A Study on Lower-Limb Muscle Activities during Daily Lower-Limb Motions

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Abstract

The lower-limb muscle activities during the daily lower-limb motions such as sitting down, standing up, squatting, walking, ascending and descending stairs motions have been studied to enable power-assist robotic systems to estimate human lower-limb motions based on muscle electromyographic (EMG) signals. The relationship between the lower-limb motions and the activity levels of main muscles concerning the daily lower-limb motions are analyzed in this study. The human intention for lower-limb motion can be estimated based on the activation pattern of lower-limb muscles. The analyzed results would be used to design the controllers of the lower-limb power-assist robotic systems for physically weak persons.

1. Introduction

The lower-limb motions are very important for the human daily activities, such as sitting down, squatting, walking, ascending and descending stairs. It is sometimes difficult for physically weak persons (elderly, disabled, and injured persons) to perform daily lower-limb motions. In the society in which the birthrate is decreasing and the aging are progressing, it is important that physically weak persons are able to take care of themselves. It is also important for them to use their own body functions to keep them healthy. Recently, power-assist robotic systems have been developed to assist physically weak persons' daily life motions [1]-[12]. These power-assist robotic systems are mainly activated based on the user's electromyographic (EMG) signals which directly reflect the muscle activity levels of the user. The EMG signals are important information for power-assist robotic systems to understand how the user intends to move. Therefore, it is important to analyze the relationships between the human lower-limb motions and related muscles activities to perform the power-assist of the lower-limb motion. In this study, experiments were preformed to figure out the relationship between the human lower-limb motions

and the related muscles activities.

In the experiment, sitting down, squatting, ascending and descending stairs and walking motions were performed as the daily lower-limb motions. The angle of each joint was measured by the motion capture system and the EMG signals of the related muscles were also measured to figure out the relationship between them. The analyzed results would be used to design the controllers of the lower-limb power-assist robotic systems for physically weak persons.

2. Human Lower-Limb Motion

Agonist-antagonist muscles exist in human joints such as elbow, hip, wrist, knee, ankle, etc. Such human joint is usually activated by several muscles. Some of muscles are bi-articular muscles and the others are uni-articular muscles. Flexion/extension motion of human hip joint is mainly actuated by the muscles of iliacus, psoas, rectus femoris, tensor fasciae latae, biceps femoris, and semitendinossus [14]. Many of these muscles are bi-articular muscles, such as the muscle of rectus femoris biceps femoris and semitendinossus, since they work on both hip joint and knee joint. Flexion/extension motion of human knee joint is mainly actuated by the muscles of biceps femoris, semitendinossus, gastrocnemius, rectus femoris, vastus lateralis and vastus medialis. Most of these muscles are bi-articular muscles also, such as the muscles of biceps femoris, semitendinossus, and rectus femoris since they work on both hip joint and knee joint, and the bi-articular muscle of gastrocnemius work on both knee joint and ankle joint. Dorsiflexion/plantarflexion motion of human ankle joint is mainly actuated by the muscles of gastrocnemius, soleus, and tibialis anterior. Here, only gastrocnemius is the bi-articular muscle and it work on both knee joint and ankle joint. The muscle activity levels can be described by EMG signals.

In order to analyze the EMG signals, features should be extracted from the raw EMG data. Root mean square (RMS) has been applied as a feature extraction method of the EMG signals in this study. The equation

of RMS is written as:

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} v_i^2} \qquad (1)$$

where v_i is the voltage value at ith sampling and N is the number of the samples in a segment. N is set to be 100 and the sampling frequency is set to be 2,160 Hz. An example of raw EMG signal and its RMS are shown in Fig. 1.
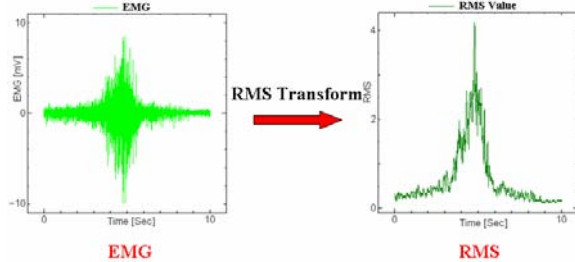

Fig. 1 Example of EMG and RMS

3. Methods and Tools

In order to obtain the relationships between the human lower-limb motions and related muscles' activities, the experiments were performed with a healthy young male (27 years old) subject. In the experiment, sitting down (the process of the human from standing posture to sitting posture and return to standing posture), squatting (the process of the human from standing posture to squatting posture and return to standing posture), ascending and descending stairs, walking (change the forward direction) motions were performed as daily lower-limb motion as shown in Fig. 2. The kinematics (angles of each joint) of the lower-limbs of human subject during daily activities were measured using the motion capture system (Vicon MX+, VICON) [13] at a sampling frequency of 60 Hz. Reflective markers were attached to subjects at key anatomical locations as shown in Fig. 3. Human subject was instructed to perform of the same lower-limb motion three times. EMG signals of the related muscles (ch.1: tensor fasciae latae, ch.2: rectus femoris, ch.3: vastus lateralis, ch.4: tibialis anterior, ch.5: adductor longus, ch.6: gracilis, ch.7: vastus medialis, ch.8: gluteus medius (posterior part), ch.9: gluteus maximus, ch.10: biceps femoris – short head, ch.11: gastrocnemius, ch.12: soleus, and ch.13: semitendinosus) for above activity were measured. The location of electrodes on lower-limb muscles is shown in Fig. 4.

Fig. 2 Human daily activities

Fig. 3 Location of markers

CH1:Tensor fasciae latae
Ch2:Rectus femoris
Ch3:Vastus lateralis
Ch4:Vastus medialis
Ch5:Adductor longus
Ch6:Gracilis
CH7:Tibialis anterior
CH8:Gluteus medius
CH9:Gluteus maximus
CH10:Biceps femoris
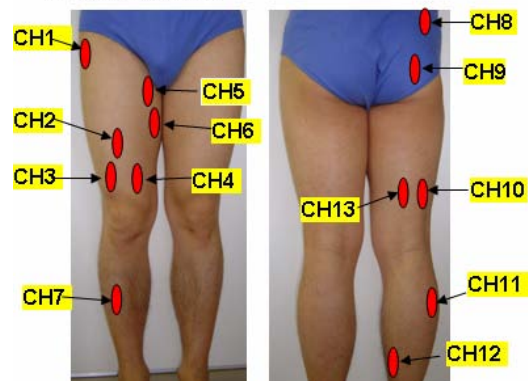CH11:Gastrocnemius
CH12:Soleus
CH13:Semitendinosus

Fig. 4 Location of electrodes

4. Experimental Results

The experimental results of the squatting, and standing up motions are shown in Fig. 5. It shows the

relationship between the EMG levels and angles of hip and knee motions relate to squatting and standing up motions. In the figure, the squatting motion and standing up motions are shown in region A and region B, respectively.

Fig.6, Fig.7, Fig.8 and Fig.9 show the experimental results of sitting down, walking, ascending stairs and descending stairs motions, respectively.
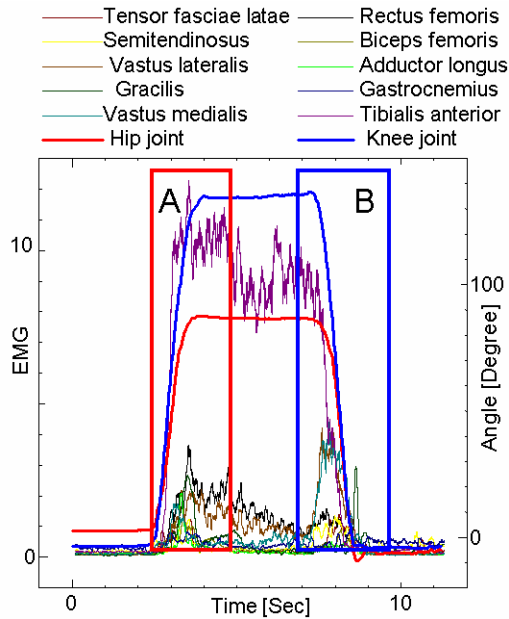

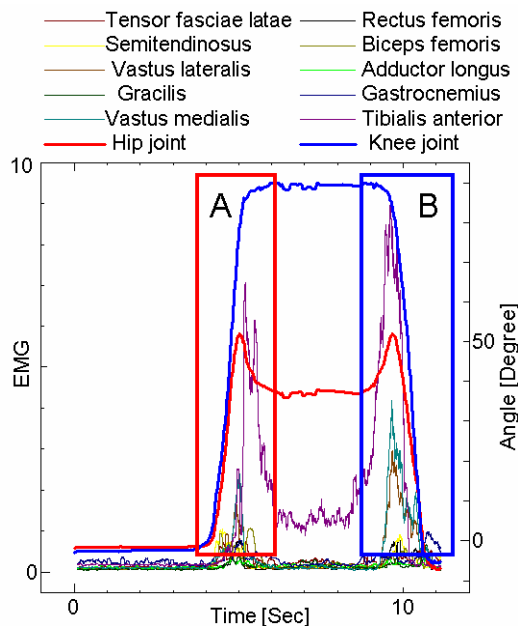Figure 5 Squatting and stand up motions
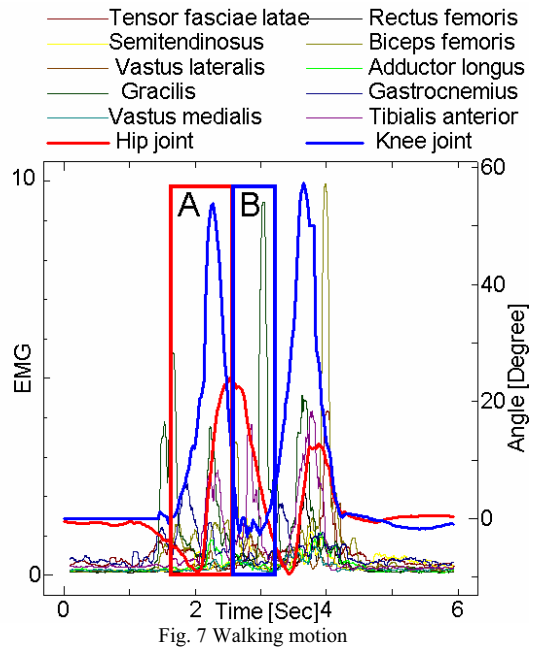

Fig. 6 Sitting down and standing up motions
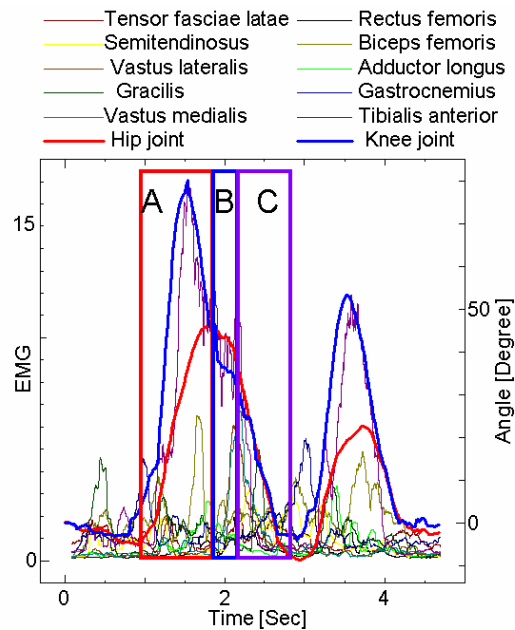

Fig. 7 Walking motion

Fig. 8 Ascending stairs motion

4. Discussion

In this section we describe the several daily motions such as squatting, sitting down, walking, ascending stairs and descending stairs motions and how to figure out the motions using EMG signals of the related muscles.
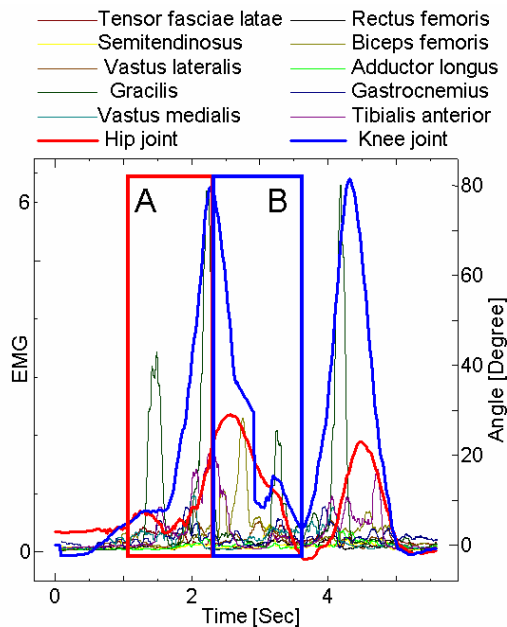
Fig. 9 Descending stairs motion

4.1 squatting and stand up motion

Squatting motion (region A in Fig. 5) is generated when hip joint, knee joint and ankle joint flex together. Muscles of tensor fasciae latae, adductor longus, and rectus femoris are mainly activated for hip joint flexion, muscles of gracilis, biceps femoris, semitendinosus and gastrocnemius are mainly activated for knee joint flexion, and muscle of tibialis anterior is mainly activated for ankle joint dorsiflexion. On the other hand, standing up motion (region B in Fig. 5) is generated when hip joint, knee joint and ankle joint extend together. Muscles of gluteus medius-posterior part, gluteus maximus and semitendinosus are mainly activated for hip joint extension, muscles of rectus femoris, vastus laterlis and vastus medialis are mainly activated for knee joint extension, and muscle of gastrocnemius is mainly activated for ankle joint plantar flexion (extension).

In the motion of region A (Fig. 5), the muscles of tensor fasciae latae, adductor longus, rectus femoris, gracilis, biceps femoris – short head, and semitendionosus are activated simultaneously, especially the activity level of tensor fasciae latae, adductor longus and rectus femoris are high to flex the hip joint. Although some bi-articular muscles such as rectus femoris and semitendionosus are activated also for standing up, walking, ascending stairs and descending stairs motions, the squatting motion can be distinguished since the activity level of the uni-articular muscles (i.e., adductor longus and biceps femoris – short head) are high at the same time.

In the motion of region B (Fig. 5), the muscles of the tensor fasciae latae, rectus femoris, gracilis, semitendinosus, vastus laterlis, and vastus medialis are activated simultaneously, especially the activity level of adductor longus is low and that of vastus laterlis and vastus medialis are high to extend the knee joint. Although the rectus femoris and semitendinosus bi-articular muscles are activated also for squatting, walking, ascending stairs and descending stairs motions, the standing up motion is classified since the activity level of the uni-articular muscles (i.e., vastus laterlis and vastus medialis) are high at the same time.

4.2 Sitting down and standing up motion

Figure 6 shows the joint angles for hip and knee joint, and EMG signals for active the muscles of hip and knee joint, when subject performs sitting down and standing up motions. Sitting down motion (Region A in Fig. 6) is generated when hip joint, knee joint and ankle joint flex together. Muscles of tensor fasciae latae, adductor longus, and rectus femoris are mainly activated for hip joint flexion, muscles of gracilis, biceps femoris, semitendinosus and gastrocnemius are mainly activated for knee joint flexion, and muscle of tibialis anterior is mainly activated for ankle joint dorsiflexion. On the other hand, standing up motion (Region B in Fig. 6) is generated when hip joint, knee joint and ankle joint extend together. Muscles of gluteus medius-posterior part, gluteus maximus and semitendinosus are mainly activated for hip joint extension, muscles of rectus femoris, vastus laterlis and vastus medialis are mainly activated for knee joint extension, and muscle of gastrocnemius is mainly activated for ankle joint plantar flexion (extension). Although the same muscles are activated when subject performs sitting down motion and squatting motion, the active levels of those muscles are different.

In the motion of region A (Fig. 6), the muscles of tensor fasciae latae, adductor longus, rectus femoris, gracilis, biceps femoris – short head, and semitendionosus are activated simultaneously. In this case, the activation level of tensor fasciae latae and adductor longus are smalller than that in region A in Fig. 5, and the activation level of rectus femoris is high. Although some bi-articular muscles such as rectus femoris and semitendionosus are activated also for standing up, walking, ascending stairs and descending stairs motions, the sitting down motion is classified since the activity level of the uni-articular muscles (i.e., adductor longus and biceps femoris – short head) are low. In region B (Fig. 6), the standing up motion is classified if the activity level of the uni-articular muscles such as vastus laterlis and vastus medialis are high.

4.3 Walking motion

Figure 7 shows the angles of hip and knee joints and EMG signals of the related muscles during walking motion of the subject. The motion of walking is mainly divided into two phases (swing phase and support phase). The swing phase is the behavior that the foot leaves the ground surface and the leg swings forward. The support phase is the behavior that the foot stays in contact with the ground surface and the body is supported by the leg. In the swing phase (region A in Fig. 7), the muscles of tensor fasciae latae, adductor longus, and rectus femoris are mainly activated for hip joint flexion. At the same time, the knee joint flexes from the extension position. The muscles of gracilis, biceps femoris, semitendinosus and gastrocnemius are mainly activated for knee joint flexion and the muscle of tibialis anterior is mainly activated for ankle joint dorsiflexion. In the support phase (region B in Fig. 7), the muscles of gluteus medius-posterior part, gluteus maximus and semitendinosus are mainly activated for hip joint extension. The muscles of rectus femoris, vastus laterlis and vastus medialis are mainly activated for knee joint extension and the muscle of gastrocnemius is mainly activated for ankle joint plantar flexion (extension).

In the phase of the region A (Fig. 7), tensor fasciae latae, adductor longus, rectus femoris, gracilis, biceps femoris, semitendinosus and gastrocnemius are activated simultaneously. However, the activity level tensor fasciae latae, adductor longus and rectus femoris is higher than that in region A in Fig. 5 and Fig. 6, when the foot leaves the ground surface. Although bi-articular muscles (i.e., rectus femoris, gastrocnemius and semitendionosus) are activated also for support phase in walking motion, squatting, sitting down, standing up, ascending stairs and descending stairs motions, the swing phase is classified since the activity level of the uni-articular muscles (i.e., adductor longus and biceps femoris-short head) are higher. In the phase of the region B (Fig. 7), tensor fasciae latae, rectus femoris, gracilis, semitendinosus, vastus laterlis and vastus medialis are activated simultaneously. In this case, the activity level of tensor fasciae latae, adductor longus and rectus femoris is smaller than that in region A (Fig. 7), and the activity level of vastus laterlis and vastus medialis is more than that in region B in Fig. 5 and Fig. 6. Although bi-articular muscles (i.e., rectus femoris and semitendinosus) are activated also for swing phase in walking, squatting, sitting down, ascending stairs and descending stairs motions, the support phase (region B in Fig. 7) is classified since the activity level of the uni-articular muscles (i.e., vastus laterlis and vastus medial) is higher.

4.4 Ascending stairs motion

Figure 8 shows the angles for hip and knee joints and EMG signals of the related muscles during the motion of ascending stairs. The subject ascends stairs of 12cm height and 40 cm width. The motion of ascending stairs is mainly separated into three phases. Phase 1 is the behavior that the foot is lifted from the stair surface and then the leg is lifted up and swung forward. Phase 2 is the behavior that leg is slightly lowered in order to establish contact of the foot with the next stair surface, after the foot is lifted up above the stair surface in phase 1. Phase 3 is the behavior that the foot contacts with the next stair surface and the body is lifted up. In phase 1 (region A in Fig. 8), the muscles of tensor fasciae latae, adductor longus, and rectus femoris are mainly activated for hip joint flexion. On the other hand, the knee joint flexes from the extension position. The muscles of gracilis, biceps femoris, semitendinosus and gastrocnemius are mainly activated for knee joint flexion. In phase 2 (region B in Fig. 8) and phase 3 (region C in Fig. 8), the muscles of gluteus medius-posterior part, gluteus maximus and semitendinosus are mainly activated for hip joint extension and the muscles of rectus femoris, vastus laterlis and vastus medialis are mainly activated for knee joint extension.

In the region A (Fig. 8), tensor fasciae latae, adductor longus, rectus femoris, gracilis, biceps femoris, semitendinosus and gastrocnemius are activated simultaneously. Since the leg must be lifted up higher than that in walking motion, the activity level of tensor fasciae latae, adductor longus and rectus femoris is higher than that in walking motion. Although bi-articular muscles (i.e., rectus femoris, gastrocnemius and semitendionosus) are activated also for squatting, sitting down, walking and descending stairs motions, the phase 1 (region A in Fig. 8) can be classified since the activity level of the uni-articular muscles (i.e., adductor longus, beceps femoris-short head) is much higher. In the region C (Fig. 8), tensor fasciae latae, rectus femoris, gracilis, semitendinosus, vastus laterlis and vastus medialis are activated simultaneously. Since the body must be lifted up, the activity level of tensor fasciae latae, adductor longus and rectus femoris is higher than that in standing up motion as shown in the region B in Fig. 5 and Fig. 6. The activity level of vastus laterlis and vastus medialis is also higher than that in region B in Fig. 5 and Fig. 6. Although bi-articular muscles (i.e., rectus femoris and semitendinosus) are activated also for walking, squatting, sitting down, ascending stairs and descending stairs motions, the phase 3 (region C in Fig. 8) can be classified since the activity level of the uni-articular muscles (i.e., vastus laterlis and vastus

medialis) is high.

4.5 Descending stairs motion

Figure 9 shows the angles for hip and knee joints and EMG signals of the related muscles during the motion of descending stairs. The motion of descending stairs is mainly separated into two phases. Phase 1 is the behavior that the foot leaves the stairs surface and then the leg is lifted up and swung forward. Phase 2 is the behavior that the foot contacts with the next stair surface. In phase 1 (region A in Fig. 9), the muscles of tensor fasciae latae, adductor longus, and rectus femoris are mainly activated for hip joint flexion. At the same time, the knee joint flexes from the extension position. The muscles of gracilis, biceps femoris, semitendinosus and gastrocnemius are mainly activated for knee joint flexion and the muscle of tibialis anterior is mainly activated for ankle joint dorsiflexion. In phase 2 (region B in Fig. 9), the muscles of gluteus medius (posterior part), gluteus maximus and semitendinosus are mainly activated for hip joint extension. The muscles of rectus femoris, vastus laterlis and vastus medialis are mainly activated for knee joint extension.

In the region A (Fig. 9), tensor fasciae latae, adductor longus, rectus femoris, gracilis, biceps femoris, semitendinosus and gastrocnemius are activated simultaneously. However, the activity level of tensor fasciae latae, adductor longus and rectus femoris is smaller than that in the other motions such as squatting, sitting down, walking and ascending stairs motions. Although bi-articular muscles (i.e., rectus femoris, gastrocnemius and semitendionosus) is also activated for squatting, sitting down, walking and ascending stairs motions, the phase 1 (region A in Fig. 9) can be classified since the activity level of the uni-articular muscles (i.e., adductor longus and biceps femoris-short head) is low. In the region B (Fig. 9), the activity level of tensor fasciae latae, adductor longus, vastus laterlis and vastus medialis is smaller than that in the other motions. The phase 2 (region B in Fig. 9) can be classified since the activity level of the uni-articular muscles (i.e., vastus laterlis and vastus medialis) is low.

5. Conclusions

In this research, the lower-limb muscle activities during the daily lower-limb motions such as sitting down, standing up, squatting, walking, ascending and descending stairs motions have been studied. The relationship between the lower-limb motions and the activity levels of main muscles concerning the daily lower-limb motions are analyzed. The results of analyzed could be used to design the controllers of the lower-limb power-assist robotic systems for physically weak persons.

Acknowledgment

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