Gait Kinetic Analysis of the Mechanical Vibration Stimulus Approved for Gait Ability Enhancement

K. Y. Kwak, M. H. Park and D. W. Kim

Abstract— During gait postural balance is important. Postural balance is requires sensory, muscular and central nerve systems. Therefore, to improve gait disorder, the senses related to postural balance should enhanced by using the external stimulus on sensory system. But, there have not been many studies on kinetic changes of gait, when a somatosensory stimulation is applied. Gait kinetic analysis was performed to validate the vibratory mechanical stimulation device in actual situation with 3D gait motion analysis. The results showed changed ground reaction force and lower-limb kinetic properties which was considered that local vibratory mechanical stimulation gave immediate feedback and changed the characteristics of gait. This study used a real-time analysis of patient's gait and external stimulation applied at proper timing and its results would be applied in patients who have gait abnormality due to lack of postural balance for rehabilitation.

Keywords—Somatosensory, Vibration Stimulation, Motion Analysis, Biomechanics, Gait.

I. INTRODUCTION

Postural balance control is the ability to maintain the balance and equilibrium of the human body in the space domain. Normal-postural balance control is defined as the ability to maintain the centroid of the body amid a minimum postural sway. It is attained in the midst of the postural equilibrium of the sight, vestibular sense, somatosensory sense (which plays an essential role in postural balance control and development), and motions [1]. Particularly in the gait, postural balance control is a complex process of controlling motions such sensory information integration, neural boundary processing, and biomechanics factors [2-4]. However, as the senses needed for postural control weaken with age, weak sensory information and inappropriate feedback are provided in the system related to postural control [5]. For this reason, the loss of body functions due to aging increases the risk of gait ability decline and getting hurt from a fall [6]. To solve such problems, bodily functions should be evaluated and diagnosed through gait analysis [7]. To enhance postural stability, senses related to postural control should be reinforced.

Among the researches that analyzed the correlation between the somatosensory system and postural stability, Gravelle [8] used electric stimulation for somatosensory stimulation, and confirmed the reduction of body sway. Dickstein [9] approved electric stimulation on the soleus of the lower-limb, and as a result, he proved the effect of static upright postural stability. However, an electric stimulus, has limitations of causing such problems as skin damage on the part to which an electrode is attached, dysphoria and pain from the stimulus, and muscle fatigue from long-time use [10].

Benedetti [11] performed three-dimensional kinematic gait analysis using the motion analysis system, and Wall [12] performed kinematic gait analysis using a force plate. Stolze [13] used a dynamic electromyogram, and Hayafune [14] used a gait parameter obtained through the results of the analysis of planta pressure. However, the above-mentioned analyses have spatial limitations, so they are inadequate for the analysis of gait in daily life[15].

To solve these problems, small sensors such as FSR sensor, acceleration sensor, and angular velocity sensor have been used [16-18].The gait analysis using small sensors can detect a relatively accurate gait event and solve the diverse spatial limitations of the existing gait analyses, so its application range is increasingly expanding.

Tong and Grant detected gait period by measuring the angular velocity of the shank and the thigh and the degree of slope of the rotating axis of the gyro sensor using gyro sensors [19]. Ahn Seung-chan, et al. developed the system that detects the gait period using FSR sensor attached to the sole and the gyro sensor attached to the heel. Using these, they detected the gait period in the level gait and the stair gait and evaluated the reliability [20]. However, the researches on the analysis of the gait using these small sensors have limitations that they were applied only to the normal gaits.

To overcome electric stimulus risk, spatial imitations of analysis, and the lack of diversity of gait, there is research that detects the gait period of abnormal gait using gyro signal of the small sensor and accordingly approves mechanical vibration stimulus and enhances senses [21-22]. This research detected the gait period accurately and showed that by approving the

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government(MSIP)(NRF-2014R1A2A1A11053073).

Dong-Wook Kim is with the Division of Biomedical Engineering, Chonbuk National University, Jeonju-si, Jeollabuk-do, Korea(Corresponding author to provide phone:+82-63-270-4060; fax:+82-63-270-2247; e-mail: biomed@jbnu.ac.kr)

Ki-Young Kwak is with the Department of Healthcare Engineering, Chonbuk National University, Jeonju-si, Jeollabuk-do, Korea(e-mail: kykwak@jbnu.ac.kr)

Min-Hwa Park is with the Department of Healthcare Engineering, Chonbuk National University, Jeonju-si, Jeollabuk-do, Korea(e-mail: pmh1004@jbnu.ac.kr).

vibration stimulus, the GRF pattern in the abnormal gait was induced to the GRF pattern in the normal gait. However, it is necessary to approve the vibration stimulus by measuring the actual movement of the ankle and to analyze the effects of the vibration stimulus in the biomechanical aspect of the Lower-limb.

Accordingly, this research developed the equipment that detects the gait period by measuring the angle of the movement of the ankle during walking, and approves the mechanical vibration stimulus. Moreover, this research analyzed the biomechanical changes caused by the vibration stimulus approved during gait.

II. METHOD

In this research, we have developed the small-sized instrument on our own to approve vibration stimulus, and by attaching it on the subject's top of the foot while walking, approved vibration stimulus to the subject's Achilles tendon. To analyze gait kinetical changes according to stimulus, the 3D motion analysis system and interpretation program were used.

A. Subjects

The subjects of this research were five male adults in their 20s who had no neurological disease, whose musculoskeletal functions were normal, and who could walk independently. Their height was 173.6±4cm, and their weight, 67.4±5.6 kg. They participated voluntarily in this research. This research was approved by the National Bioethics Committee (IRB File No. JBNU 2013-07-001).

B. Instrument

We developed the instrument on our own to detect the gait period and approve the mechanical vibration stimulus. The MPU-6050 (Invensense Co., USA) sensor module, which prints out three axis gyro signals and three axis acceleration signals, and ATmega128, which processes the signal received from the sensor and controls the vibration, were used. The Bluetooth module FB155C (Firmtech, Korea) for wireless Bluetooth communications was used. The linear actuator (DMJBRN1036AH, Samsung Electronics, Korea) was used to generate mechanical vibration. The sensitivity of the gyro signal and the acceleration signal were set at 500 degrees/sec and 2 g, respectively, and the sampling rate was set at 1,000 Hz. To control the mechanical vibration characteristics, the PWM method was used. The developed hardware is shown in Fig. 1.

Fig. 1 Vibratory mechanical stimulus Hardware

To analyze the biomechanical changes during walking, a three-dimensional motion analysis environment was constructed. First, to measure the gait movement, a total of 21 infrared luminescent markers were attached to the subjects, the locations of which, according to the movements in real time, were collected using three position sensor (Optotrak Certus, NDI Inc., Canada). Also, to collect ground reaction forces, a total of four of force plates (Bertec, USA) were used. All gait movement measurement processes were controlled using the First Principle software (NDI Inc., Canada). To analyze the biomechanical changes using measured movement data, SIMM (Musculo Graphics Inc., USA), a three-dimensional musculoskeletal modeling and analysis software, was used.

C. Stimulus Location and Vibration Stimulus Characteristics

To enhance postural stability, we had performed research that approves mechanical vibration stimulus and vitalizes the somatosensory system [21-30]. We approved mechanical vibration stimulus to Achilles tendon and anterior tendon and confirmed the changes of COP according to stimulated regions [23, 24] and confirmed the muscles that are vitalized according to stimulated regions [21-22, 25-28]. Also, we confirmed that biomechanical changes occurred in the midst of dynamic movement [21-22, 28-30], and confirmed that the same changes also occurred in the perceived sub-threshold vibration strength [21-22, 28]. To stimulate calf muscle that plays an important role during the stance phase, Achilles tendon was chosen as stimulated region based on the previously researches. And vibration band 190Hz where proprioceptive sensibility reacts sensitively was set as vibration frequency and vibration was approved with the intensity in which vibration could not be recognizable.

D. Protocol

We equipped the top of the subject's foot with the instrument we developed, and performed normal level walking and abnormal level walking. We randomly conducted experiments on the vibration stimulus conditions and the walking conditions, and asked the subjects to walk three times in each condition. To induce abnormal flatland gait, a sandbag was attached to the subject's ankle.

E. Analysis

To evaluate the accuracy of the detection, by the developed instrument, of the gait period, the ground reaction force signals and the angle signal outputted from there were compared. The time deviations in the heel strike time and the toe-off time were compared.

To analyze the biomechanical changes, ground reaction forces, and movement angles of each joint of the lower-limb, the joint moment and the joint power in each condition were compared and analyzed.

III. RESULTS

A. Hardware Algorithm

The instrument developed in this research was designed to continuously measure the movement of the ankle joint and to approve the mechanical vibration stimulus according to the degree of the plantar flexion. Accordingly, to extract the movement of the ankle joint, a gyro signal and an acceleration signal were inputted from the sensor module; and to extract the ankle angle by removing the measurement noise of the signal, a complementary filter was applied. The algorithm of the developed instrument is shown in Fig. 2.

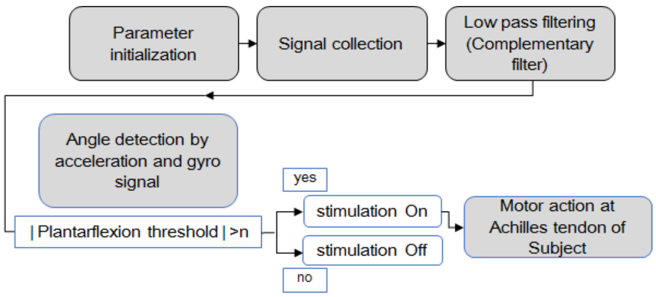
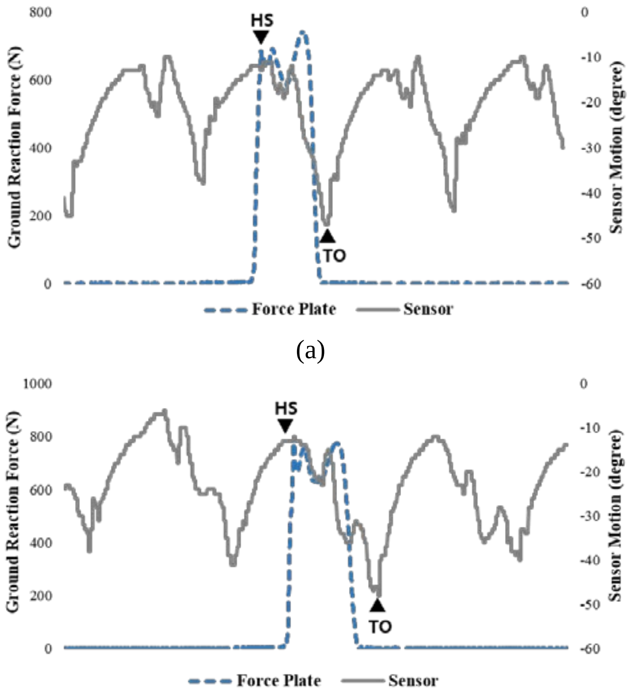


Fig. 2 Algorithm of the Vibratory Mechanical Stimulation Device

B. Hardware Verification and Effect

The gait period should be detected accurately to approve the vibration stimulus at the appropriate time while walking. Accordingly, to evaluate the detection of the gait period by the instrument developed in this research, the ground reaction force while walking was synchronized and compared with that in the normal walking and abnormal walking conditions.

To compare the periods with regard to the vibration stimulus algorithm used in this research, the angle received from this hardware and the frame of the signal of the GRF outputted from the FP were synchronized and compared. This is shown in Fig. 3.



(a)

(b)

Fig 3. Signal portable device and force plate during normal and abnormal gait
(a) Normal gait (b) Abnormal gait

As showed above, the cycle of forceplate GRF appears HS(heel strike) event, TO(toe off) event in order.

Table 1. HS and TO time deviation from portable device and force plate

Unit: msec

	Non stimulation				**Stimulation**			
	Normal gait		**Abnormal gait**		**Normal gait**		**Abnormal gait**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
HS	-3.25	46.28	10.73	28.03	-5.50	55.97	7.37	37.94
TO	64.43	50.73	92.80	64.98	62.63	34.04	88.00	61.31

As showed in Table 1, we compare the HS(heel strike) of sensor and forceplate with TO(toe off) time deviation when applying stimulation and not applying it.

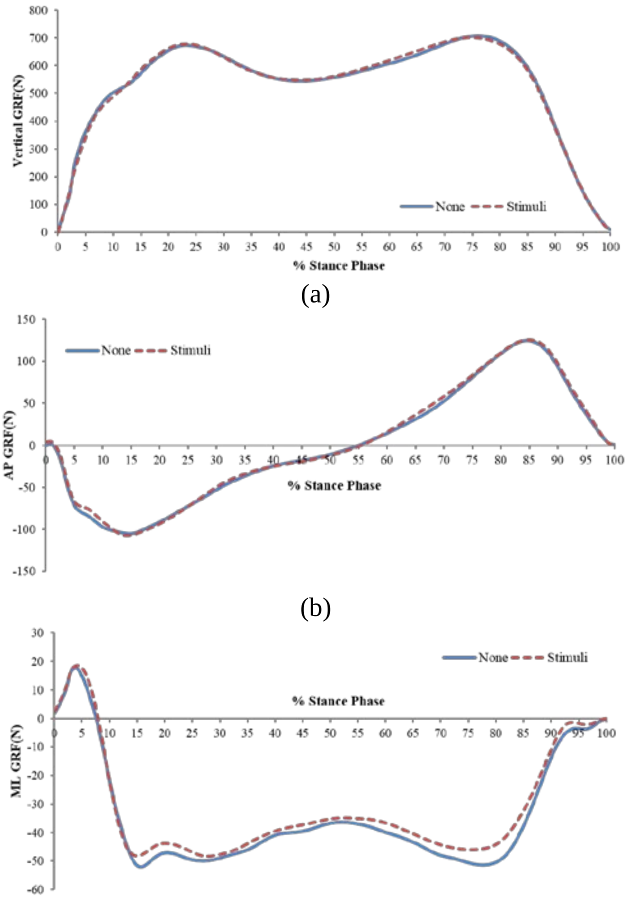
When walking without applying stimulation, the HS of sensor in normal gait appears 3.25msec earlier than that of forceplate and TO appears 64.43msec later than that of forceplate. The HS of sensor in abnormal gait appears 10.73msec later than that of forceplate and TO appears 92.80 later than that of forceplate. When walking with applying stimulation, the HS of sensor in normal gait appears 5.50msec earlier than that of forceplate and TO appears 62.63msec later than that of forceplate. The HS of sensor in abnormal gait appears 7.37msec later than that of forceplate and TO appears 88.00msec later than that of forceplate.

In the two types of normal gaits, HS of the instrument appears fast. The ankle is curved while walking and contacts the forceplate. In other words, since the ankle is curved before contacting the forceplate, HS appears faster, and afterwards the contact with the force plate takes place, so subsequently HS in the force plate appeared. In the abnormal gait, however, it appeared later than HS of the forceplate. The reason is deemed to be that the ankle was not curved sufficiently due to the sandbag. TO that appeared from there appeared later in all the gaits than the forceplate. TO appears later than the forceplate because maximum planta flexion appears after the toes are detached. Finally, when stimulus was approved, time error was reduced. This is deemed to be the results of changes in the gait period and the reason is presumed to be that vibration stimulus influenced muscles and the curve of the ankle was reduced and extension increased. In other words, it can be said that vibration stimulus elicited biomechanical changes.

The results of the comparison of time errors show that the gait period can be detected according to the movement of the feet while walking. This indicates that the angles of the ankle detected by the algorithm can be used for the detection of the actual gait events. In addition to overcoming the problems with the existing fixed system, this system can successfully approve stimulus to the gait event where the stimulus time is needed in normal gait and abnormal gait.

C. Normal Level Walking

The biomechanical changes when the mechanical vibration stimulus was approved are shown in Fig. 4-7. There was no change in the peak magnitude of the vertical GRF and the AP GRF according to the stimulus in the GRF, but the peak magnitude of the medial GRF decreased (Fig. 4).



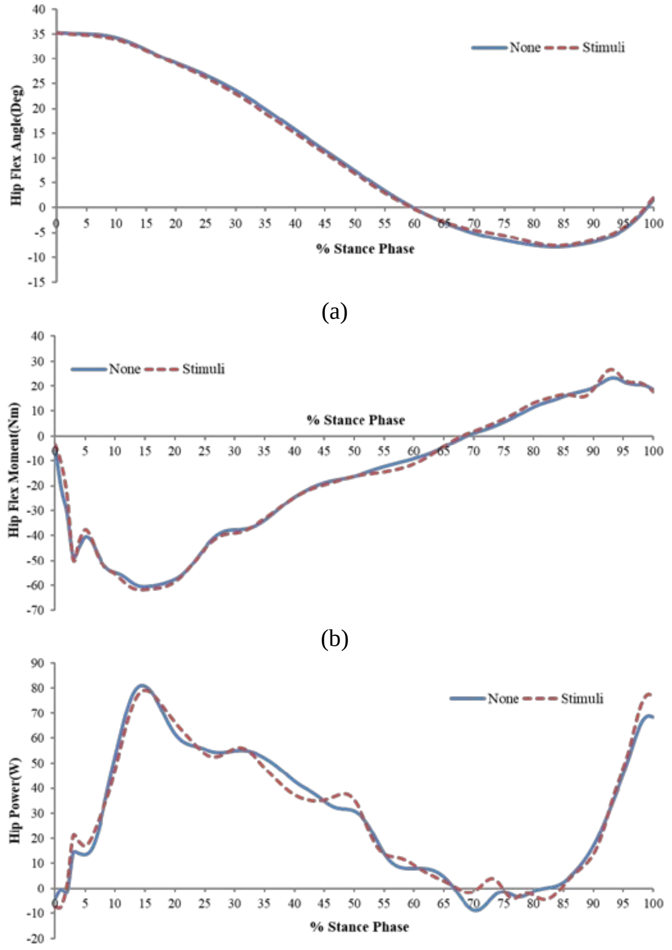
(a)

(b)

(c)

Fig. 4 Ground Reaction Force during Normal Level Gait (a) Vertical Ground Reaction Force (b) Anterior-Posterior Ground Reaction Force (c) Medial-Lateral Ground Reaction Force

In the hip joint, there was no change in the characteristics pattern according to the stimulus (Fig. 5).



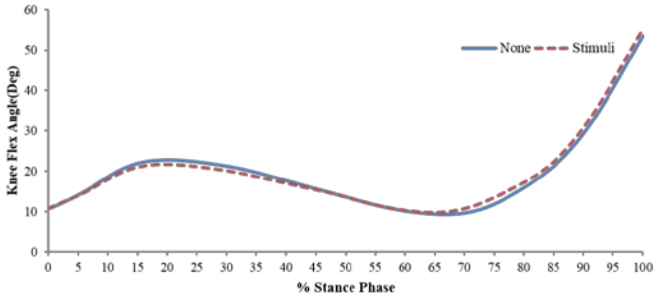
(a)

(b)

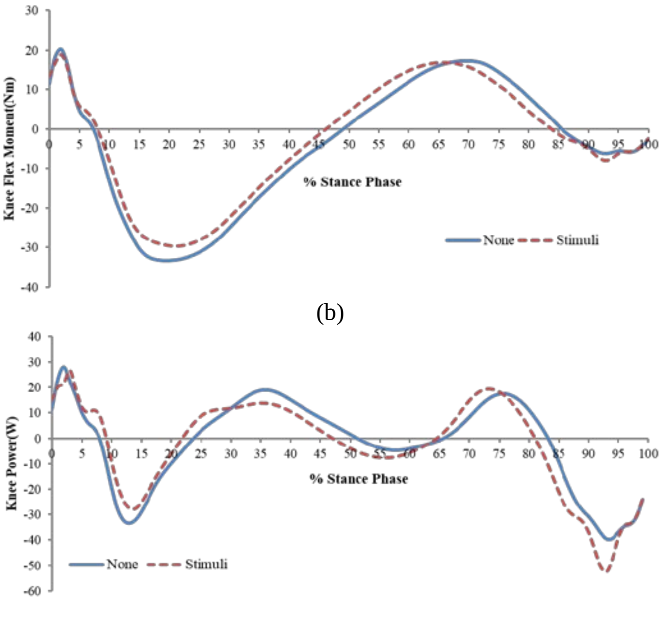
(c)

Fig. 5 Hip Joint Angle, Moment and Power during Normal Level Gait (a) Hip Joint Angle (b) Hip Joint Moment (c) Hip Joint Power

In the knee joint (Fig. 6), the knee extensor moment and the knee negative power in the 0-45% sections decreased according to the stimulus; and after 45%, there was a fast increase and decrease in the knee flexor moment and an increase in the knee power.



(a)

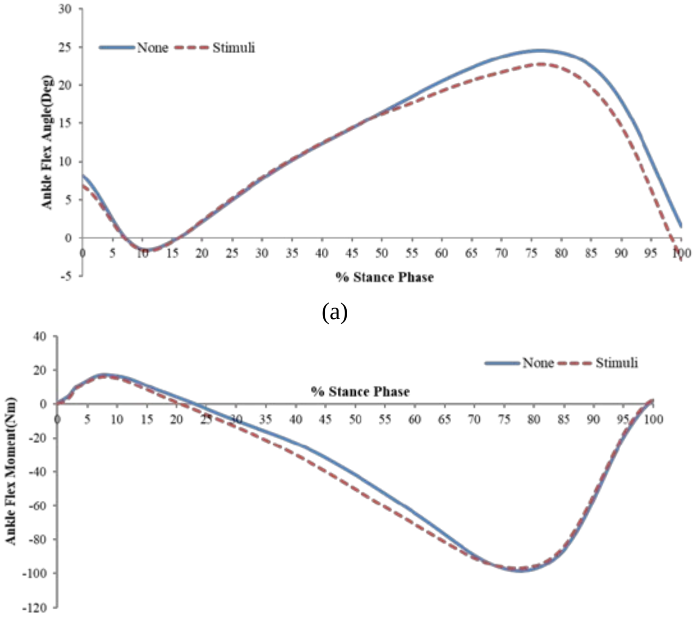


(b)

(c)

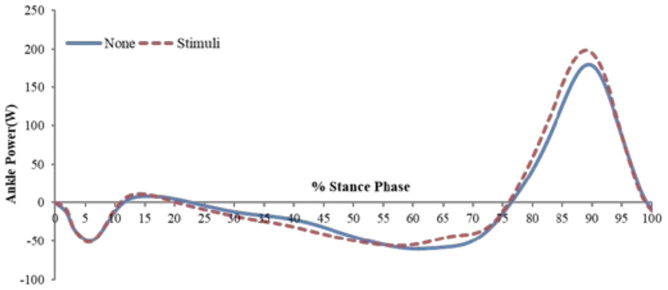
Fig. 6 Knee Joint Angle, Moment and Power during Normal Level Gait
(a) Knee Joint Angle (b) Knee Joint Moment (c) Knee Joint Power

In the ankle joint (Fig. 7), there was no change in the dorsiflexion in the 0-45% section, but there were increases in the ankle extensor moment and the negative power. After the 45% section, the ankle dorsiflexion decreased, the ankle extensor moment remained the same, and the positive power increased.



(a)

(b)

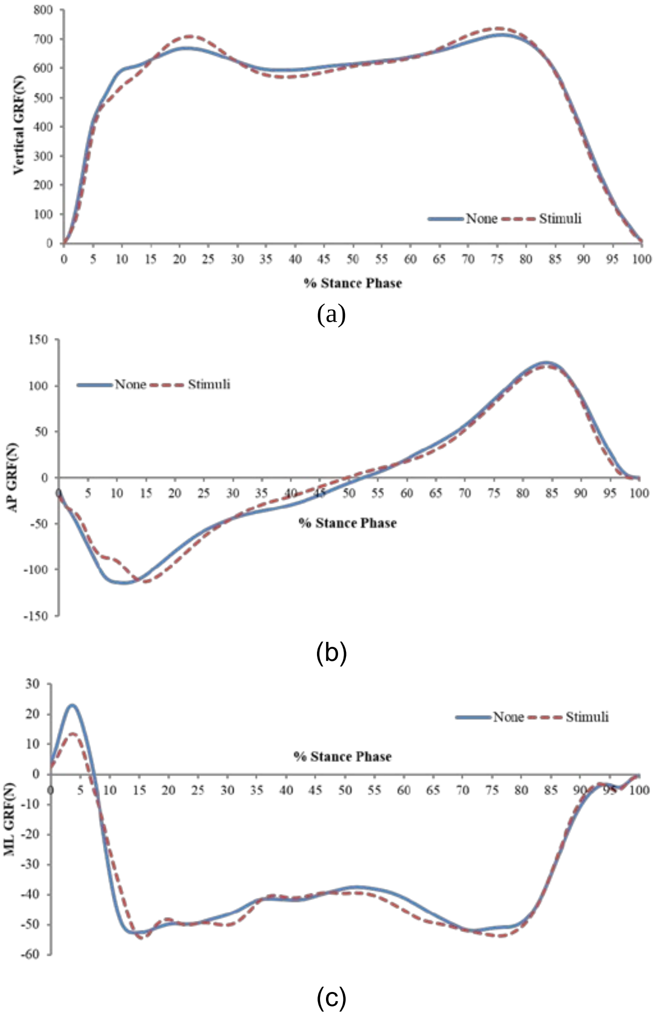


(c)

Fig. 7 Ankle Joint Angle, Moment and Power during Normal Level Gait
(a) Ankle Joint Angle (b) Ankle Joint Moment (c) Ankle Joint Power

D. Abnormal Level Walking

The biomechanical changes when the mechanical vibration stimulus was approved are shown in Fig. 8-11. Fig. 8(a) shows that when the mechanical vibration stimulus was approved, the first and second peaks increased, and the period from the heel strike (HS, 0% stance phase) to the end of the mid-stance phase (MSt, 40% stance phase) was extended. Fig. 8(b)-(c) show that the peak shifted according to the lengthening of the IC-MSt period.



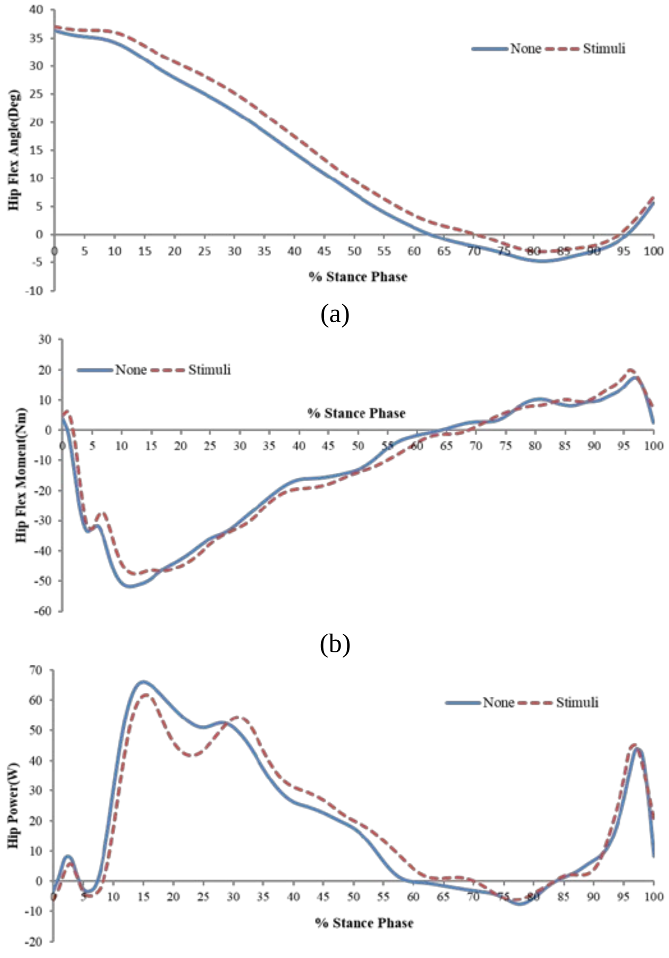
(a)

(b)

(c)

Fig. 8 Ground Reaction Force during Abnormal Level Gait
(a) Vertical Ground Reaction Force (b) Anterior-Posterior Ground Reaction Force (c) Medial-Lateral Ground Reaction Force

In the hip joint (Fig. 9), the hip flexion increased and the extension decreased; and in the loading response period (LR, 0-20% stance phase), the decreased hip extensor moment and the decreased hip positive power appeared.



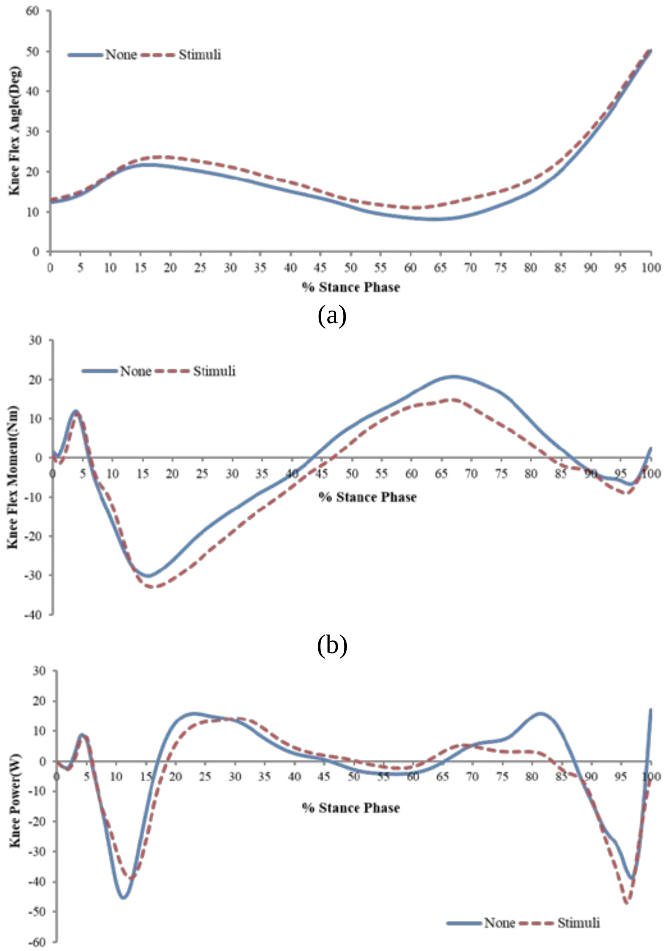
(a)

(b)

(c)

Fig. 9 Hip Joint Angle, Moment and Power during Abnormal Level Gait
(a) Hip Joint Angle (b) Hip Joint Moment (c) Hip Joint Power

In the knee joint (Fig. 10), there was an overall increase in the knee flexion, the knee extensor moment increased, and the flexor moment decreased. In the LR period, the knee negative power peak shifted and decreased; and in the pre-swing period (PS, 75-100% phase), the negative peak increased.



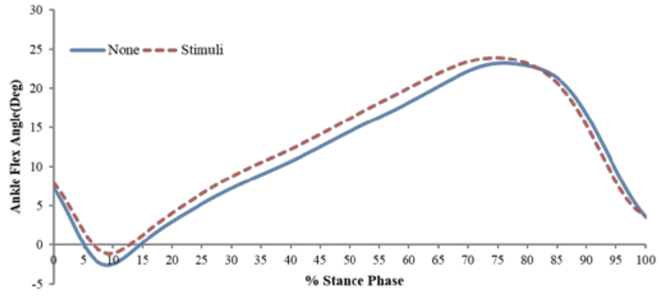
(a)

(b)

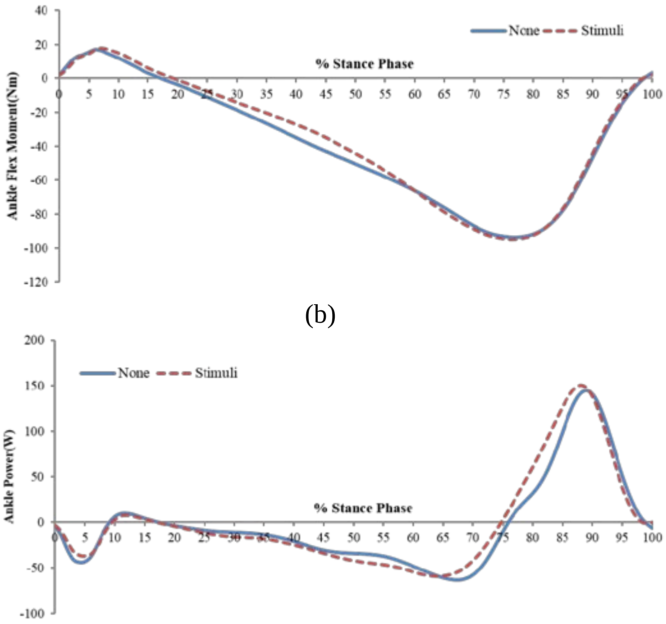
(c)

Fig. 10 Knee Joint Angle, Moment and Power during Abnormal Level Gait
(a) Knee Joint Angle (b) Knee Joint Moment (c) Knee Joint Power

In the ankle joint (Fig. 11), the power from the HS to before the PS was similar; but in the PS period, the positive peak increased.



(a)



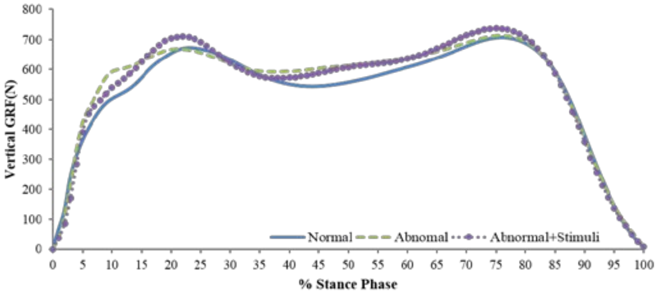
(b)

(c)

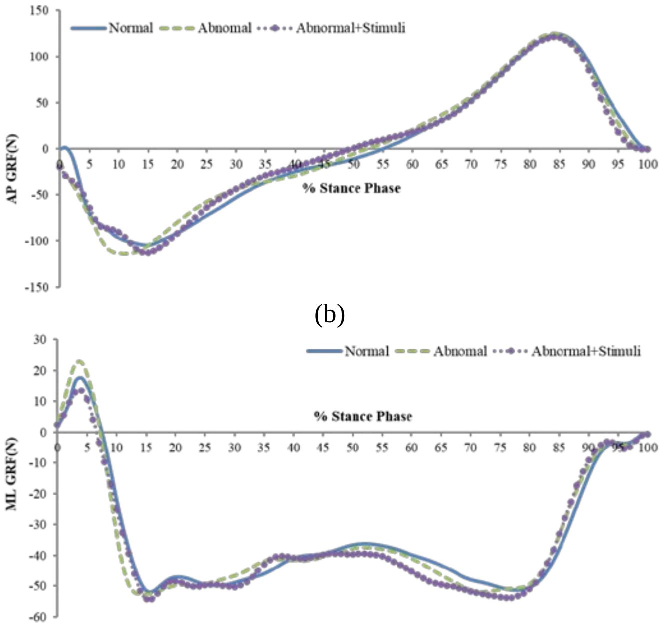
Fig. 11 Ankle Joint Angle, Moment and Power during Abnormal Level Gait
(a) Ankle Joint Angle (b) Ankle Joint Moment (c) Ankle Joint Power

E. Gait Kinetics Vibratory Mechanical Stimulation

To show the effects of the mechanical vibration stimulus on the abnormal gait, the unstimulated normal gait was compared with the abnormal gait, as shown in Fig. 12-15. In the vertical GRF in Fig. 12 (a), the HS-MSt period during the normal gait was 0-45%; and during the abnormal gait, it was 0-34%. When the mechanical vibration stimulus was approved in the abnormal gait, the first peak clearly developed and the HS-MSt period was extended to 0-38%. In other words, it can be seen that the abnormal gait pattern was induced to change to the normal gait pattern. In the same way, when the stimulus was approved as shown in Fig. 12(b), the first peak of the abnormal gait shifted and was induced to change to the normal gait pattern. This can also be seen in Fig. 12(c).



(a)

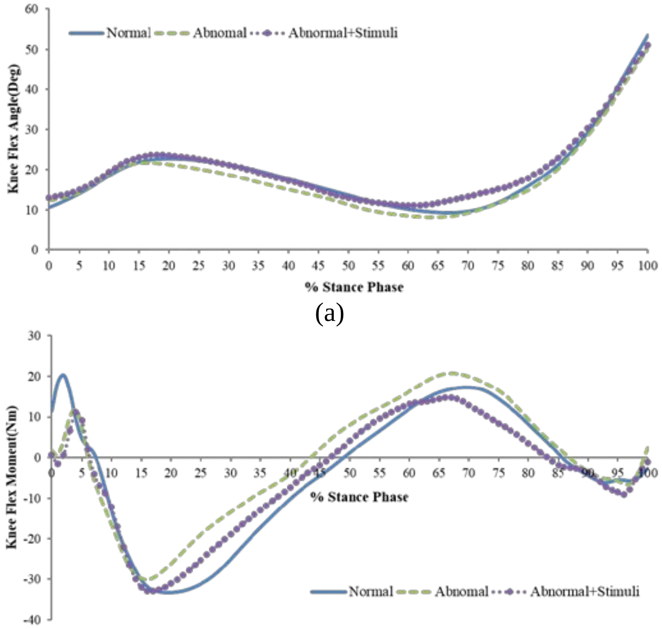


(b)

(c)

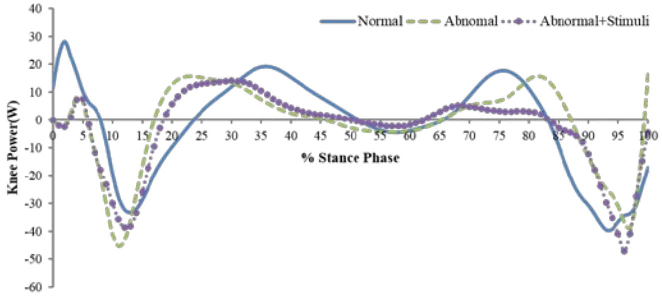
Fig. 12 Ground Reaction Force Change with Vibratory Mechanical Stimulation
(a) Vertical Ground Reaction Force (b) Anterior-Posterior Ground Reaction Force (c) Medial-Lateral Ground Reaction Force

Fig. 13(a) shows that when the vibration stimulus was approved, the knee flexion of the abnormal gait was induced to follow the normal gait pattern. The same results are shown in the knee joint moment in Fig. 13(b). When the vibration stimulus was applied to the knee joint power shown in Fig. 13(c), the first negative peak of the abnormal gait decreased and shifted, as it did in the first positive peak and the second positive peak. Finally, the second negative peak of the abnormal gait increased and shifted, due to which it followed the tendency of the normal gait pattern.



(a)

(b)

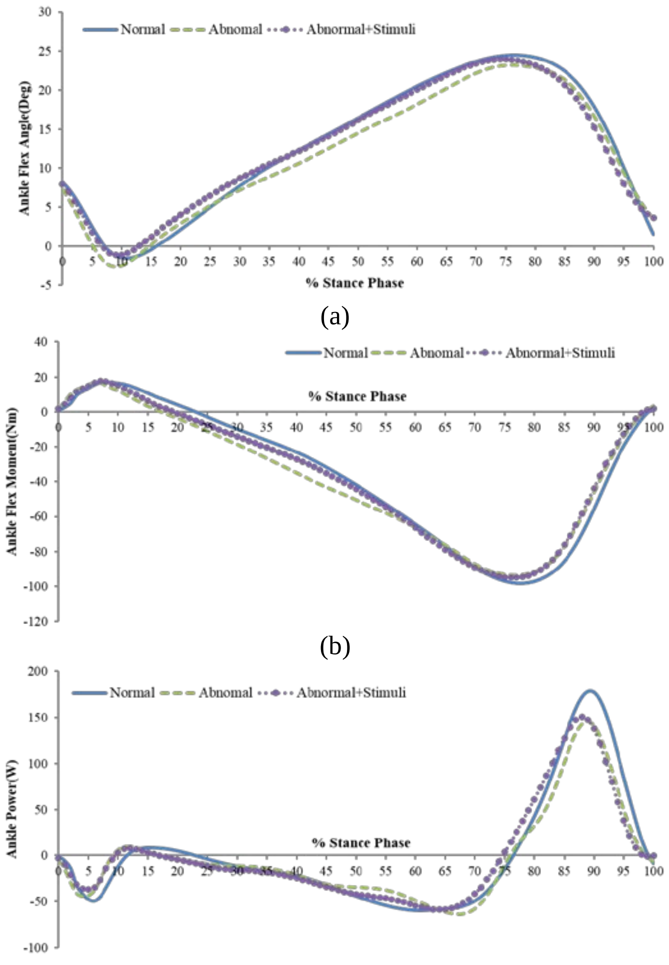


(c)

Fig. 13 Knee Joint Kinetics Change with Vibratory Mechanical Stimulation

(a) Knee Joint Angle (b) Knee Joint Moment (c) Knee Joint Power

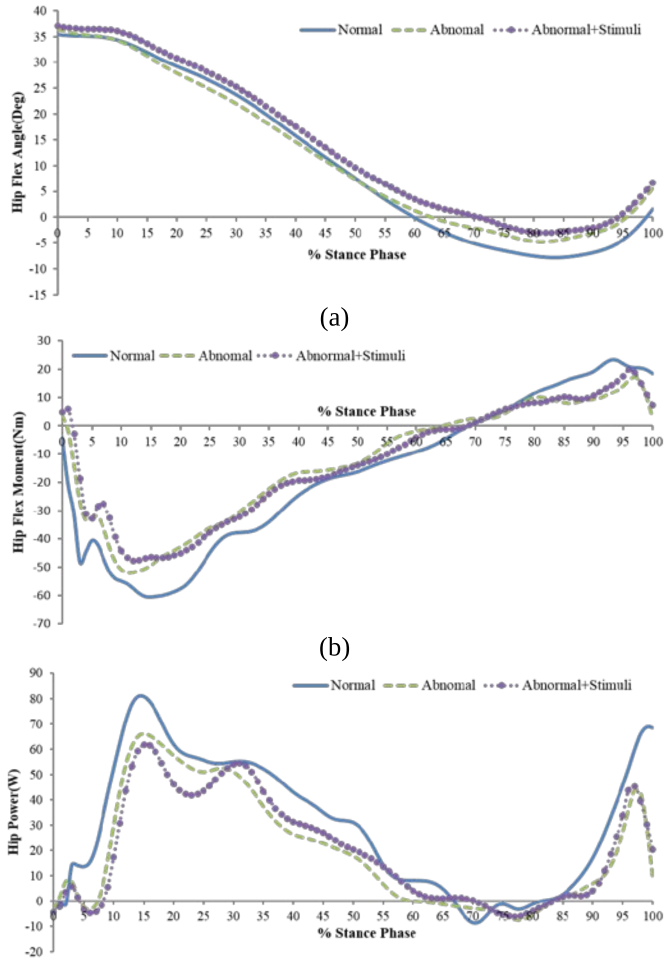
When the vibration stimulus was applied, as shown in Fig. 14(a), the peak magnitude of the ankle flexion changed and shifted, and followed the normal gait pattern. The same results can be seen in Fig. 14(b) and (c). In the hip joint, however, the changes that appeared until as shown in Figs. 12-14 did not appear. This is deemed to be because the pelvis is connected to the muscles of the upper body, due to which it is affected by the gait posture of the individual subject.



(c)

Fig. 14 Ankle Joint Kinetics Change with Vibratory Mechanical Stimulation

(a) Ankle Joint Angle (b) Ankle Joint Moment (c) Ankle Joint Power



(c)

Fig. 15 Hip Joint Kinetics Change with Vibratory Mechanical Stimulation

(a) Hip Joint Angle (b) Hip Joint Moment (c) Hip Joint Power

The conformity of the normal gait and the three gait patterns (unstimulated abnormal gait pattern, vibration stimulus abnormal gait pattern, vibration stimulus normal gait pattern) are shown in Table 3. The average of the differences between the normal gait pattern value and the three other gait pattern values was calculated and it shows that the smaller the value the more similar the gait pattern to the normal gait pattern.

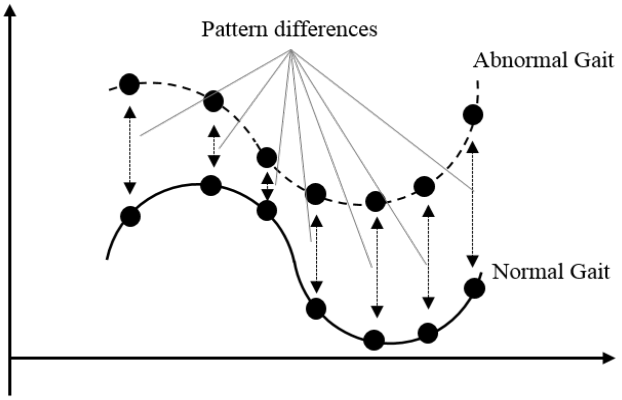


Fig. 16 Example of pattern difference

Table 2. Gait pattern deviation

	Abnormal Gait (Stimuli Off)	Abnormal Gait (stimuli On)	Normal Gait (Stimuli On)
Hip Angle	1.8±1.27	3.07±1.55	0.48±0.23
Knee Angle	1.5±0.91	1.19±0.99	0.83±0.56
Ankle Angle	1.37±0.64	0.91±0.76	1.21±1.29
Hip Moment	7.35±4.44	6.83±5.82	1.19±1.28
Knee Moment	5.07±3.8	3.49±3.12	2.51±1.22
Ankle Moment	6.25±3.51	3.92±2.82	3.69±2.63
Hip Power	10.55±6.21	10.38±9.39	3.15±2.23
Knee Power	9.92±7.77	8.21±6.05	4.77±2.94
Ankle Power	10.77±10.68	10.61±12.33	7.28±6.38
Vertical GRF	26.82±24.17	28.14±16.41	6.8±4.83
AP GRF	6.94±5.66	6.49±5.7	2.63±1.84
ML GRF	2.47±2.34	2.72±1.93	2.62±1.5

Table 2 shows that the difference from the normal gait pattern was lowest when the vibration stimulus was approved in the normal gait, and next lowest when the vibration stimulus was approved in the abnormal gait. This means the gait pattern when the vibration stimulus was approved in the normal gait was most similar to the normal gait, followed by the gait pattern when the vibration stimulus was approved in the abnormal gait.

These results were probably because the functions of muscles changed due to vibration stimulus. Lapole et al [31, 32] reported increase in MVC and EMG of target muscles after applying ATV to the subjects, and also reported the reduction of muscle stiffness. And Luo et al [33] reported that EMG activity was reinforced. In addition, a lot of research on the correlation between the vibration stimulus and muscle functions have been performed [34]. The results of this research also, like aforesaid past researches, are that muscle functions are changed by vibration stimulus. Due to vibration stimulus, changes in flexion of each joint according to changes in stiffness of muscles and changes in moment and power of each joint according to changes in vitality appeared. In other words, vibration stimulus increased performance of muscles and as a result, the abnormal gait pattern was induced to the normal gait pattern.

IV. Conclusion

In this research, we have developed portable mechanical vibration stimulus instrument that can give help to gait by easy application to daily life. And using this instrument, we approved the vibration with the intensity in which vibration is not recognizable during the gait. As a result, we could confirm that, when vibration stimulus was approved during abnormal gait, the abnormal gait pattern was induced to the normal gait pattern. In other words, we could confirm that vibration stimulus is effective in improving the gait during abnormal gait without disturbing senses. Since the instrument developed in this research is small-sized and can immediately approve vibration stimulus, it can be sufficiently utilized in daily life and rehabilitation treatment.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (NRF-2014R1A2A1A11053073).

References

[1] C. Ghez, Posture, In: Principles of neural science, E.R. Kandel, J.H. Schwartz, T.M. Jessell Eds., Elsevier, New York, pp.596–602, 1991.

[2] C.L. Hubley-Kozey, M.J. Vezina, Muscle activation during exercises to improve trunk stability in men with low back pain, *Archives of Physical Medicine and Rehabilitation*, vol.83 , pp. 1100-1108, 2002.

[3] U.C. Kim, S.J. Jang, M.Y. Park, Affecting the gait parameters of stroke patients, *Journal of Korean Academy of Rehabilitation Medicine*, vol.16, pp. 443-451, 1992.

[4] H.S. Lee, H.S. Cho, O.Y. Kwon, A literature review on balance control factors, *Physical Therapy Korea*, vol.3, pp.82-91, 1996.

[5] R.S. Mazzeo, P. Cavanagh, W.J. Evans, M. Fiatarone, J. Hagberg, E. McAuley, J. Startzell, ACSM position stand on exercise and physical activity for older adults, *Medical and Science in Sports and Exercises*, vol.30, pp.992–1008, 1998.

[6] S.R. Lord, J.A. Ward, P. Williams, K. Anstey, Physiological factors associated with falls in older community-dwelling women, *Journal of the American Geriatrics Society*, vol.42, pp.1110–1117, 1994.

[7] S. Corazza, L. Mündermann, A. M. Chaudhari, T. Demattio, C. Cobelli, T. P. Andriacchi, A markerless motion capture system to study musculoskeletal biomechanics: visual hull and simulated annealing approach, *Annals of Biomedical Engineering*, vol.34, pp.1019-1029, 2006.

[8] D. C. Gravelle, C. A. Laughton, N. T. Dhruv, K. D. Datdare, J. B. Niemi, L. A. Lipsitz, J. J. Collins, Noise-enhanced balance control in older adults, *Neuroreport*, vol.13, pp.1853-1856, 2002.

[9] R. Dickstein, Y. Laufer, M. Katz, TENS to the posterior aspect of the legs decreases postural sway during stance, *Neuroscience letters*, vol.393, pp.51-55, 2006.

[10] C. Mauter, T. Mergner, B. Bolha, F. Hlavacka, Human balance control during cutaneous stimulation of the plantar soles, *Neuroscience Letters*, vol.302, pp.45-48, 2001.

[11] M. G. Benedetti, A. Merlo, A. Leardini, Inter-laboratory consistency of gait analysis measurements, *Gait Posture*, vol. 38, pp.934-939, 2013.

[12] J. C. Wall, J. Crosbie, Accuracy and reliability of temporal gait measurement, *Gait Posture*, vol.4, pp.293-296, 1996.

[13] H. Stolze, J. P. Kuhtz-Buschbeck, C. Mondwurf, A. Boczek-Funcke, K. Jöhnk, G. Deuschl, M. Illert, Gait analysis during treadmill and overground locomotion in children and adults, *Electroencephalography and Clinical Neurophysiology*, vol.105, pp.490-497, 1997.

[14] N. Hayafune, Y. Hayafune, H.A.C. Jacob, Pressure and force distribution characteristics under the normal foot during the push-off phase in gait, *The foot*, vol. 9, pp.88-92, 1999,.

[15] K. Parvataneni, L. Ploeg, S. J. Olney, B. Brouwer, Kinematic, kinetic and metabolic parameters of treadmill versus overground walking in healthy older adults, *Clinical Biomechanics*, vol.24, pp.95-100, 2009.

[16] J.S. Kim, J.W Koo, Y.K Kim, The effect of a visual and auditory cognitive tasks on the walking performance, *Bulletin of Korean Industrial Medicine*, vol.48, pp.1-9, 2009.

[17] J.T. Han, M.H Lee, K.H Lee, Effects of local muscle vibration on the displacement of center of pressure during quiet standing, *Journal of Physical Therapy Science*, vol.25, pp.1643-1645, 2013.

[18] T.S. Bae, H. J. Kim, S. B. Kim, Y. H. Chang, S. K. Kim, M. S. Nun, Effect

of multi-channel vibration stimulation on somatosensory sensibility, *Journal of The Korean Society for Precision Engineering*, vol. 28, pp. 651-656, 2011.

[19] K. Tong, M. H. Granat, A practical gait analysis system using gyroscopes, *Medical Engineering and Physics*, vol. 21, pp. 87-94, 1999.

[20] S.C. Ann, S.J. Kang, Y.H. Kim, Development and evaluation of a new gait phase detection system using FSR sensors and a gyrosensor, *Jounrnal of the Korean Society of Precision Engineering* **21** (2004), 196-203.

[21] H. J. So, S. H. Kim, D. W. Kim, "A study on the changes in gait characteristics by applying sub-threshold vibration stimulus in the ankle", *Journal of Vibroengineering*, Vol 16, Issue 7, pp.3331-3339, Nov 2014.

[22] H. J. So, S. H. Kim, D. W. Kim, "The effects of application site and time of vibration stimulation: Changes in gait pattern and muscle activity", *Applied Mechanics and Materials*, Vols. 479-480, pp.475-479, 2014.

[23] M. Yu, H. I. Eun, D. W. Kim, T. K. Kwon and N. G. Kim, "Effects of Vibratory Stimulus on Postural Balance Control during Standing on a Stable and an Unstable Support", *J. Biomed. Eng. Res*, Vol. 28, pp.647-656, Oct 2007.

[24] H. I. Eun, M. Yu, D. W. Kim, T. K. Kwon and N. G. Kim, "The effects of human lower limb vibration on postural stability during unstable posture", *J. Biomed. Eng. Res*, Vol. 28, pp.628-635, Oct 2007.

[25] M. Yu, "Study on postural control using somatosensory stimulation", Ph.D dissertation, Dept. Biomedical Eng., Chonbuk Nat. Univ., jeonju, Korea, 2009.

[26] H. J. So, S. H. Kim, D. W. Kim, "Effects of muscular response for the intensity of vibratory stimulus applied on the ankle tendon", *Journal of Vibroengineering*, vol. 14, Issue. 4, pp.1469-1477, DECEMBER 2012.

[27] H. J. So, H. Y. Oh, S. H. Kim, D. W. Kim, "The study on the correlation of vibration stimulation intensity and muscle activity", *Applied Mechanics and Materials*, Vols. 284-287, pp.1651-1655, 2013.

[28] H. J. So, "Analysis of responses by applying sub-threshold vibration stimulus and development of therapy system for gait disturbance using the stimulus", Ph.D dissertation, Dept. Healthcare Eng., Chonbuk Nat. Univ., jeonju, Korea, 2014.

[29] H. J. So, K. Y. Kwak, S. H. Kim, Y. S. Yang, N. G. Kim and D. W. Kim, "The analysis of GRF and joint angles of young and older adult by vibration stimulation on the ankle-joint in stair-descent activity", *J. Biomed. Eng. Res*, Vol. 32, pp.61-73, 2011.

[30] K. Y. Kwak, H. J. So, S. H. Kim, Y. S. Yang, N. G. Kim and D. W. Kim, "Effects of somatosensory stimulation on lower-limb joint kinetic of older adult during stair descent", *J. Biomed. Eng. Res*, Vol. 32, pp.93-104, 2011.

[31] T. Lapole and P. Chantal, "Effect of repeated achilles tendon vibration on triceps surae force production", *Journal of Electromyography and kinesiology*, vol. 20, issue. 4, pp.648-654, Aug 2010.

[32] T. Lapole and P. Chantal, "Effect of repeated achilles tendon vibration on triceps surae stiffness", *Journal of Electromyography and kinesiology*, vol. 21, issue. 1, pp.87-94, Feb 2011.

[33] J. Luo, B. McNamara, K. Moran, "A portable vibrator for muscle performance enhancement by means of direct muscle tendon stimulation", *Medical Engineering & physics*, vol. 27, issue 6, pp.513-522, July 2005.

[34] J. Luo, B. McNamara, K. Moran, "The use of vibration training to enhance muscle strength and power", *Sports Med*, vol. 35, issue. 1, pp.23-41, Sep 2005.

Ki-Young Kwak received master's degree in Healthcare Engineering from Chonbuk National University, Jeonju, South Korea in February of 2011. Now he is a graduate school student of Department of Healthcare Engineering in Chonbuk National University, Jeonju, South Korea. He current research interests include Sensory-Motor integration, Biomechanics, Motion Analysis and Healthcare System.

Min-Hwa Park received master's degree in Healthcare Engineering from Chonbuk National University, Jeonju, South Korea in February of 2015. Now she is a graduate school student of Department of Healthcare Engineering in Chonbuk National University, Jeonju, South Korea. Her current research interests include sensory-motor integration, diagnosis and healthcare system.

Dong-Wook Kim received Ph.D. degree in Biomedical Engineering from Hokkaido University, Sapporo, Japan in 1995. Now he is a professor at Division of Biomedical Engineering and Vice President of Academic Affairs Office in Chonbuk National University, Jeonju, South Korea. His current research interests include biomedical engineering, rehabilitation engineering, sensory-motor integration, diagnosis and healthcare system.