランニング運動解析

佐藤 喬，見坐地 一人

We satisfy the combination of α_i $(0 \le \alpha_i \le 1)$ that an equation (1) and that the square sum.

$$\sum_{i=1}^{n}\left(\alpha_i \cdot F_0^i\right) r_{i,j} = M_j^* \qquad (1)$$

F_0^i is the maximum isometric contraction power of the muscle of the number i . M_j^* is the driving torque of around the joint of the number j that we calculate using the motion capture data. $r_{i,j}$ is the moment arm length of the muscle of the number i for around the joint of the number j . The moment arm length $r_{i,j}$ is calculated by an equation (2).

$$r_{i,j} = \frac{dl_i}{d\theta_j} \qquad (2)$$

l_i is the length of the muscle of the number i . θ_j is the angle of around the joint of the number j .

2・2 Calculation of angular momentum of each muscle

We substitute the muscle activation α_i , the maximum isometric contraction power F_0^i of the number i , and the moment arm length $r_{i,j}$ of the muscle of the number i for around the joint of the number j below an equation (3). Then, we calculate the driving torque $M_{i,j}$ by each muscle of around the joint of the target.

$$M_{i,j} = \alpha_i \cdot F_0^i \cdot r_{i,j} \qquad (3)$$

An equation (4) is gotten by using $M_{i,j}$.

$$I_{i,j} \cdot \ddot{\theta}_{i,j} = M_{i,j} \qquad (4)$$

$I_{i,j}$ is the inertia moment of the muscle of the number i for around the joint of the number j . $\ddot{\theta}_{i,j}$ is the angular acceleration of the muscle of the number i for around the joint of the number j . This inertia moment $I_{i,j}$ is defined as the constant. Then, an equation (5) is gotten by to definite integrate both side of an equation (4) in a cycle (from t_1 to t_2) of the motion. An equation (5) is angular momentum of the muscle of the number i of around the joint of the number j .

$$I_{i,j}\int_{t_1}^{t_2} \ddot{\theta}_{i,j}dt = \int_{t_1}^{t_2} M_{i,j}dt$$

$$I_{i,j} \cdot \dot{\theta}(t_2) - I_{i,j} \cdot \dot{\theta}(t_1) = \int_{t_1}^{t_2} M_{i,j}dt \qquad (5)$$

2・3 Calculation of driving power of around each joint

An equation (6) is gotten by using M_j . P_j is the driving power of around the joint of the number j .

$$P_j = \frac{1}{2(t_2 - t_1)}\int_{\theta_1(t_1)}^{\theta_2(t_2)} M_j d\theta \qquad (6)$$

3. Experimentation

3・1 Experimentation summary

We input measured joint positions and the motion date into the created three - dimensional skeletal model. Each joint angle is calculated by the inverse kinematics calculation. We calculate the driving torque of each joint by the inverse kinematics calculation. We estimate the muscle activation of each muscle by using a three - dimensional musculoskeletal model. The muscle activation is estimated by using EMG data as the guide. This EMG data is measured by using a telemetry electromyograph MQ16 (below, EMG). Then, we calculate the driving power of around each joint by the driving power of around each joint calculated by a three - dimensional musculoskeletal model. In addition, we calculate the driving torque of necessary each muscle to calculate the angular momentum of the each muscle by a three - dimensional musculoskeletal model.

We show about the experiment contents that actually executed in the next clause.

3・2 Experimentation content

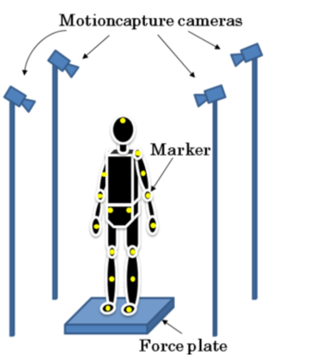
1) Create 3D skeletal model

We decide the central position central of the joint and the segment length by the position of the reflection marker that pasted to a subject.

We created a three - dimensional musculoskeletal model of a subject by calculating the posture of the segment that based on the coordinate definition.

2) Measurement of motion data

As figure 4, we surround a subject with capture cameras and record the motion of a subject on the force plate. The motion of the subject of this time is the running motion. The condition of this time is that the speed of the motion to raise the leg and the motion to lower the leg is two patterns. They are eight times in five seconds and ten times in five seconds. We show a state of the motion that a subject executed in figure 5.



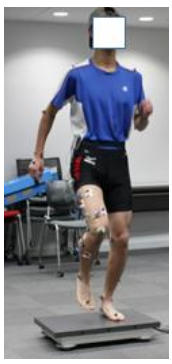


Fig.4 Labware positions (left)

Fig.5 Movement of the subject (right)

3) Measurement of EMG data

We attach the EMG to a subject, and measure the EMG data of each muscle. We calculate the muscle activation of each muscle from this EMG data. The attaching part of the EMG is Rectus femoris muscle, vastus medialis muscle, vastus lateralis muscle, tibialis anterior muscle, hamstring, gastrocnemius muscle (medialis・lateralis). We show the attaching part of the EMG in figure 6.

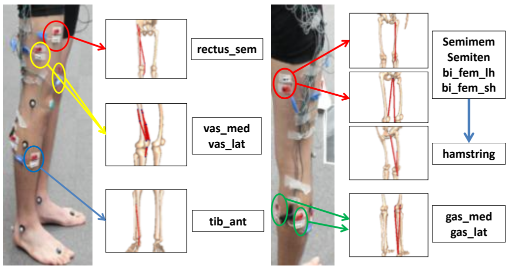


Fig.6 Position of paste the electromyograph

4. Analysis result

4・1 Inspection of 3D musculoskeletal model

We show the torque that calculated by inverse dynamics analysis by a method of 2・2 using the three - dimensional musculoskeletal model shown in figure 1. This torque is the torque of around the joint for the running motion. As an example, we show the torque of around the hip joint in fast motion and slow motion in figure 7. From these results, we understand that this three - dimensional musculoskeletal model is enough analysis precision.

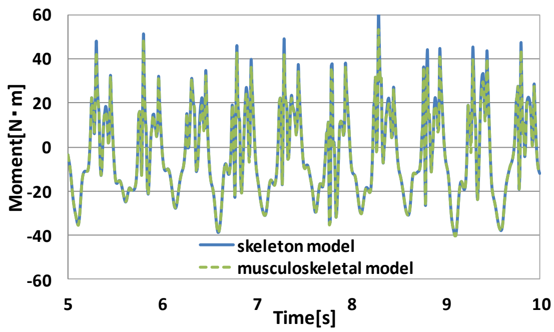


Fig.7 Torque of hip joint in fast motion

4・2 Driving power of around each joint

We calculate the driving power of around the hip joint and the knee joint from the equation (7). In addition, we divide into the motion to raise the leg and the motion to lower the leg in the motion of the fast running motion and the slow running motion each, and calculate each driving power. We show it in figure 8. From the figure 8, about the driving power of around each joint, the fast motion is bigger than the slow motion. Especially, about the hip joint, the driving power in the motion to raise the leg is nearly four times. In addition, about the driving power of the hip joint in the fast motion, the motion to lower the leg is smaller than the motion to raise the leg. But, it is the reverse in the slow motion. About the knee joint in the fast motion, the driving power in the motion to lower a leg is a little over two times of the driving power in the motion to raise a leg. About the knee joint in the slow motion, the driving power in the motion to lower a leg is nearly a half of the driving power in the motion to raise a leg.

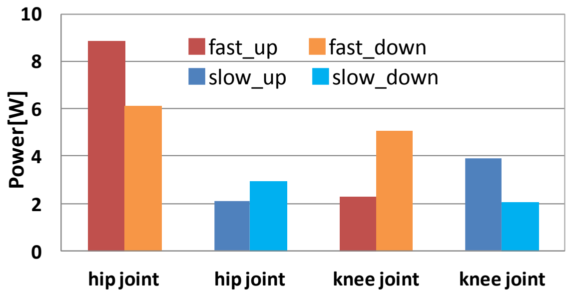


Fig.8 Driving power of around the joint

4・3 Angular momentum of around each muscle

About the driving torque of around the hip joint and the knee joint that calculate from the equation (4), we show the driving power of around the knee joint by the biceps femoris muscle (long head) in the fast motion in a red line in figure 11 as an example. We make a function of this driving torque of around the knee joint by a polynomial of six order. We show a graph of the function in a black line of the figure 9, and show the function expression in the equation (8). We understand that the precision of the function is good from the figure 9.

$$M = 105833t^6 - 173977t^5 + 108420t^4 - 30821t^3 + 3632.6t^2 - 97.918t + 3.2021 \qquad (8)$$

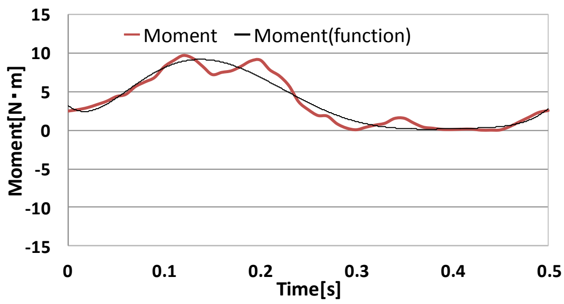


Fig.9 Indication of torque by function

We substitute these function expression of each muscle for the equation (5). We divide into the motion to raise of a leg and the motion to lower of a leg, and calculate the angular momentum of all muscle that involve to the driving torque of around the each joint. We show the angular momentum of each muscle of around the hip joint in the figure 10. Similarly, we show the angular momentum of each muscle of around the knee joint in the figure 11.

From the figure 10, in the fast motion of around the hip joint, the angular momentum of each muscle in the motion to raise the leg is a little over two times of the angular momentum of each muscle in the motion to lower the leg. In addition, about the angular momentum of the hip joint by the muscle in the front side of the thigh (rectus femoris muscle), we understand that the angular momentum in the slow motion is bigger than the angular momentum in the fast motion. Conversely, about the angular momentum of around the hip joint by the muscle in the back side of the thigh (semimembranosus muscle, semitendinosus muscle, biceps femoris muscle (long head)), we understand that the angular momentum in the fast motion is bigger than the angular momentum in the slow motion (about the motion to raise the leg).

From the figure 11, about the angular momentum of around the knee joint by the muscle in the front side of the thigh (rectus femoris muscle, vastus medialis muscle, vastus lateralis muscle), we understand that the angular momentum in the slow motion is bigger than the angular momentum in the fast motion (about the motion to raise the leg). In addition, we understand that biceps femoris muscle (short head) work intensively from the angular momentum. Conversely, about the angular momentum of around the knee joint by the muscle in the back side of the thigh (semimembranosus muscle, semitendinosus muscle, biceps femoris muscle (long head)), we understand that the angular momentum in the fast motion is bigger than the angular momentum in the slow motion (about the motion to raise the leg).

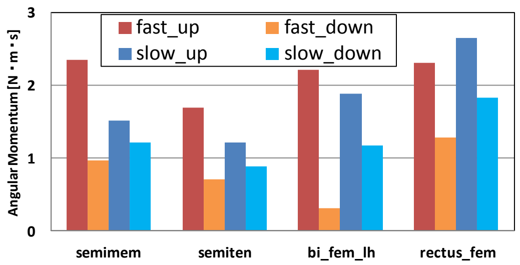


Fig.10 Angular momentum of around hip joint

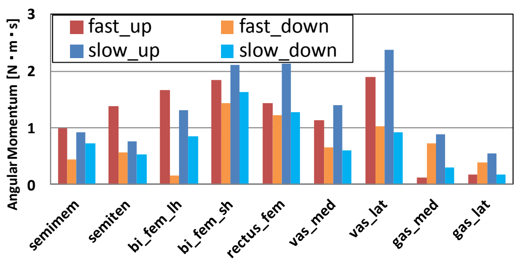


Fig.11 Angular momentum of around knee joint

5. Conclusion

In this paper, we used the driving power to evaluate the motion performance and the angular momentum to express intensity of the motion. By them, we can consider that becomes possible following things by the method that evaluate quantitatively the motion

1) In the running motion that we showed in this paper, we can quantify the motion performance of the subject, because we can calculate quantitatively the driving power of around the joint.
2) We can quantify the fatigue degree of each muscle by the motion, because we can calculate quantitatively the angular momentum of around each joint of each muscle.
3) We can consider the better training method to improve the performance at the time of the motion and to prevent the injury by analyzing the result of (1) and (2).

To apply the evaluation method that we suggested for various motion, we analyze about the motion in the upper limb such as the bending and stretching of the elbow. Then, we want to inspect value and usefulness of the method more.

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