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Muscle Activities in the Lower Limbs for the Different Movement Patterns on an Unstable Platform

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Abstract

We performed experimental studies on the muscle activities in the lower limbs for the different movement patterns on an unstable platform. A training system for postural control using an unstable platform that we previously developed was applied for the experiments. This unstable platform provides 360 degrees of movement allowing for training of posture in various directions and provides simultaneous excitations to visual sensory, somatic sensation and vestibular organs. Compare with the stable platform, keeping body balance on the unstable platform requests more effective sensation from vision, vestibular sense and somatic sense. Especially, the somatosensory inputs from the muscle proprioceptors and muscle force are crucial. To study the muscle activities for the different movement patterns and find the best training method for improving the ability of postural control through training and improving the lower extremity muscular strength, fifteen young healthy participants went through trainings and experiments. The participants were instructed to move the center of pressure following the appointed movement pattern while standing on the unstable platform. The electromyographies of the muscles in the lower limbs were recorded and analyzed in the time and the frequency domain. Our experimental results showed the significant differences in muscle activities for the different movement patterns. Especially, the spectral energy of electromyography signals in muscle for the movement pattern in anterior-posterior direction was significantly higher than those occurred in the other patterns. The muscles in the lower leg, especially tibialis anterior and gastrocnemius were more activated compared to the others for controlling the balance of body on the unstable platform. The experimental results suggest that, through the choice of different movement pattern, the training for lower extremity strength could be performed on specific muscles in different intensity. And, the ability of postural control could be improved by the training for lower extremity strength.

Key words : muscle activities, unstable platform, postural control

I. INTRODUCTION

Posture control is a continuous process and is constantly controlled or adjusted so that the center of gravity (COG) of the body can be maintained in stable condition. It is a perceptual-motor process that includes the sensation of position and motion from the visual, somatosensory and vestibular system, the processing of the sensory information to determine orientation and appropriate movement, and the selection of motor responses that can maintain or bring the body to equilibrium. The visual system is a major contributor to balance, providing information about the environment, location, and the direction and speed of the movement. The vestibular system provides information about movement of the head, independent of visual cues. The somatosensory system provides information about the position of the body based on sensations through the skin regarding pressure, vibration, tactile sensors and muscle proprioceptors [1].

Diminished balance ability is multifactorial. It can be due to degenerations in visual and vestibular sensory systems, degenerations of proprioception, impairments in central processing, or combinations of these factors. Several studies

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have shown that lower extremity muscular strength is a common factor associated with balance impairment in elderly fallers [2]. Lord et al.[3] found that ankle dorsiflexion strength was one of the three variables that significantly discriminated between order adults who had no falls or one fall and those with a history of multiple falls. A study of nursing home residents with a history of fallings found that muscle forces (torque) and isokinetic power were significantly lowerin knee flexors (quadriceps) and extensors (hamstrings), and ankle dorsiflexors (tibialis anterior) and plantar flexors (gastrocnemius and soleus) [4]. These studies show a strong relationship between lower extremity strength and the ability to control posture. The association between weak leg muscles and falling has led to studies of strength training to enhance balance in balance-impaired older adults. These studies have evaluated the effects of strength training alone or in combination with other activities such as tai chi, aerobic exercise, and balance training [5-7].

Muscle activity is typically studied using electromyography (EMG). As a task is being performed, the muscle activity will generate signals that give valuable information about muscle fatigue, strength and movement patterns. EMG is a technique to measure muscle activity where surface electrodes are placed on the skin overlying a muscle or group of muscles. When muscles contract the active fibres emit myoelectric signals that can be recorded with EMG. The wavelet decomposition of EMG signals coupled to principal component analysis can identify the variable nature of EMG mean frequencies in cerebral palsy, and it was suggested that it may be possible to use the EMG signals to derive a physiologically based quantitative index for assessing motor function. Thus, the information about spectral shape, intensity, and co-activations between muscles could be incorporated in time-frequency analyses of the EMG signals [8]. In our research, the EMG signals also were analyzed into time-frequency domain. The integrated EMG, probability density, median frequency and spectral energy of muscles were employed in evaluating the muscle activities.

The purpose of this study was to investigate the muscle activities in the lower limbs for the different movement patterns using a training system with an unstable platform which we have preciously developed for the training of postural control. Through the studies on the muscle activities for the different movement patterns on the unstable platform, we tried to find the best training method to improve the ability of postural control through improving the lower extremity muscular strength.

II. EXPERIMENTAL DEVICE

Fig. 1 shows the training system for posture control that consists of an unstable platform, a monitoring device, a computer interface, a computer and a safety harness. This system provides the simultaneous excitations to visual sensory, somatic sensation and vestibular organs. The unstable platform is shown in Fig. 2. This unstable platform provides 360 degrees of movement allowing for training in various directions. The dimensions of the unstable platform are 550mm long, 390mm wide and 130mm high. The curvature radius of the unstable platform is 300mm. The maximum tilt angle in left-right direction is 18° the maximum tilt angle in anterior-posterior direction is 28°. Two tilt sensors were installed inside of the unstable platform. Through the tilt sensors, we can compute the center of pressure (COP) of the subject on the unstable platform. The signals of the tilt sensors were input to a computer using a PCI-6024E card (National instruments) by a SCB-68S (National instruments) connecter.

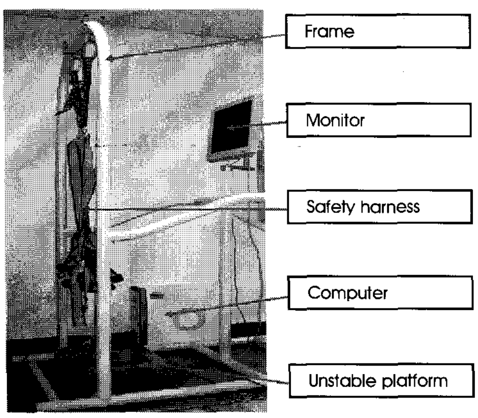

Fig. 1. Training system for postural control utilizing an unstable platform

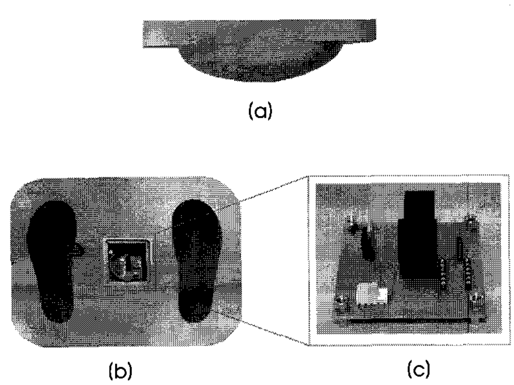

Fig. 2. The unstable platform: (a) Side view (b) Top view (c) Tilt sensor

III. METHOD

A. Subjects

Fifteen healthy volunteers, 9 males and 6 females, whose age ranged from 23 to 33 years, participated in the study. The average age was 27.88±4.09 years. The average weight of the subjects was 64.13±9.39kg. The average height of the subjects was 173±5.26cm. Before the start of the examination, the volunteers were all informed of the experiment and signed a consent form.

B. Acquisition of EMG Signals

We measured the EMG of the muscles in the lower limbs using a MP150 system (BIOPAC system, Inc.). The sampling rate is 1000 and the gain is 1000. A band pass filter was used to filter the EMG signal. The selected band was between 5Hz and 500Hz. The surface electrodes were EL500. The surface electrode shape was discs. The diameter of the electrode was 20mm. Alcohol was applied to cleanse skin. Eight muscles were measured in the right leg. They were rectus femoris(RF), biceps femoris(BF), tensor fasciae latae(TFL), vastus lateralis(VL), vastus medialis(VM), tibialis anterior(TA), gastrocnemius(Ga) and soleus(So).

C. Movement Patterns

The subjects were request to perform the movements following the appointed moving patterns on the unstable platform. Fig. 3 shows various movement patterns. As shown in the figure, the line shows the moving direction, the circle shows the desired movement pattern and the point shows the COP of subject. The subject should try his best to move the COP following the circle. In our experiments, the maximum distance of the 8 directions from the center was 60mm. The moving speed of the target circle was 6.25mm/sec.

D. Experimental Procedure

Before the experiments, the surface electrodes were put on specific muscles and were wired to the MP150 system. Then, the subjects were requested to stand and balance on the unstable platform. The distance of two feet is 200mm. After 5 minutes of free training, the actual test took place. The subject was request to move his COP by moving his posture following a desired movement pattern. The movement patterns include movements in the anterior-posterior direction, movements in the left-right direction, movements in the 45° direction and movements in the -45° direction. The experimental sequence was chosen in a random order. The rest time between each trial was 1 minute. All of the experiments were repeated twice. In this process, The EMG signals were recorded by a MP150 system. Fig. 4 shows the experimental procedure.

E. Data Analysis

Muscle activity is typically studied using EMG. As a task is being performed, the muscle activity will generate signals that give valuable information about muscle fatigue, strength and movement patterns. EMG is a technique to measure muscle activity where surface electrodes are placed on the skin overlying a muscle or group of muscles. Since the magnitude

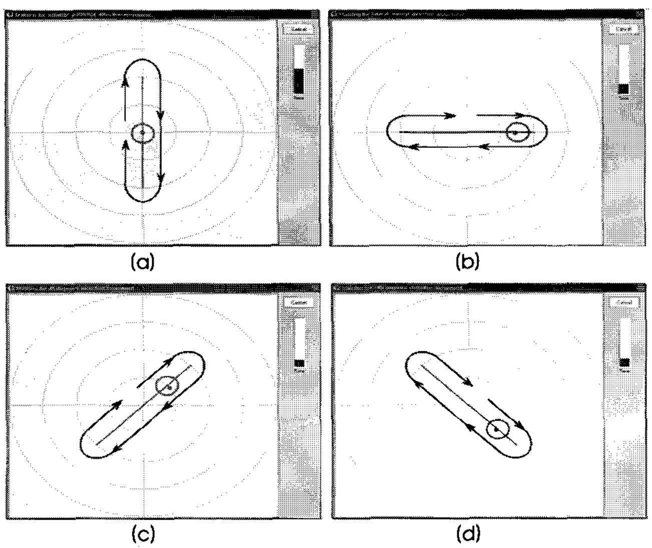

Fig. 3. Movement patterns:
(a) Movement in the anterior-posterior direction (b) Movement in the left-right direction (c) Movement in the 45° direction (d) Movement in the -45°direction

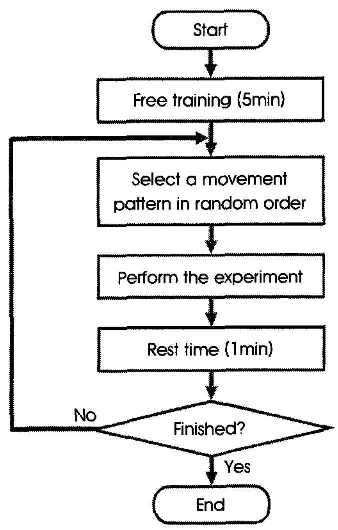

Fig. 4. Experimental procedure

of EMG activity is required to be estimated, a transformation procedure in the time domain can be used, such as rectification, linear envelope, integration, and root mean square. EMG force measurements seek to quantify the average number and firing rate of motor units contributing to a particular muscle contraction. This observation can relate the quantity to the actual force produced. The integrated EMG (IEMG) is quantity analogous to electrical work or energy that associated with the magnitude of EMG activity, frequency, and continuance time. In our research, IEMG was used to evaluate the muscle activities [9]. Equation (1) shows the calculation method of IEMG. The time block chosen was 1 second. Frequency domain processing is an attempt to solve the complex problem of EMG demodulation by an entirely different perspective. It is a mathematical technique by which transformation from time domain to frequency domain is performed. This is commonly used to identify EMG frequency spectrum shifts related to muscle fatigue. A localized muscle fatigue could be demonstrated in the EMG frequency domain by observing a decrease of power density in the high frequency region and an increase of power density in the low frequency region during fatiguing contractions. The EMG signals were also analyzed in frequency domain. The probability density, median frequency and spectral energy of EMG signals of active muscles in frequency domain were calculated and applied to evaluate the muscle activities. Equation (2) showed the method for median frequency calculation.

$$IEMG = \frac{1}{T}\int_{t}^{t+T} |x(t)|\,dt \qquad (1)$$

where, $x(t)$ is the EMG signal, T is the time block.

$$\int_{0}^{f_{med}} s(f)df = \int_{f_{med}}^{\infty} s(f)df = \frac{1}{2}\int_{0}^{\infty} s(f)df \qquad (2)$$

where, $s(f)$ is the power density spectrum of EMG signal in frequency domain.

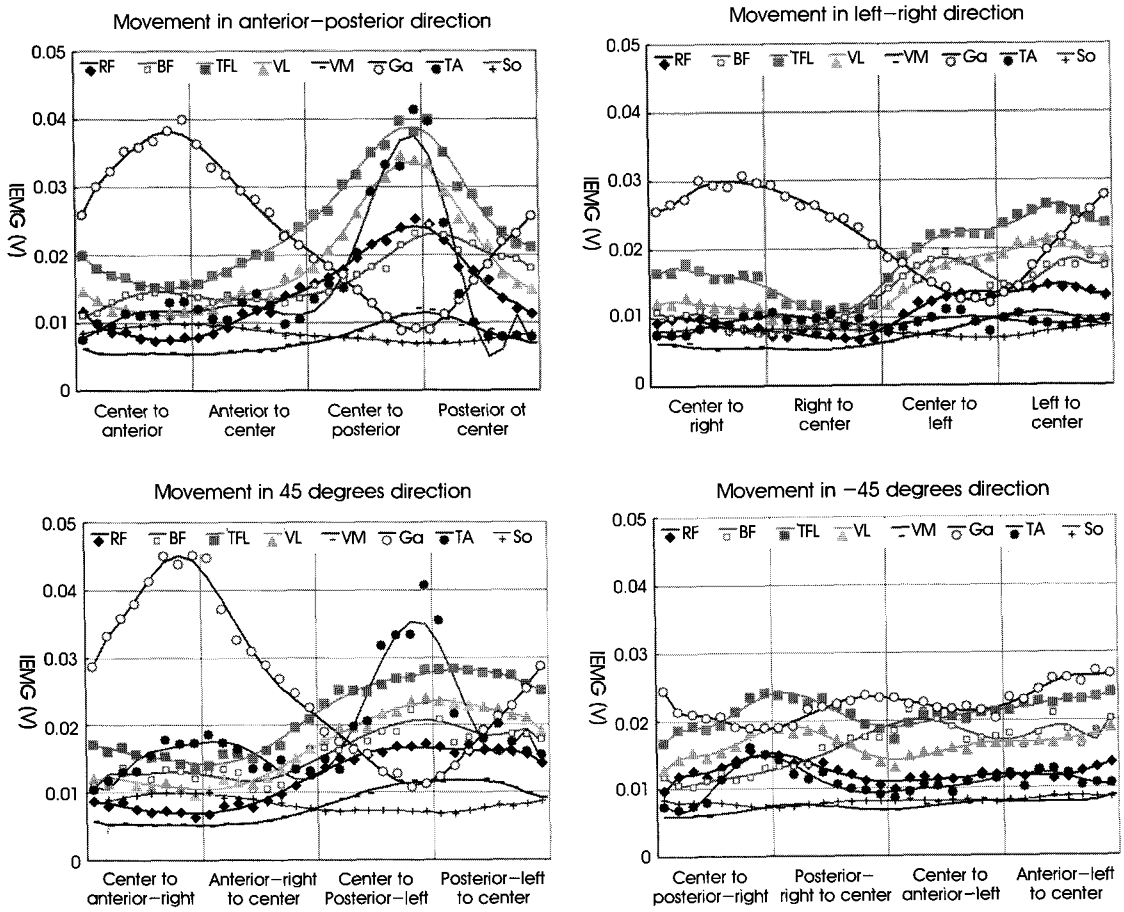

Fig. 5. IEMG of the muscles in different movement patterns

Ⅳ. RESULTS

The EMG of the muscles in the lower limbs was recorded and analyzed in the time and the frequency domain. IEMG, median frequency and spectral energy of EMG signals were obtained for the evaluation of muscle activities. The followings are the findings from our experimental results.

A. IEMG of Muscle in Different Movement Patterns

The EMG of the muscles in the right leg was measured using a MP150 system. The EMG signals were analyzed as IEMG. The block size for IEMG was 1 second. Fig. 5 shows the IEMG of the muscle in different movement patterns. A general polynomial fit function was used for curve fitting.

For the different moving directions, muscle activities showed different pattern. In the direction from the center to the anterior, the Ga and So muscles were mostly activated. The RF, BF, TFL, VL, VM and TA muscles were activated for the direction from center to posterior. The Ga, TFL and So were activated in the direction from the center to the right. The RF, BF, TFL, VL and VM were activated in the direction from the center to the left. The Ga and So were activated in the direction from the center to the anterior-right. The RF, TFL, VL and TA were activated in the direction from the center to the posterior-right. The TA, TFL, BF, RF, VL and VM were activated in the direction from the center to the posterior-left. The Ga, BF, VL and TFL were activated in the direction from the center to the anterior-left.

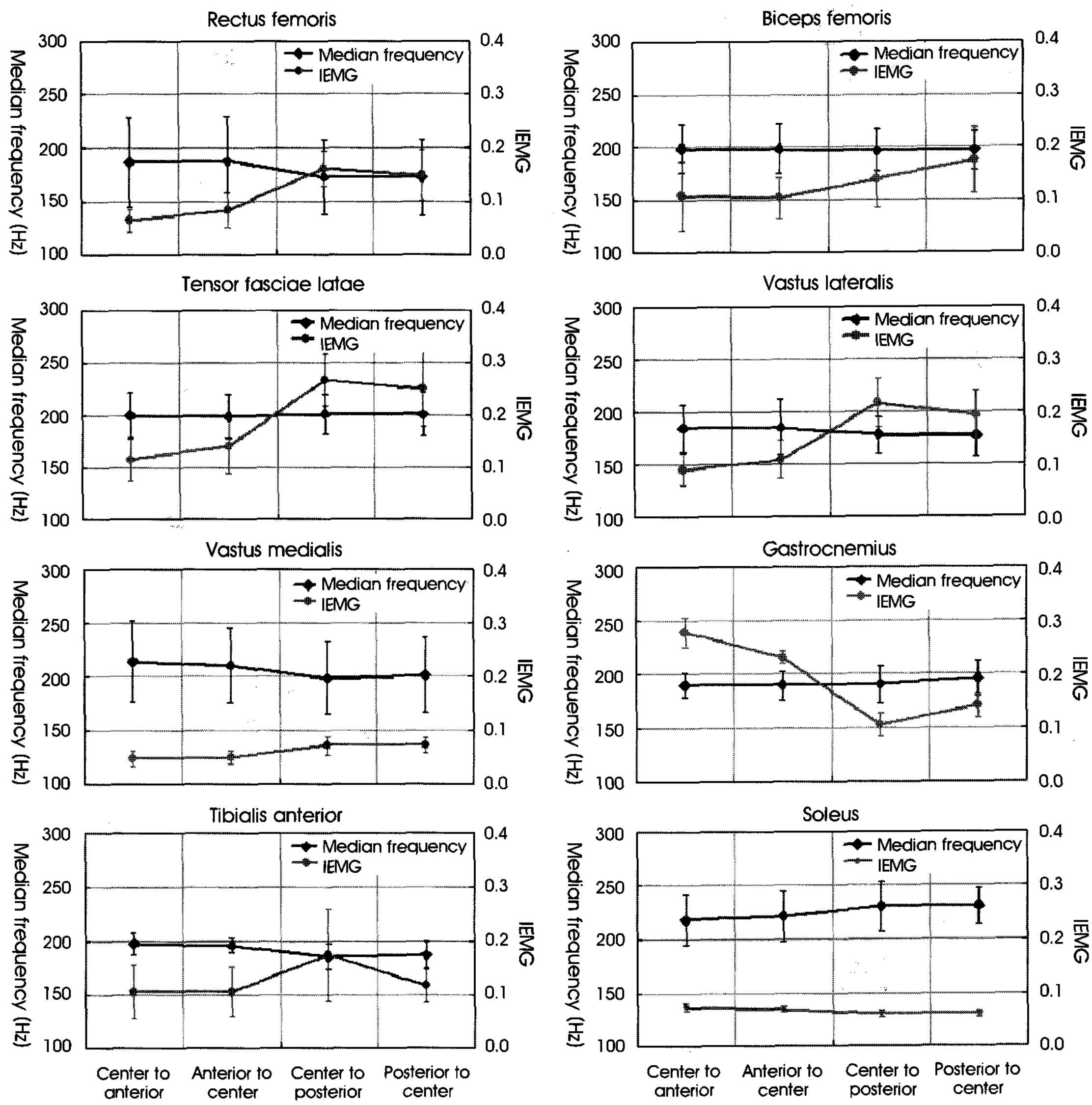

Fig. 6. The median frequency and the IEMG of the movement pattern in the anterior-posterior direction

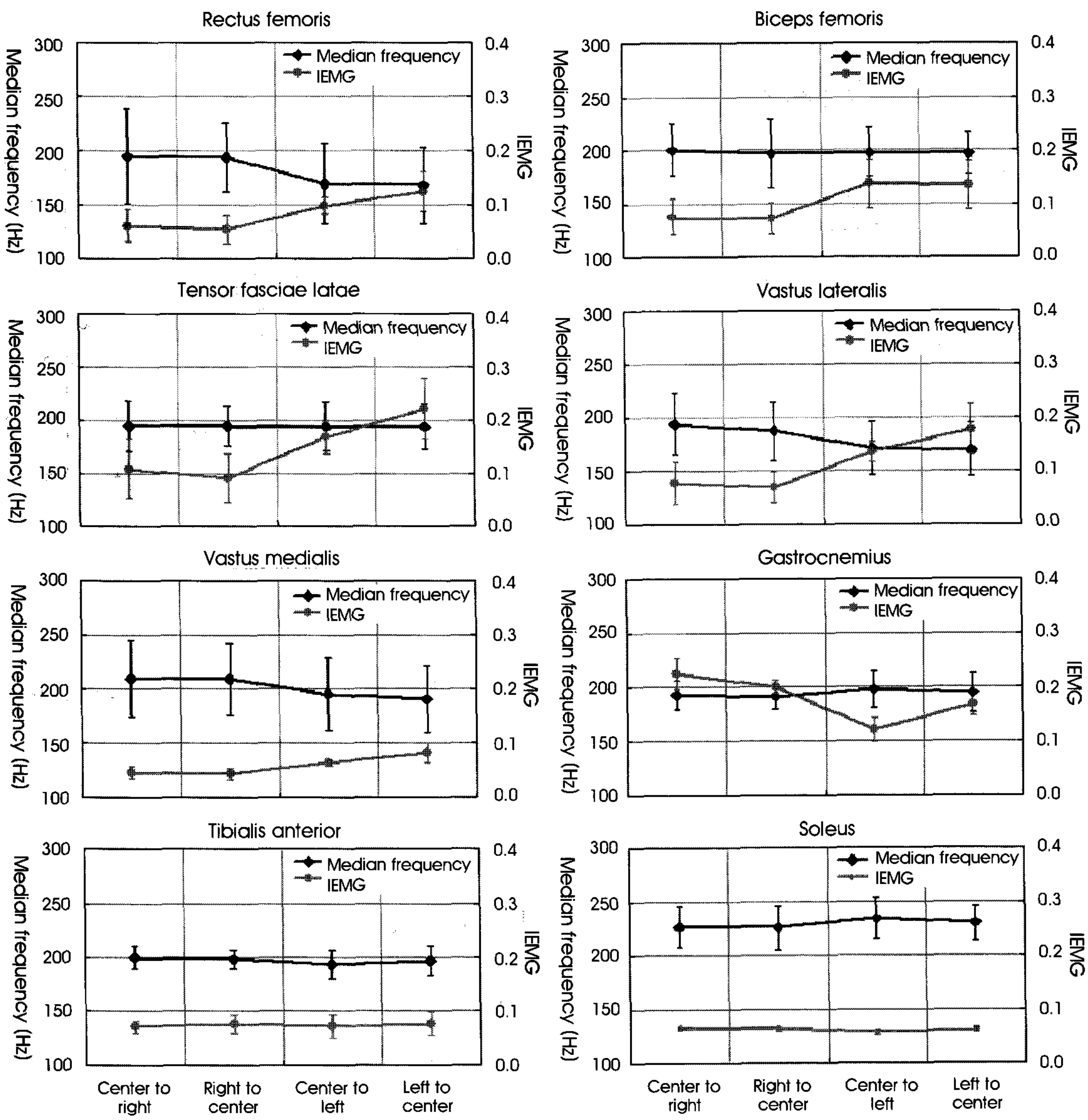

Fig. 7. The median frequency and the IEMG of the movement pattern in the left-right direction

B. Median Frequency and IEMG of Different Movement Patterns

The EMG signals were translated into frequency domain using Fast Fourier Transform (FFT) and were analyzed. The median frequency of the EMG signals in frequency domain was calculated to evaluate the muscle activities. The median frequency obtained for the different movement patterns were compared with the IEMG. Fig.'s 6-9 showed the median frequency and IEMG for the different movement patterns.

For the different muscles, the median frequency and the IEMG showed significant differences for the different movement patterns. For the RF, the median frequency was declined in all movement patterns. The median frequency of the movement from the center to the left, the posterior and the posterior-left direction was lower than the other directions. Especially for the movement in the left-right direction, the median frequency was significantly changed. For the BF, the median frequency was no different from the four movement patterns. But, the IEMG of the movements in the left-right and the 45° direction showed similar tendencies. The movements in the anterior-posterior and the -45°direction showed the similar tendency. For the VM and So, the median frequency and the IEMG showed similar tendency for all of the movement patterns. For the Ga, the median frequency and the IEMG showed similar tendency for the movement patterns of the anterior-posterior, the left-right and the 45° direction. But, the IEMG of the movements in the anterior-posterior and the 45°direction were higher than the movement in the left-right

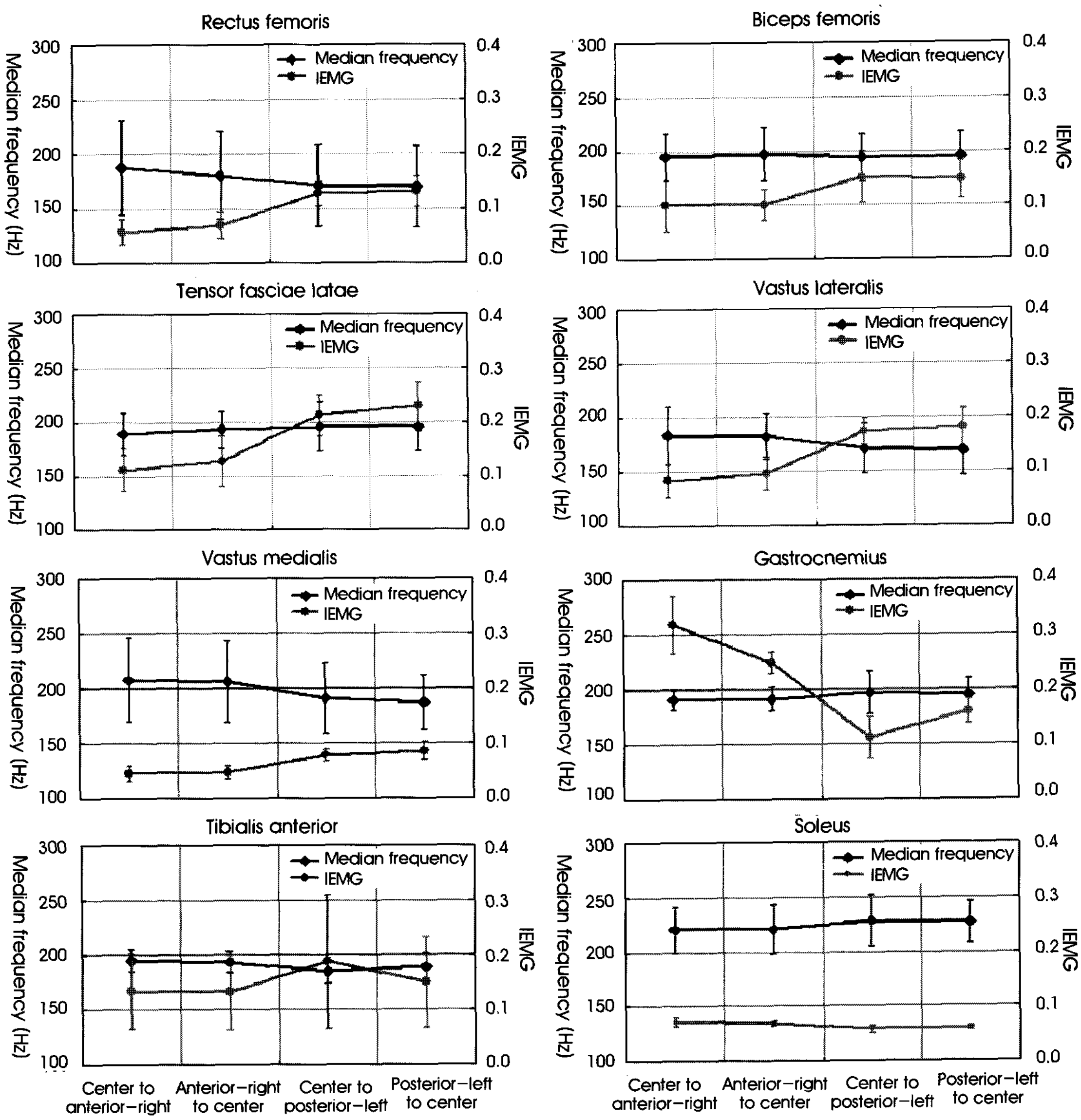

Fig. 8. The median frequency and the IEMG of the movement pattern in the 45° direction

direction. For the TA, the median frequency and the IEMG showed similar tendency for the movement patterns of the anterior-posterior and the 45° direction; similar tendency in the movement patterns of the left-right and the -45° directions. For the TFL and VL, the median frequency and the IEMG showed similar tendency for the movement patterns of the anterior-posterior, the left-right and the 45° direction.

C. Spectral Energy of EMG Signals in Different Movement Patterns

The spectral energy of the EMG signals in frequency domain was calculated to evaluate the muscle activities. The method of m-DYN (mean dynamic activity) was used to normalize the EMG signals [10].

Fig. 10 showed the spectral energy of EMG signals in different movement patterns. For the different muscles and movement patterns, the spectral energy showed significant difference. The spectral energy for the Ga and TA was higher in the movement patterns of the 45° and the anterior-posterior direction. The spectral energy of all of the measured muscles of the movement in the left-right direction was lower than the others. On the other side, the spectral energy of the movement in the anterior-posterior direction was higher than the other patterns. Except the Ga and TA, there was no significant difference between the movement in the 45° and the -45° direction. It was due to the measured muscles were in the right leg. The Ga and TA of the right leg were more activated in the 45° direction than the -45° direction. On the other side, the Ga

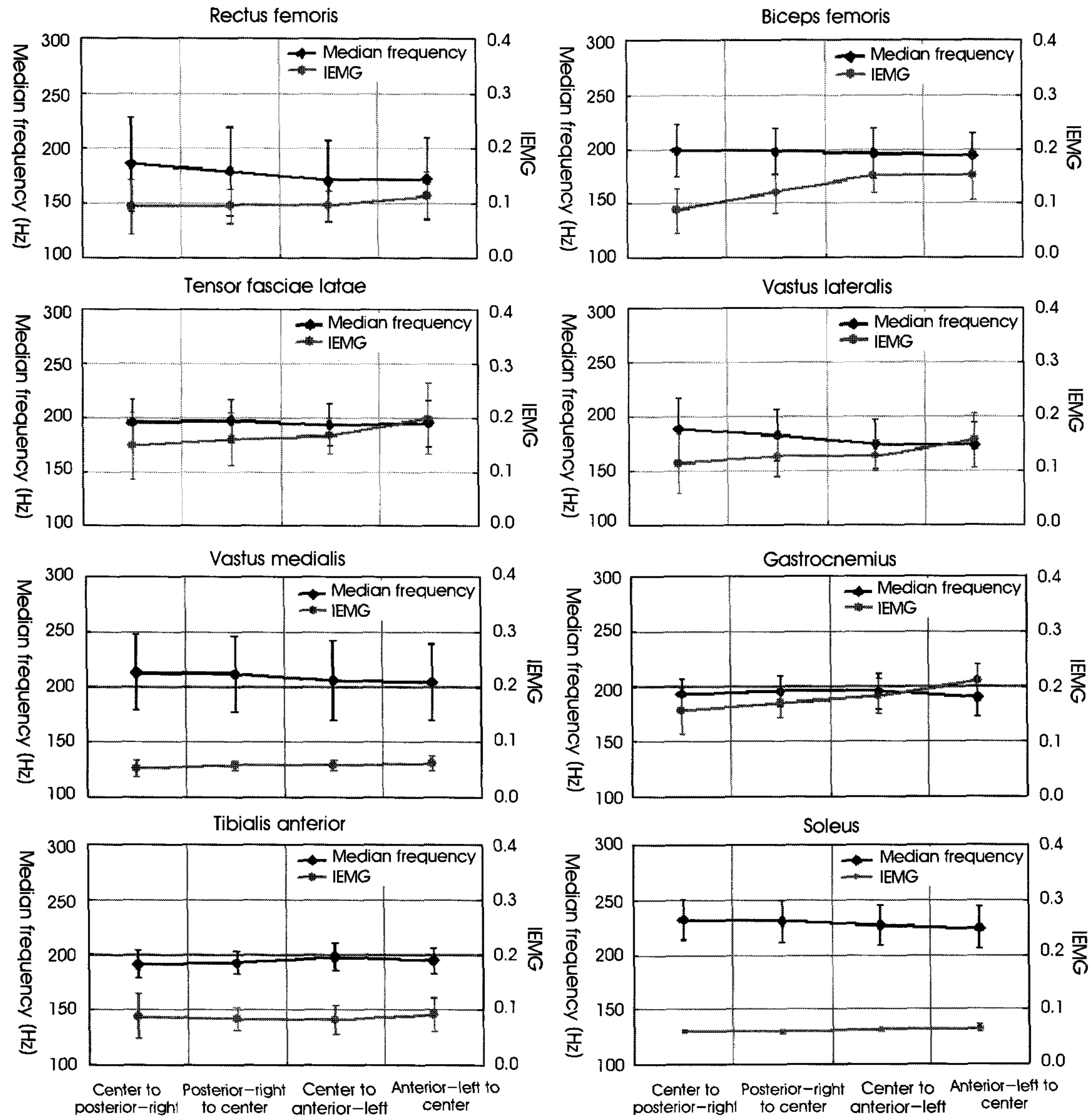

Fig. 9. The median frequency and the IEMG of the movement pattern in the -45° direction

and TA of the left leg were more activated in the -45° direction than the 45° direction. For the VM and So, there was no significant difference between the movement patterns.

V. DISCUSSIONS

Among the four kinds of movement patterns, the pattern of movement in the anterior-posterior direction shows the highest values of IEMG. This implies that the movement in the anterior-posterior direction on the unstable platform could bring out more muscle activities in the lower limb. For the different muscles, the Ga and TA showed more voluntary contractions in the movement patterns of the 45° direction and the anterior-posterior direction. The TFL, BF, VL and RF showed more voluntary contractions in the movement pattern of the anterior-posterior direction. The VM were more activated in the movement pattern of the 45° direction compared to other movement patterns.

The muscle activity profile for the movement patterns in the 45° and the -45°direction did not exhibit any symmetry. In the pattern of movement in the 45° direction, the Ga muscle was mostly activated during the movement from the center to the anterior-right direction. The TA, RF, BF, TFL and VL were contracted during the movement from the center to the posterior-left direction. This does not show any symmetry muscle activations for a symmetric movement. It's due to the postural control on the unstable platform. When a subject moves COP from the center to the anterior-left direction on the

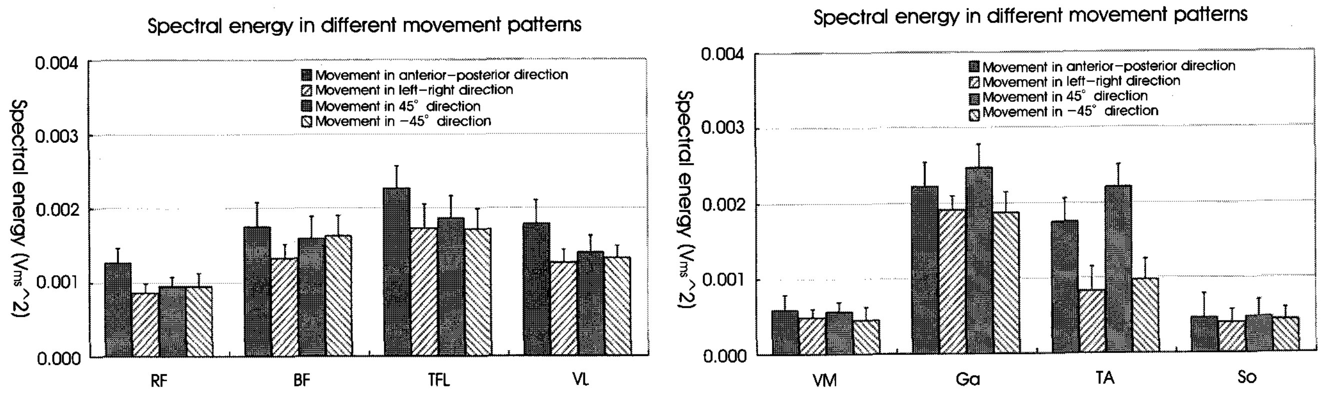

Fig. 10. Spectral energy of EMG signals in different movement patterns

unstable platform, the muscles in the left leg should be activated. This moves his COP towards the target direction. The muscles in the opposite leg (right leg) should also be contracted to keep the balance on the unstable platform.

For all of the muscles, the movement in the anterior-posterior direction and the movement in the 45° direction showed the common tendency of the median frequency and the IEMG. For the RF, BF, VL, VM, TA and So, the IEMG was increased following the decline of the median frequency. Generally, following the increase of muscle contraction, the IEMG was increased and the median frequency was decreased. But the TFL and the Ga did not show this tendency. This seemed to be due to the difference in the muscle contraction phase. For the movements in the anterior-posterior and the 45° direction, the TFL and the Ga were activated in the beginning of the phase. The muscular fatigue was increased in this phase. Even though, the muscular contraction was declined in the following phase. But, the muscular fatigue was continuous. Muscular fatigue had not been restored. So, the change of the median frequency was not significant. But,the results of IEMG showed the quantity of muscle activities in the different moving phase. For the movement in the left-right direction, the BF and TFL also showed the common characteristics.

For all of the movement patterns, the RF, TFL and VL showed the common characteristic that these muscles as the agonist muscle were more activated in the movement from the center to the left, the posterior and the posterior-left directions. On the other side, the Ga as the antagonist muscle showed the opposite tendency, it was more activated in the movement from the center to the anterior, the right and the anterior-right directions. The Ga and the TA as another group of agonist and antagonist muscles also showed this characteristic. Generally, the RF, TFL and VL as the agonist muscles was opposed BF as the antagonist muscle. But, in our experiments, this characteristic was not shown. It was because the postural control was done on the unstable platform. Compared with balancing on the stable platform, keeping body balance on the unstable platform needed more cooperation of the muscles. As the antagonist muscle of the RF, TFL and VL, the Ga was more activated than the BF. When a subject moves the COP to the appointed direction, controlling the body balance on the

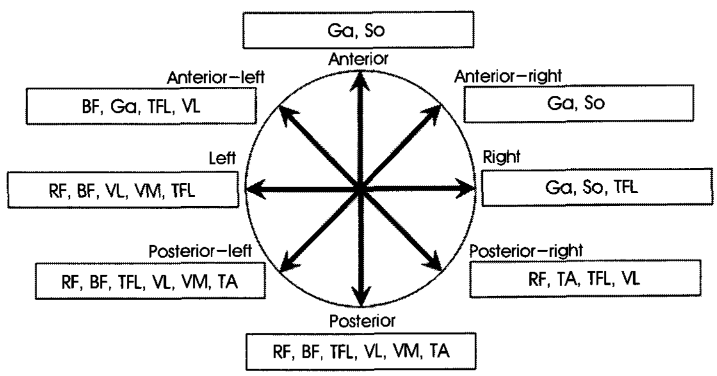

Fig. 11. Activated muscles in the different moving directions

unstable platform was especially more important than the movement of the COG of body. To keep the balance of the body on the unstable platform, the muscles in lower leg, especially the TA and the Ga were more activated than the muscles in thigh. The muscles in thighs mostly used to move the COG of body and compensate for the insufficiency of muscle contraction of the lower leg. Compared with the Ga, the insufficiency of TA activities was compensated by the RF, TFL and VL. The insufficiency of the Ga activities was compensated by the BF. The IEMG of the different muscles in different movement patterns (shown in Fig. 5) just proved this point exactly.

According to the results obtained from our experiments, the activated muscles in different moving directions were summarized as shown in Fig. 11. In the direction from the center to the anterior and from the center to anterior-right, the BF, TA, Ga and So were more activated. The RF, BF, TFL, VL, VM and TA were activated in the direction from the center to the posterior and from the center to the posterior-left. In the direction from the center to the left, the RF, BF, TFL, VL, Ga and So were more activated the TFL, TA, Ga and So were more activated in the direction from the center to the right. The BF, TFL, VL, Ga and TA were more activated in the direction from the center to the anterior-left. The RF, BF, TFL, VL and TA were more activated in the direction from the center to the posterior-right.

For the movement patterns in the anterior-posterior direction and in the 45° direction, the activated muscles showed similar tendencies. But, there were some exceptions in the analyzed results of spectral energy. For the RF, BF, TFL and VL, the spectral energy of the movement pattern in the anterior-posterior direction was higher than the movement pattern in the 45° direction. But the spectral energy of the Ga and the TA of the movement pattern in the anterior-posterior direction was lower than the movement pattern in the 45° direction. The other muscles also showed similar tendencies. So, according to the different subjects, the different movement patterns could be applied for improving the lower extremity strength for the appointed muscles and improving the ability of postural control. The movement in the left-right direction could be applied in the training for lower extremity strength in lower intensity the movement in the anterior-posterior direction could be applied in the training in higher intensity. Through the study of the muscle activities in the different movement patterns on the unstable platform, an appropriate training scheme for lower extremity strength could be applied for the specific muscles, and improve the ability of postural control.

Ⅵ. CONCLUSIONS

In this paper, we investigated the muscle activities in the lower limbs for the different movement patterns on an unstable platform. The experimental results lead us to following conclusions:

1. There was significant difference of muscle activities in the different movement patterns on the unstable platform.
2. There was significant difference of activated muscles in the different moving direction on the unstable platform.
3. For the same muscle, there was significant difference of spectral energy in the different movement patterns.

According to the different subjects, the different movement patterns could be applied for improving the lower extremity strength for the appointed muscles. Through the choice of different movement patterns, a pertinent training scheme for lower extremity strength could be applied for different muscles in different intensity. Also, the ability of postural control could be improved through the strengthening of the lower extremity muscles.

REFERENCES

[1] F. B. Horak, C. L. Shupert, and A. Mirka, "Components of posturaldyscontrol in the elderly: a review," Neurobiology of Aging, vol. 10, no. 10, pp. 727-738, 1989.

[2] C. A. Laughton, M. Slavin, K. Katdare, L. Nolan, J.F. Bean, D.C. Kerrigan, E. Philips, L.A. Lipsite, and J.J. Collins, "Aging, muscle activity and balance control: physiologic changes associated with balance impairment," *Gait and Posture*, vol. 18, no. 2, pp. 101-108, 2003.

[3] S. R. Lord, J. A. Ward, P. Williams, and K. J. Anstey, "Physiological factors associated with falls in order community-dwelling women," *J. Am. Geriatr. Soc.*, vol. 42, pp. 1110-1117, 1994.

[4] R. H. Whipple, L. I. Wolfson, and P. M. Amerman, "The relationship of knee and ankle weakness to falls in nursing home residents," *J. Am. Geriatr. Soc.*, vol. 35, no. 1, pp. 329-332, 1987.

[5] D. M. Buchner, M. E. Cress, B. J. de Lateur, P. C. Esselman, A. J. Margherita, and R. Price, "The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults," *J. Gerontol. Biol. Sci. Med. Sci.*, vol. 52, no. 4, pp. M218-224, 1997.

[6] M. E. Cress, D. M. Buchner, K. A. Questad, P.C. Esselman, B. J. de Lateur, and R. S. Schwartz, "Exercise: effects on physical functional performance in independent older adults," *J. Gerontol. Biol. Sci. Med. Sci.*, vol. 54, no. 5, pp. M242-248, 1999.

[7] R. G. Hamman, I. Mekjavic, A. I. Mallinson, and N. S. Longride, "Training effects during repeated therapy sessions of blance training using visual feedback," *Arch. Phys. Med. Rehabil.*, vol. 73, no. 8, pp. 738-744, 1992.

[8] J. Wakeling, R. Delancy, and I. Dudkiewicz, “A method for quantifying dynamic muscle dysfunction in children and young adults with celebral palsy,” *Gaint and Postural*, vol. 25, no. 5, pp. 580-589, 2007.

[9] C. B. Ahn, E. J. Woo, Y. R. Yoon, and K. J. Lee, “Recent development tendency and future of biosignal processing,” *J. Biomed. Eng. Res.*, vol. 20, no. 2, pp. 119-138, 1999.

[10] D. L. Beoit, M. Lamontagne, G. Cerulli, and A. Liti, “The clinical significance of electromyography normalisation techniques in subjects with anterior cruciate ligament injury during treadmill walking,” *Gait and Postural*, vol. 18, no. 2, pp. 56-63, 2003.