Biomedical Science and Engineering, 2015, Vol. 3, No. 1, 9-14
Available online at http://pubs.sciepub.com/bse/3/1/3

DOI:10.12691/bse-3-1-3

EMG Signals for Co-Activations of Major Lower Limb Muscles in Knee Joint Dynamics

Md. T. I. Khan*, T. Kurita

Department of Advanced Technology Fusion, Graduate School of Science & Engineering, Saga University 1 Honjo-machi, Saga, Japan
*Corresponding author: khan@me.saga-u.ac.jp

Received April 30, 2015; Revised June 03, 2015; Accepted June 09, 2015

Abstract Integrity analysis of knee joint involves a detail study of several anatomical parts such as bones, cartilage, tendons etc. Any disorder or damage of these anatomical parts causes severe knee disease, like osteoarthritis (OA), which is generally found in an increasing tendency, particularly, in an aged society. Although, the reasoning of OA in knee joint is not concentrated to the present paper, however, the influences of related muscular co-activities to knee flexor-extensor actions are figured out in the present research. Particularly, the muscle reflection actions of two major skeletal muscles at knee are investigated with aging functions of participants. EMG signals have been collected from the vastus lateralis and the gastrocnemius for the dynamic movements (standing and sitting) of knee joint. Aged participants (over 60 years old) and young participants (20 -25 years old) joined the experiments. Data have been collected from both legs, however, analysis is shown only for left leg in this paper. EMG sensors and the related devices of the present sensing technique have been installed based on the instructions of Biometric Co. Ltd. Result show that the voltage amplitudes of EMG signals fluctuate largely with increasing ages and thus, the result focuses on the postural effectiveness in muscular activities for the stability challenges of knee joints in their movements.

Keywords: *EMG signals; osteoarthritis, dynamic analysis of knee joint, lower limb muscles.*

Cite This Article: Md. T. I. Khan, and T. Kurita, "EMG Signals for Co-Activations of Major Lower Limb Muscles in Knee Joint Dynamics." *Biomedical Science and Engineering*, vol. 3, no. 1 (2015): 9-14. doi: 10.12691/bse-3-1-3.

1. Introduction

Muscles and tendons actuate movements of knee joint by developing and transmitting appropriate forces to the human skeleton. Therefore, the maintenance of the dynamic stability of knee joint is dependent upon the muscular reflex activities around the knee joint. The responses of muscle reflex upon perturbations of knee joint play the important roles in the dynamic alignments and stabilities of musculoskeletal structures [1].

Osteoarthritis (OA) is the most common type of arthritis. It is well-known as a disease of joints, particularly of knee joints. It is the leading cause of chronic disability to the millions of people all over the world, particularly in an ageing society. One of the major causes of this disease is having damage in articular cartilage. This disease causes debilitative joint pain, and often stiffness and causes loss of ability to walk. Without taking early measure of this disease joint replacement surgery may be necessary for improving the situation [2].

The anatomy of knee joint is made up of three bones (femur the tibia and the patella) and a variety of ligaments. The motion control as well as the protection of the knee joint is done by several muscles and ligaments. Two ligaments called the medial and lateral collateral ligaments are located on either side of the knee joint for stabilizing the knee joint from side to side. Two other ligaments called anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) are crossed in a pair of ligaments in the center of the knee for stabilizing the knee from front-to-back during normal and athletic activities. The ligaments of the knee make sure that the weight which is transmitted through the knee joint must be centered within the joint for minimizing the amount of wear and tear on the cartilage inside the knee [3].

Two popular methods of getting electromyography (EMG) signals are well-known as invasive EMG technique (electrode inserted EMG system) and non-invasive EMG technique (surface EMG system). As surface EMG system is easer in application, this technique is widely used in getting the muscle information. However, the reliability of detection in this type of EMG technique depends on the placement of the electrode. If several electrodes are placed closely among each other, they generate difficult technical problems in signal imaging as well [4]. Moreover, the impedance of electrode-skin contact necessarily be low, having similarity among each other, and should be time-stable. Also the power line interference must be reduced and the artifacts should be avoided. Implementation modalities and performance of electrode grids should be progressively improved. For dry electrode systems, conductive gel is employed for improving time-stability and reducing artifacts.

According to the importance of detail understanding of muscular reflex activities as explained above, experiments of muscle force during movements of knee joint have been conducted. Two major lower limb muscles (at upper and lower postures of knee skeleton), named as vastus lateralis and gastrocnemius respectively, have been investigated by present EMG technique. As EMG sensors can identify the electromyogram signals generated by the muscle fibers during the production of muscle force, the exact muscular activities of concurrent muscles where the sensors are attached can be measured [5,6,7]. Major objectives of this research are to focus on the characteristics of ageing effects upon the general muscular activities of two major lower-limb muscles for understanding their influences to knee joint stabilities. Although, the research for complete understanding of all muscle activities around the knee joint are under investigation, the present paper is confined to acknowledge some present important results related to the mentioned topic of muscle functions of two major lower-limb muscles based on their comparisons between young and aged participants.

2. Experimental Methodology

2.1. Experimental Domain

EMG signals have been taken from vastus lateralis and gastrocnemius as two major muscles around knee joint. As these two muscles play important roles in balancing knee joint in supporting body weight along with other muscles, their muscle force are analyzed based on aging characteristics. Five young participants (average age: 22 years) and five aged participants (average age: 67.2 years) have been joint in the present joint modeling experiments. All of them possessed no remarkable muscle disease or any other physical disorders which may affect the results.

EMG signals have been collected from lower-limb muscles (left leg) as mentioned in Figure 1. Sensor attachments for EMG signals are shown in this figure as well.

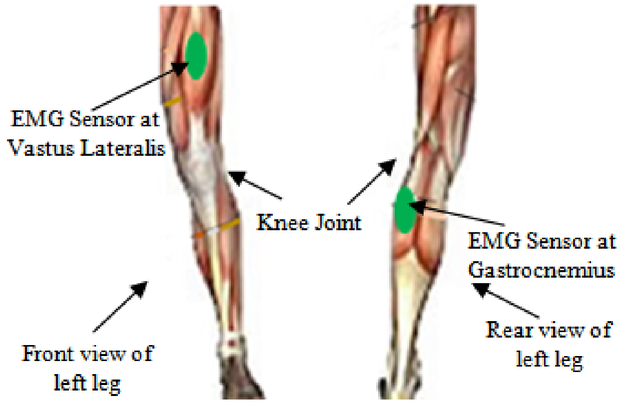


Figure 1. EMG sensing domain for muscular effects on left leg [8,9]

2.2. Experimental Apparatus

The schematic diagram of experimental apparatus is shown in Figure 2. Two EMG sensors of Biometrics Ltd., UK have been used for two selected muscles, vastus lateralis and the gastrocnemius. EMG sensors are connected to the 8 channel data input and amplifying devices before entering into data transmitter and data acquisition devices. For avoiding noise and instability in EMG signals, appropriate grounding techniques have been adopted and connected to the sensor connectors. A four channel digital oscilloscope of Tektronix (DPO2024C) is used as data acquisition device. Finally, data have been transmitted to a personal computer (PC) for conducting the related data analysis and result documentation.

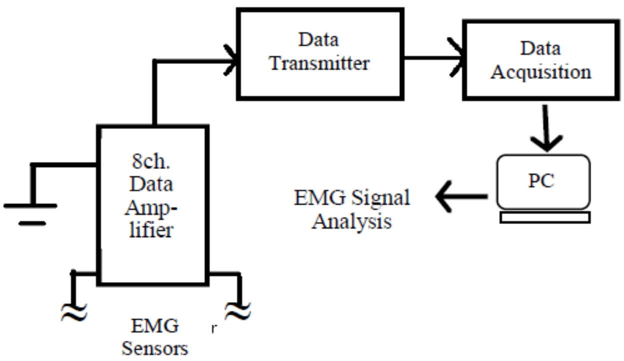


Figure 2. Block diagram of Experimental apparatus and methods

2.3. Experimental Procedures

Although, several types of electrodes are available for EMG signals, two surface electrode (non-invasive) type of EMG sensors (SX 230-1000) have been used in the experiment according to the objectives of the present work. This type of EMG sensors are easier in implementation. Moreover, as it is bipolar type of sensor, the direction of placement is very important for getting appropriate signals. Therefore, in the present experiment the sensors have been positioned parallel to the muscle fibers as their optimal positions are important for getting the maximum data of muscle signals.

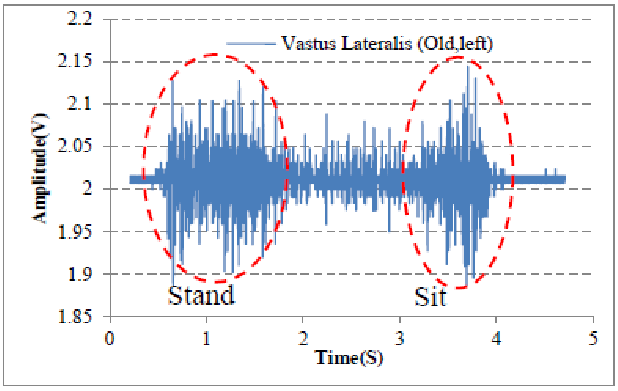
Two sensors are connected to two interested muscle chambers as mentioned above (vastus lateralis and gastrocnemius) for recording signals from both upper and lower postures of knee joint. The electrode surface of both sensors are attached to the middle position of two muscles for avoiding noise from surrounding muscles. Biomedical adhesive type tape (T350, from Biometrics Ltd.) has been used in attaching both sensors to the muscles. The probes of two sensors have been connected to 8 channel data input device where data are amplified and transferred to the data acquisition system through data transmitting device (B350, Biometrics, Ltd.). A four channel digital oscilloscope has been connected as data acquisition system of EMG signals. Finally, the transferred data have been recorded to the personal computer for further analysis and documentation.

EMG signals from two attached sensors have been collected from each natural movement of knee joint. The sensor clustering domain has been arranged only for left leg, where, the front and rear views of the attachments are shown in Figure 1. EMG signals are collected for knee flexor and knee extensor activities from the standing and sitting movements of the participants. Each sensor channel has been utilized for collecting individual muscle potentials from the respective muscle during flexor and extensor motions of the knee. One cycle of data collection has been defined as one standing and one sitting (sit-stand-sit) movements. Thus, for each position of the sensor, 20 cycles of data acquisition consist one data set. All of these data have been collected and recorded in PC for further processing.

3. Experimental Results and Discussion

The characteristics of muscle potentials of two major lower limb muscles, vastus lateralis and gastrocnemius, which largely control the knee stability have been analyzed in the present paper by collecting their myoelectric signals (EMG signals) as mentioned above. The signals are analyzed based on two groups of age condition as young people (around 20 years old) and aged people (around 60 years old). All participants were healthy and did not suffer from knee joint or muscle problems. Based on the maximum amplitudes of EMG signals, the muscle energy of two groups have been evaluated and compared.

The instantaneous EMG signals for aged and young people have been presented in Figure 3 and Figure 4. Signals for both vastus lateralis and gastrocnemius muscles at right leg are found in these figures. The myoelectric potentials for standing and siting conditions for both muscles are visualized as signal amplitudes in volts. Although, the amplitudes are varied based on the values of the signal potentials at each data cycle, however, the patterns of the muscle potentials are understood from these sampling data. Maximum amplitudes in volts for 20 iterations are summarized individually in standing and sitting cycles for both aged people and young people.



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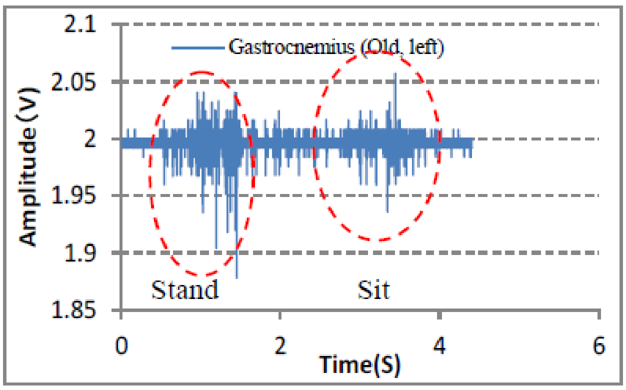
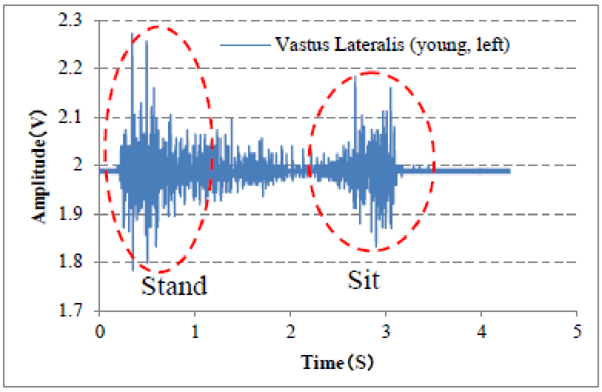


(b)

Figure 3. EMG instantaneous signals for aged people (60 years); (a) vastus lateralis signals of left leg, (b) gastrocnemius signals of left leg



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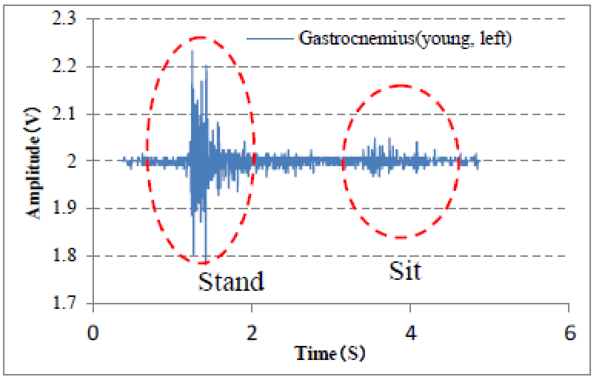
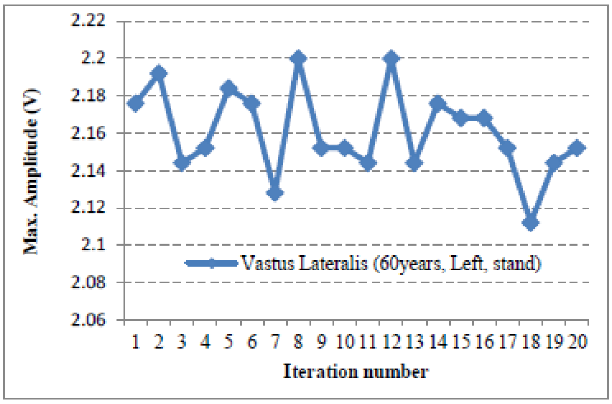


(b)

Figure 4. EMG instantaneous signals for young people (20 years); (a) vastus lateralis signals of left leg, (b) gastrocnemius signals of left leg



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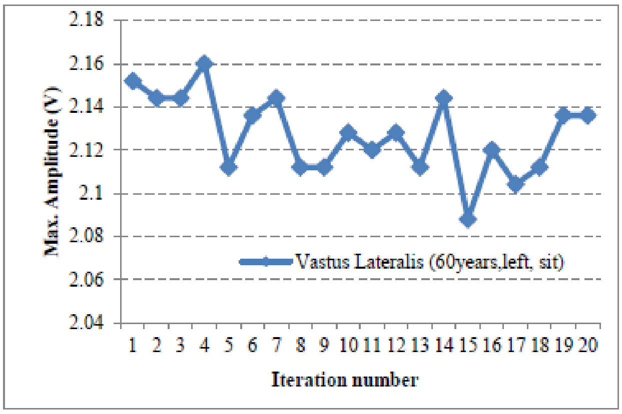
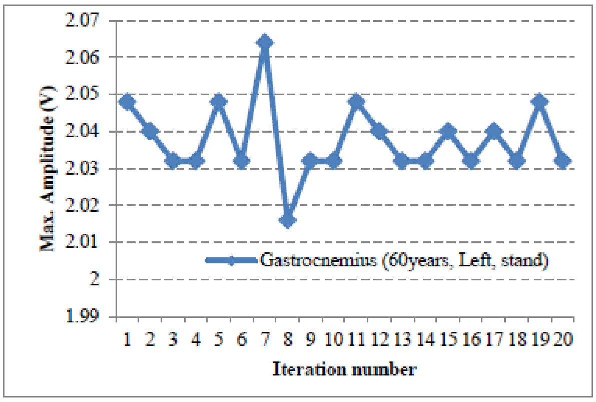


(b)

Figure 5. Maximum amplitude of vastus lateralis for aged people of left leg; (a) for standing, (b) for sitting



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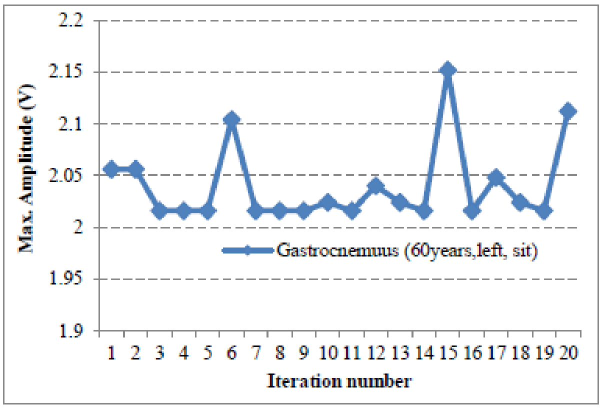
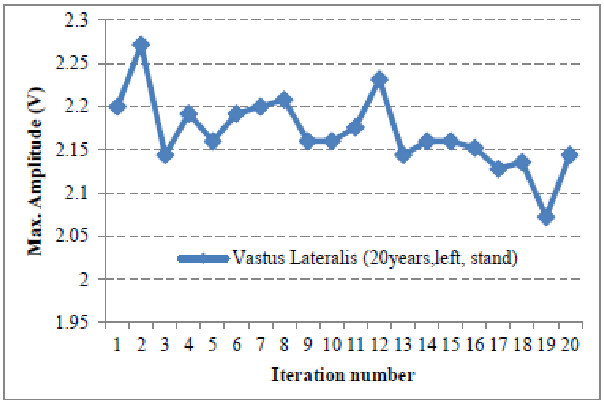


(b)

Figure 6. Maximum amplitude of gastrocnemius for aged people, left leg; (a) for standing, (b) for sitting



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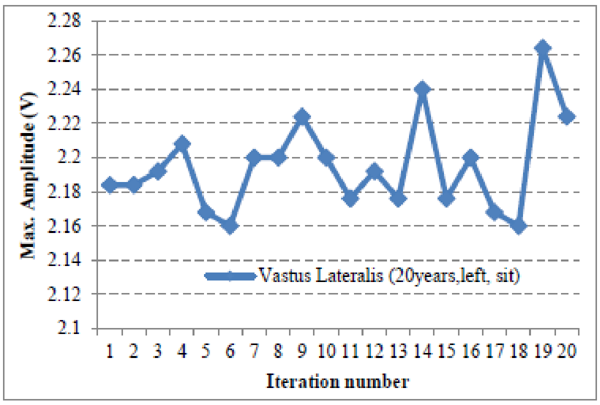
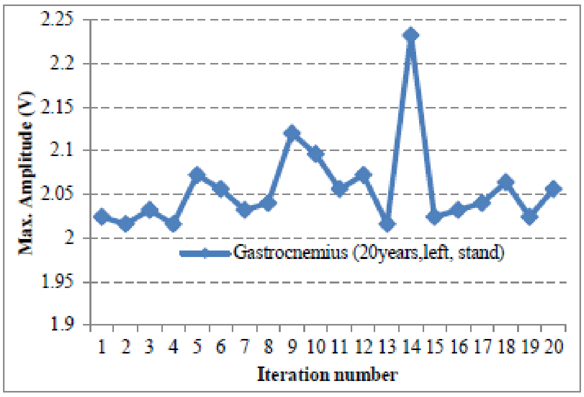


(b)

Figure 7. Maximum amplitude of vastus lateralis for young people, left leg; (a) for standing, (b) for sitting



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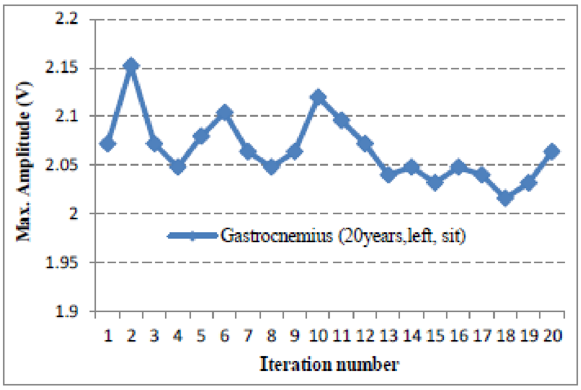


(b)

Figure 8. Maximum amplitude of gastrocnemius for young people, left leg; (a) for standing, (b) for sitting

In Figure 5 and Figure 7, the muscular potentials of vastus lateralis for aged and young peoples are respectively shown. The lumpiness of muscle force is found in both of these figures due to the variable exerted impedance for the extensor and flexor movements of muscles and knee for different temporal instances. Similar results of muscular potentials for gastrocnemius are found as well in Figure 6 and Figure 8 respectively. Moreover, the pattern of muscle force is also varied for iterations. However, the general patterns of EMG signals from the muscles are identically well notified.

The performance of muscular potential for vastus lateralis muscle has been analyzed as shown in Figure 9 ~ Figure 12 with respect to its peak frequency (PF) analysis, where, the peak frequency is defined as the frequency regarding to the peak amplitude (maximum amplitude) of each signal. In Figure 9, the PF distribution of vastus lateralis muscle for standing of old participant is shown with respect to its maximum amplitude distribution. Similar PF distribution analysis for young (20yrs) participant has been conducted as well and the result is shown in Figure 10. From these two figures it is found that muscle potentials for young participant is very strong compared to that of old participant. Contrary to that the PF perturbation for old participant is remarkably high compared to that of young participant. These results show that the vastus lateralis muscle of young people has greater performance in muscle function for their extensor and flexor activities of lower limb compared to that of older people. Similar results are shown in Figure 11 and Figure 12 for sitting dynamics of older and younger people respectively. Strong PF perturbations are found as well in EMG signals for sitting operation of older people compared to that of younger people.

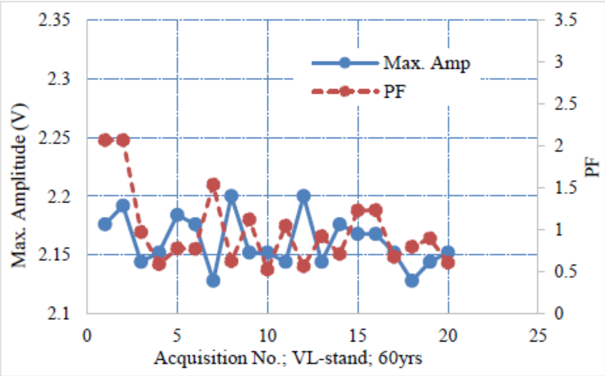


Figure 9. Maximum amplitude with respect to peak frequency (PF) of 60 years people (Vastus Lateralis) for standing

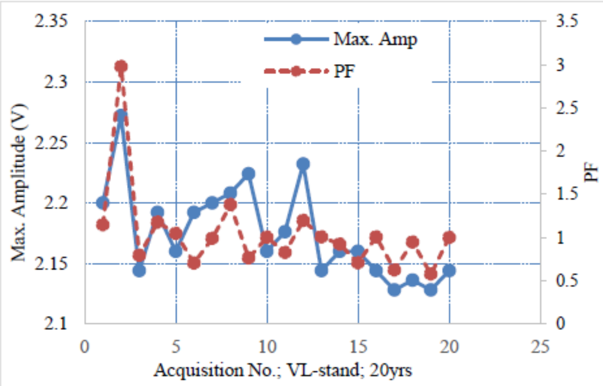


Figure 10. Maximum amplitude with respect to peak frequency (PF) of 20 years people (Vastus Lateralis) for standing

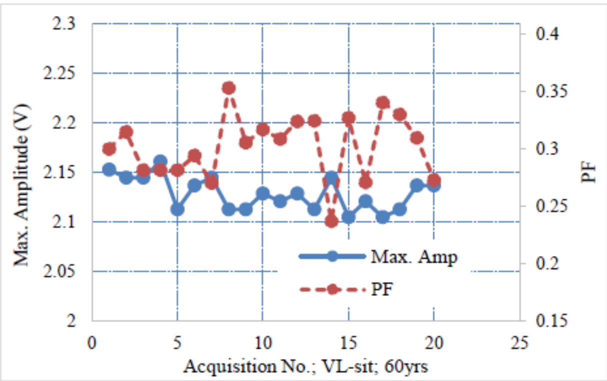


Figure 11. Maximum amplitude with respect to peak frequency (PF) of 60 years people (Vastus Lateralis) for sitting

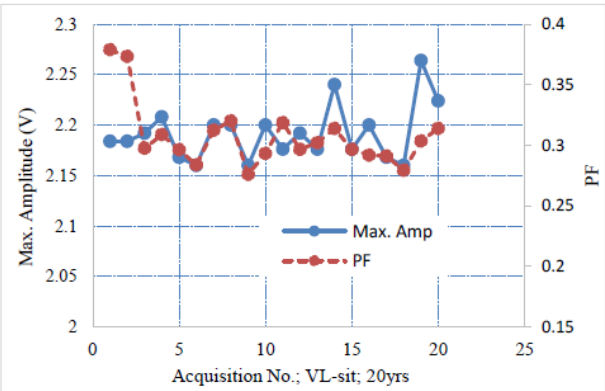


Figure 12. Maximum amplitude with respect to peak frequency (PF) of 20 years people (Vastus Lateralis) for sitting

Furthermore, the stability of peak frequency distribution for both young and old participants are also focused in above figures. Greater PF fluctuations of older participant are clearly identified in above comparisons. These results also focus on the reality of having the lower stability in the muscle-potential distribution control during the extensor and flexor actions of the lower limb movements in aged people. On the other hand, the indicated stability in PF distribution of young participant in these figures indicate the intense contributions to the muscle control in lower limb dynamics. Therefore, it is found in these PF distribution results that higher EMG potentials (maximum amplitude) are possible to get even for small PF perturbation from lower limb muscles of young participants (i.e. small co-activations of knee dynamics generate higher EMG potentials.). These results are clearly mentioned particularly in Figure 10 and Figure 12 for young people both in standing and sitting operations as well. Another related observation is found in above figures that at the beginning of co-activation operations, young vastus lateralis generates strong muscle potentials, however, old vastus lateralis muscle generates weak muscle potentials. These situations can be defined as unsaturation noise and therefore, it is avoided for not to contribute intense instability to the analysis of knee movements.

The instabilities in PF distributions for young people and aged people, explained in Figure 9 - Figure 12, are verified by the corresponding standard deviation analysis and the results are summarized in Table 1. From these analysis it is identified that the instability in muscle function of aged people enormously increases due to getting ages.

Table 1. Standard deviation (SD) for respective PF distribution condition

PF change, condition	VL-stand; 60 years	VL-stand; 20 years	VL-sit; 60 years	VL-sit; 20 years
SD	0.286416	0.213864	0.030461	0.01342

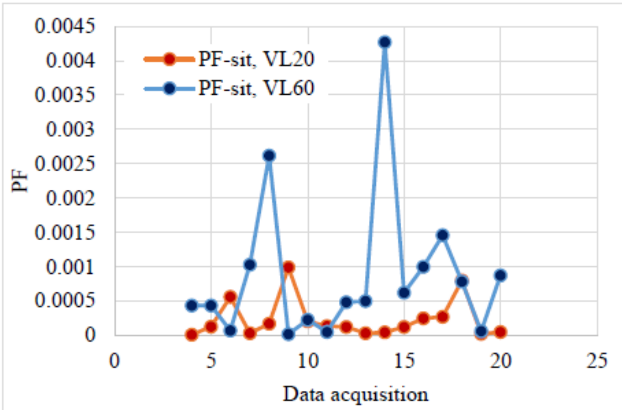
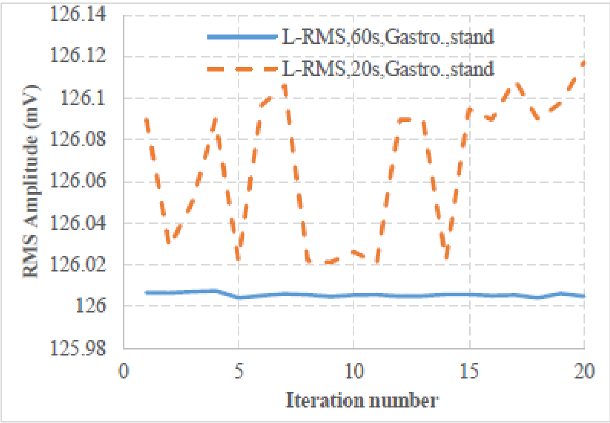
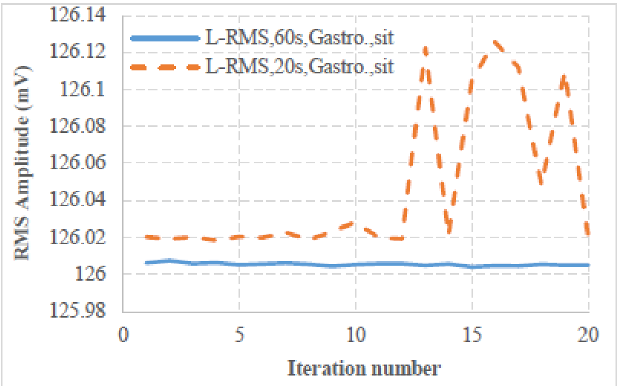


Figure 13. Comparison of squared deviation from mean value of PF for vastus lateralis during sitting of young (VL20) and aged (VL60) people

A comparison of PF deviation for vastus lateralis during sitting of young and aged people is furthermore clarified by their squared mean value differences and the results are shown in Figure 13. From this result it is identified that aging factor not only decreases muscle potentials but also increases the instability in generating required muscle force and thus it may play an important role in causing instability to lower-limb joint movements as well.



(a)



(b)

Figure 14. RMS amplitude values of gastrocnemius muscle; (a) for standing and (b) for sitting

Again, the RMS calculation for maximum amplitude of gastrocnemius muscle is conducted for averaging and comparing the muscular potentials in extensor and flexor operations by standing and sitting movements of aged (60 years) and young (20 years) participants and the results are shown in Figure 14. The result confirms the evidence that the muscular potentials for younger participants are higher than the aged people.

4. Conclusions

The myoelectric characteristics of two major lower limb muscles (upper and lower streams of knee joint), vastus lateralis and gastrocnemius, which largely control the knee joint stability have been analyzed in the present research by analyzing their EMG potentials. Getting information about the instability characteristics of muscle functions due to aging has been figured out as one of the major objectives in the present research. It has been found in above results that the intended information is successfully clarified in the present work.

The present study is a part of an ongoing investigation scheme for having functional effects of lower limb muscles in stability analysis for charactering the dynamics of human motion. The results are planned to be utilized in understanding the balancing of knee joints. Authors are intended to clarify all muscle-effects to the lower limbs in future works sequentially for identifying their complete influences to dynamic activities of knee joints.

Acknowledgment

This research has been supported by the Grants-in-Aid for Scientific Research (KAKENHI 24560297) from JSPS and MEXT of the Government of Japan. Authors also pay their respect and gratefulness to the participants as well.

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