The Improvement Effect of Muscle Strength Imbalance according to Sound Stimulus during Gait with Analysis of Muscular Activity and Foot Pressure

Seung-Rok Kang, Chul-Un. Hong, and Tae-Kyu Kwon

***Abstract*—** This study was to develop the balance insole system for detecting and improving the muscle imbalance of left and right side in lower limbs. We were to verify the validation of balance insole system by analyzing the strategy of muscular activities and foot pressure according to sound feedback. We developed the balance insole based FSR sensor modules for estimating the muscle imbalance using detecting foot pressure. The insole system was FPCB have 8-spot FSR sensor with sensitivity range of 64-level. The participants were twenty peoples who have muscle strength differences in left and right legs over 20%. We measured the muscular activity and foot pressure of left and right side of lower limbs in various gait environment for verifying the improvement effect of muscle imbalance according to sound feedback. They performed gait in slope at 0, 5, 10, 15% and velocity at 3, 4, 5km/h. The result showed that the level of muscle imbalance reduced within 30% for sound feedback of balance insole system contrast to high level of muscle imbalance at 169.9~279.15% during normal gait for increasing slope and velocity including foot force results. This study found the validation of balance insole system with sound feedback stimulus. Also, we thought that it is necessary to research on the sensitivity of foot area, detection of muscle imbalance and processing algorithm of correction threshold spot.

***Keywords*—**Muscle Strength Imbalance, Muscular Activity, Foot Pressure, Balance Insole, Sound Feedback.

I. Introduction

RECENTLY many people have various imbalance of human body and, the imbalance caused the muscular skeletal disease. The cause of the imbalance consist of the anatomical abnormality, stable abnormality and functional abnormality according to unnatural biomechanical structure and function. It was generally known that the wrong life habit were big part of main fact of imbalance except congenital abnormality[1]. The lift habit according to the wrong repetitive motion in long time into unconsciousness brought the more deformation of human body than other reasons. Generally, people more used the dominant muscle for physical activities in the life[2-3]. There include the muscle imbalance causes from daily life as leaning on one foot, a bag on the shoulder to one side and habit with walking in high-heels for the woman. These wrong daily habits could cause the muscle imbalance for continuous and unconscious repeated motions and, it has many problems that was even slight level. In addition, the exercise habits lead to ineffective exercise in the human body and persistent stress on the muscles due to the sustained posture and repetitive movements, resulting in a serious negative effect of muscle on the muscles function and body balance of the body. Continuous functional deformations in the human body lead to severe orthopedic impairments and pain, such as pelvic distortion, difference in right and left shoulders, and spinal deformity.

However, there is no system for improving muscle strength imbalance that measures muscle force imbalance and calibrates it only to measure muscle strength or foot pressure. Until recently, most studies on the imbalance of right and left imbalance were mostly for the diagnosis of injured persons in the general public or athletes, or for limb surgery. Preliminary studies on current and unusual muscle imbalances have been conducted mostly on the effects of muscle imbalance on injuries. A study on the effects of muscle imbalance reported that the deficit ratio of both sides of the knee exceeded ± 10%, which could have the possibility of injury was high to the athletes[4]. It was reported that the injuries could increase when the quadriceps muscle strength difference of left and right leg was increased over 10%. Also if the muscle imbalance is greater than 8%, there is a muscle imbalance, and if more than 10% is present, there is a possibility of injury[5-6].

However, there is a lack of systematic studies on muscle strength imbalance mainly due to the imbalance of the upper extremity muscles and the resulting back pain. It is estimated that lower extremity muscles are more common than upper extremities and musculoskeletal disorders are less[8-9]. Therefore, biomechanical, physiological and human

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psychological studies are needed. The difference in left and right muscle strength of the lower limb causes various musculoskeletal disorders, but there are few studies on precise measurement standards and improvement methods yet. Studies on muscle imbalance are limited to studies on human body effects.

Therefore, in this study, we developed a balance insole based on FSR sensor capable of measuring left and right muscle imbalance of the lower and we were to verify the improvement effect of muscle strength imbalance according to sound recognition feedback for evaluating muscular activity and foot pressure in the various gait environment.

II. METHODS

A. Developed the balance insole system

In this study, we developed FSR sensor based foot pressure sensing insole and integrated sensor module to develop balance insole for measuring the muscle strength imbalance of left and right side in lower limbs including application for detecting level. We designed the FPCB (FSR-400 mounted on flexible PCB of 0.2T thickness) with equipped FSR sensor on 8 parts for considering the foot pressure distribution(Fig. 1). The pressure detection range of the developed insole can be subdivided into 32 ~ 64 steps, so it is possible to measure more precise foot pressure and it is possible to mount sensor on both sides such as top / bottom. We developed the 9-axis module(3-axis acceleration sensor + 3-axis gyro sensor + 3-axis geomagnetic sensor) for measurement and analysis of imbalance pattern during gait and BLE integrated module for sensing data transmission(Table. 1).

TABLE I. FSR SENSOR CHARACTERISTICS IN THE DEVELOPED INSOLE

Parameter	Value
Size range	18.3 x 54.1 mm
Active area	12.7 mm
Device thickness	0.46mm
Force sensitivity range	100g ~ 10kg
Pressure sensitivity range	1.5 ~ 150psi
Break force(turn on force)	20~100g
Stand-off resistance	Over 1M Ω

B. Procedure

Before the test, we measured the muscle mass test was performed to minimize the error of the muscle unbalance result according to the amount of muscle in the physical condition of subjects. We recruited one hundred individuals who had no medical history with muscle function. We also measured their joint torque using biodex system3(biodex medical systems, Inc., USA) in the pre-test(Fig. 2). We measured knee and ankle joint torque with 60°/sec of angular velocity and 60° of range of motion. And we finally selected thirty participants(male 15, female 15) who had 20% differences of muscle strength between left and right lower limbs. We finally selected the thirty participants with over 20% of muscle strength imbalance using isokinetic muscle function test. The participants walked on the treadmill according to various gait conditions with developed balance insole in this study. The gait environment was provided with 0, 5, 10% of slope and 3 km / h, 4 km / h, 5 km / h of gait velocity. The sound recognition feedback was informed about the foot pressure with greater strength in the event of unbalanced muscle strength in the walking environment. In order to verify the effectiveness of the developed balance insole and the effect of sound recognition feedback on walking. Also, we evaluated the real-time muscular activity and foot load distribution according to muscle strength imbalance on walking environment. In order to minimize the error of the subjects' physiological changes according to the room temperature during the gait experiment, the experimental environment was maintained at a room temperature of 25 ° C and a humidity level of 50% during the experiment. During the experiment, when the patient complained of vomiting, headache or muscle pain, the experiment was stopped immediately.

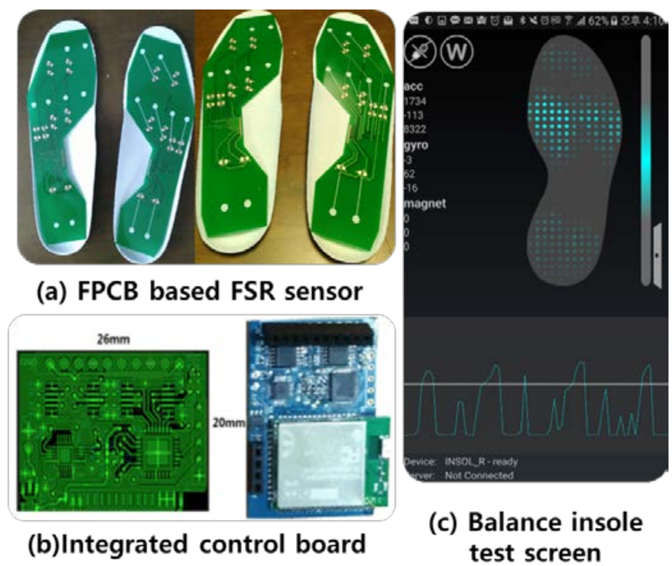

Fig. 1 Developed the balance insole system configuration((a) FPCB based FSR sensor product, (b) integrated control board, (c) balance insole test screen)

Fig. 2 Isokinetic joint torque test for estimating the muscle strength imbalance in left and right legs((a) : knee joint, (b) : ankle joint)

C. Evaluation

We measured the real-time muscular activity using Bagnoli¬8ch EMG system (Bagnoli, Delsys Inc, Boston, MA) during walking exercise to evaluate the effect of the left and right muscle imbalance and the improvement of muscle strength imbalance according to the presence of sound recognition feedback with developed balance insole equipment. Measuring muscles include rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), gastrocnemius (GN) and measurement electrodes were attached to the same muscle on both the left and right legs, minimizing EMG signal errors according to muscle position. Data sampling was performed at 1000 Hz and amplification was performed after Bagnoli modem filtering for noise minimization. Data was collected after band pass filtering 25-450 Hz with a butter-worth filter. To evaluate the effects of muscle strength imbalance on foot load distribution, we measured real-time foot pressure using PEDAR-X system (Fig. 3). We divided into eight spot and analyzed as two spot of forefoot(F1, F2), four spot of midfoot (M1, M2, M3, M4) and two spot of rearfoot (R1, R2) for estimating the foot pressure distribution according to the muscles strength imbalance of left and right in the lower limb(Fig. 4)

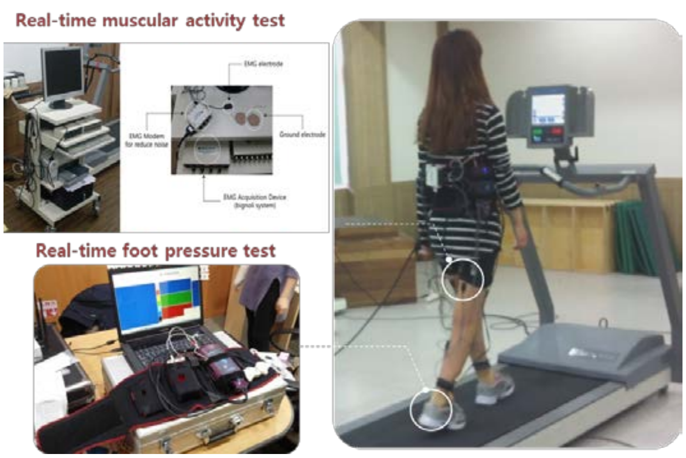

Fig. 3 Real-time muscular activity and foot pressure for estimating muscle strength imbalance according to gait environment

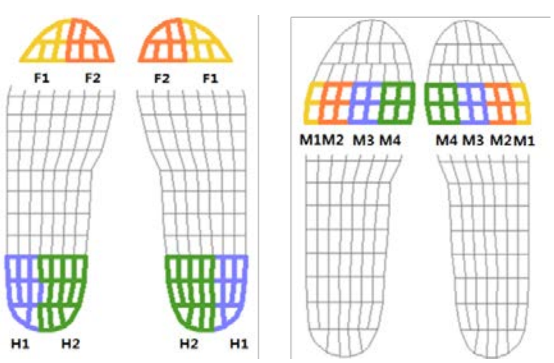

Fig. 4 The defination of foot pressure area in forefoot, midfoot and rearfoot for estimating muscle strenth imbalance

D. Data analysis

We estimated the real-time muscular activity and foot pressure in order to investigate the muscle strength imbalance according to various gait environment and analyzed the sound recognition effect for improving muscle strength imbalance. We were to verify the significance of the measured data using SPSS 13.0. First, the mean and standard deviation of real-time muscular activity and foot pressure data according to the muscle strength imbalance detection result and the sound recognition feedback in gait slope and velocity. Two-way ANOVA was used to examine the difference in muscle activity between the measurement periods according to each item in order to verify the result of muscle strength imbalance detection of developed insole by various gait environment for the significance of muscle activity and foot pressure.

III. RESULT AND DISCUSSION

In this study, we estimated the real-time muscular activity and foot pressure in order to investigate the muscle strength imbalance according to various gait environment with the sound recognition effect for improving muscle strength imbalance and found out the result as below. Muscle activity and FSR sensor test results showed similar tendency. First, as the gait velocity and slope increased, the difference in muscle activity between the left and right muscles increased in both the thigh and the hip. In the femoral region, the difference in muscle activity between the left and right muscles was greater than that at the maximum inclination at 15% and at the walking speed at 5 km/h. The similar results were obtained in the lower extremities, about 279.55% (Fig. 6). In the FSR sensor results, the difference of the left and right sensor pressure level was about 99.65% as the walking speed and tilt angle became larger (Fig. 7). This is, the greater the slope, the more kinetic energy required and the more anterior displacement of the knee, resulting in a higher muscle contraction energy mobilization. We thought that at this time, it is thought that the muscular activity mobilization is larger than the opposite muscle group, and the left and right muscle imbalance becomes larger when the dominant muscles of the lower limb produce energy. Also, we could judge that the higher the gait velocity, the faster the muscle contraction and energy mobilization. The result showed that difference between the left and right side muscles strength of the femur was reduced to within 30% and the FSR sensor value was reduced to within 50% when the sound recognition feedback was provided (Fig.8-10). We thought that the muscle strength imbalance in left and right side is decreased by the perception response according to sound recognition feedback the user's will for improving the imbalance. It is possible to improve the left-right muscle strength imbalance through the existing rehabilitation exercise. However, we were considered that there is a possibility that a left-right muscle imbalance may occur again when only the treatment of the imbalance or the rehabilitation training is performed without solving the root cause of the user's wrong lifestyle or exercise method[11]. In other words, we thought that the improvement effect using the short-term rehabilitation exercise of muscle strength imbalance may be temporary through muscle adaptation, but the interchangeable training between the user's own brain and the behavioral activity minimizes the root cause of the imbalance. The result of FSR sensor sensitivity in developed insole showed that it was a difference between the muscle activity results and the numerical value, but the level difference was not significant and it is possible to measure the muscle strength imbalance of the left and right in gait. In other words, it is considered that the muscle unbalance affects not only the difference in muscle strength but also the function of the muscle.

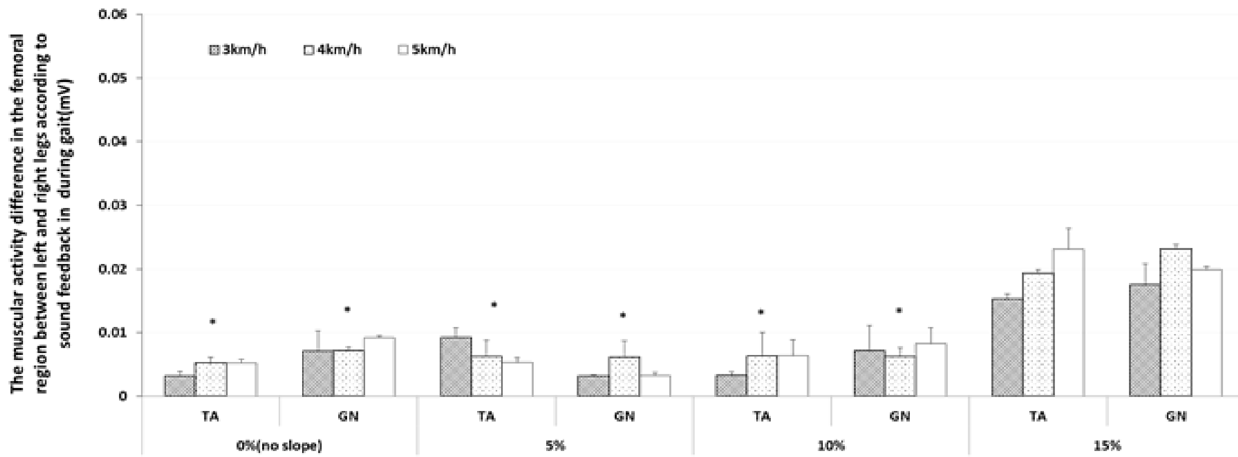

Fig. 5 The muscular activity difference of femoral region of left and right side in the lower limbs according to slope at 0, 5, 10, 15% and velocity at 3, 4, 5 km/h during gait, *p<0.05(*p is the significance of the muscular activities between the velocities and angles)

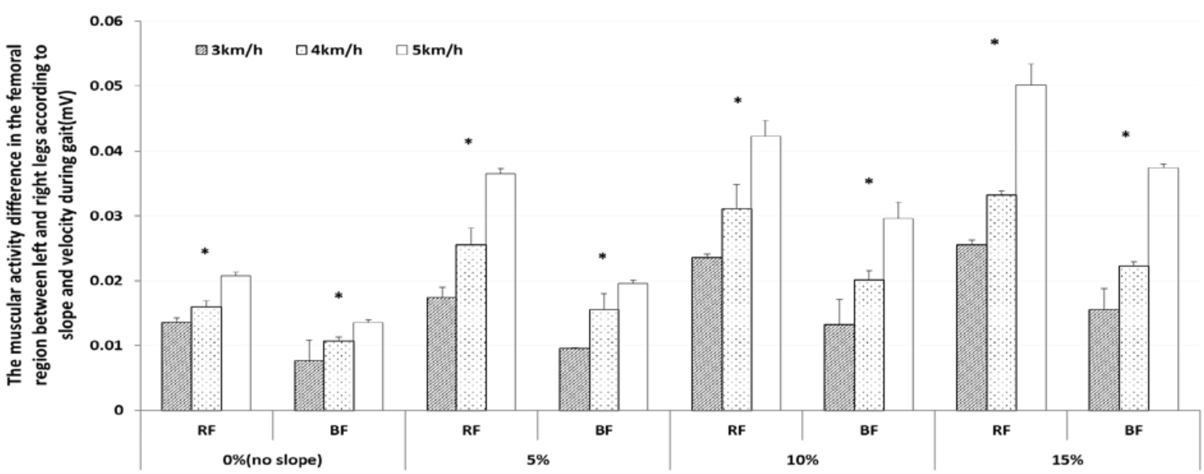

Fig. 6 The muscular activity difference of lower region of left and right side in the lower limbs according to slope at 0, 5, 10, 15% and velocity at 3, 4, 5 km/h during gait, *p<0.05(*p is the significance of the muscular activities between the velocities and angles)

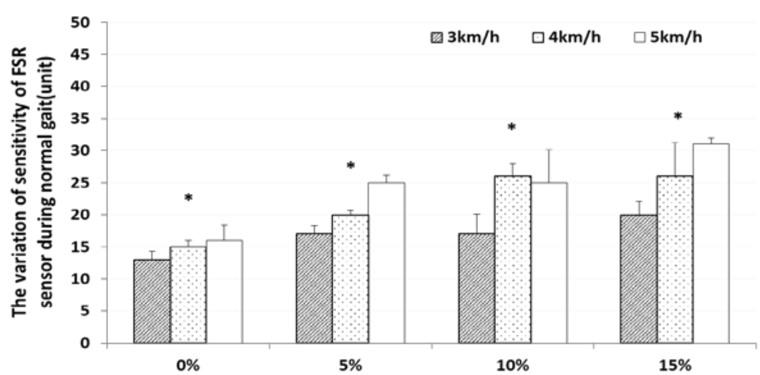

Fig. 7 The variation of FSR sensor data difference in left and right side according to slope at 0, 5, 10, 15% and velocity at 3, 4, 5 km/h during gait, *p<0.05(*p is the significance of the FSR sensor data between the velocities and angles)

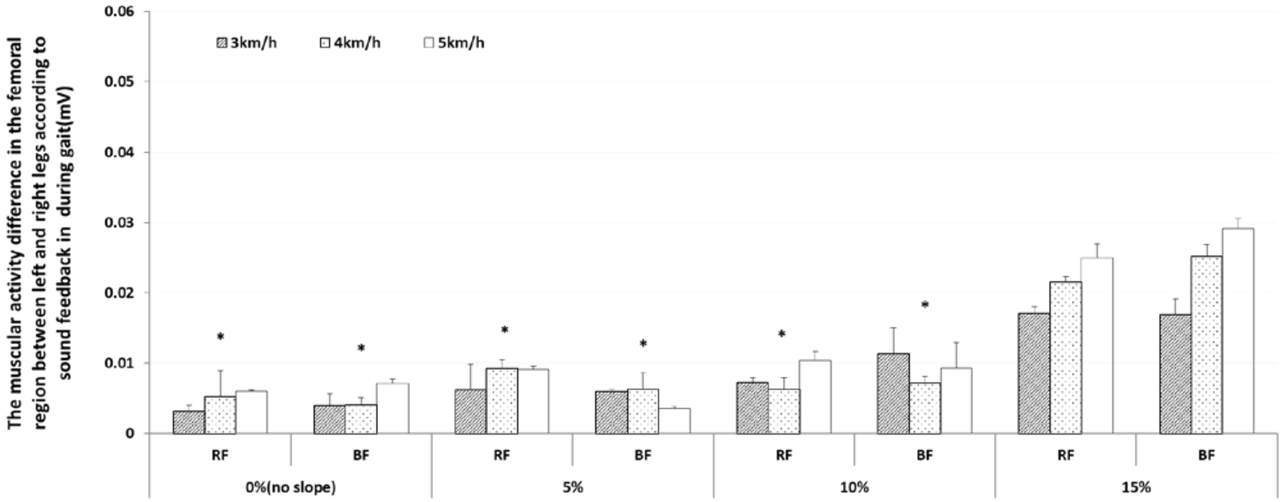

Fig. 8 The muscular activity difference of femoral region of left and right side in the lower limbs using sound recognition feedback according to slope at 0, 5, 10, 15% and velocity at 3, 4, 5 km/h during gait, *p<0.05(*p is the significance of the muscular activities between the velocities and angles)

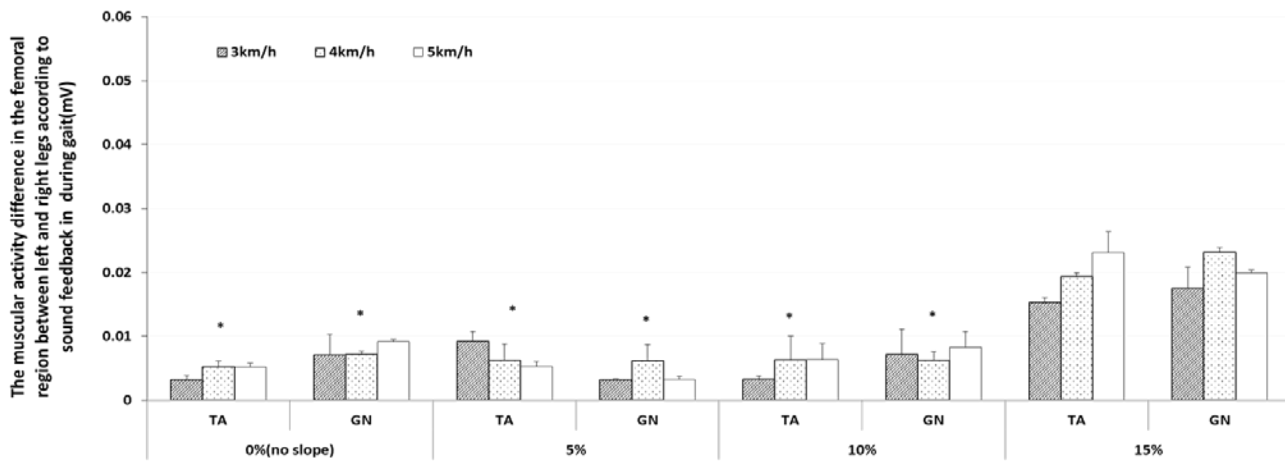

Fig. 9 The muscular activity difference of lower region of left and right side in the lower limbs using sound recognition feedback according to slope at 0, 5, 10, 15% and velocity at 3, 4, 5 km/h during gait, *p<0.05(*p is the significance of the muscular activities between the velocities and angles)

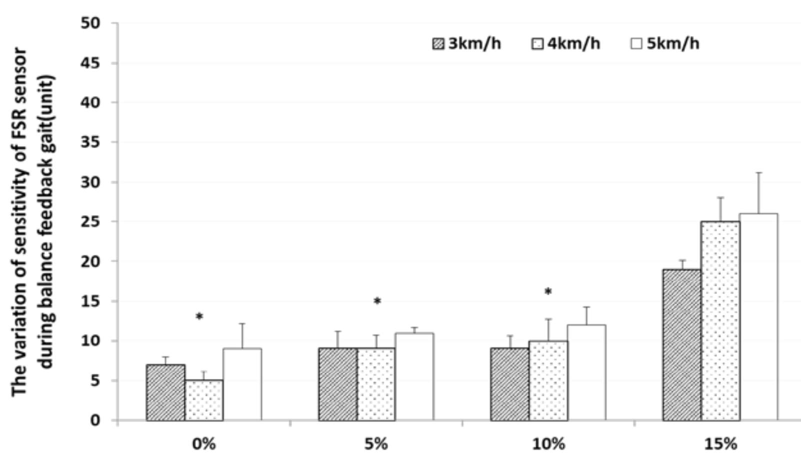

Fig. 10 The variation of FSR sensor data difference in left and right side using sound recognition feedback according to slope at 0, 5, 10, 15% and velocity at 3, 4, 5 km/h during gait, *p<0.05(*p is the significance of the FSR sensor data between the velocities and angles)

As a result of foot load distribution, as the gait velocity and slope were increased, the force of the left and right foot loads of the balanced group and the unbalanced group tended to increase. The force difference between left and right of the foot increased from 27.55% at the speed of 3km / h to 72.51% at the speed of 5km / h. The results of the gait slope showed that the lateral force applied to the foot increased 15% to 284.52% (Fig. 11). On the other hand, when the sound recognition feedback was provided, muscle strength imbalance of the left and right tended to decrease from 105.75% to 27.85% (Fig.12). This result suggests that the difference in foot force force is due to the muscle strength imbalance of the lower limbs in the forefoot section during toe off stage. In other words, it is considered that the muscle strength imbalance is generated in the toe off motion which is the action that generates the final driving force during gait. This tendency was found to increase more as the gait velocity and slope were increased. Especially, in 10% of the gait slope, it did not show a significant tendency between the foot load forces. We thought that this is because kinetic energy sources are different depending on the walking habits and physical characteristics of the participants when many gait energy sources are required. As a result, the imbalance appears to be larger, but there are many variables. We thought that the most significant difference between right and left forces in the midfoot is the transition from the stance phase to the loading response. This is the area where weight support occurs, and the largest imbalance occurs because the weight shifts over the entire foot. It is judged that there is a big difference according to the characteristics of the arch from loading response to single limb support due to imbalance during gait. The rearfoot results were similar to those of the forelock and midfoot. The rearfoot area is the weight acceptance period, which refers to the foot pressure at the transition from the initial contact to the weight support. We thought that the muscle strength imbalance according to the body weight and muscle force is first transmitted to the foot, and the imbalance tends to increase as the gait slope and velocity increase. The results show that when the unbalance occurs in the rearfoot part compared with the forefoot, the difference in the force of the foot load is more likely to occur, with both legs contacting the ground. Also, it is considered that the difference in the load force between the left and right legs of the lower leg is larger because it is the section in which the driving force is generated due to toe off preparatory stage with floating condition in the heel of the opposite leg. This means that there is a close relationship between the left and right muscle imbalance of the lower limb and the movement of the center of gravity of the human body. In other words, it seems that the muscle imbalance affects the movement of the center of gravity as well as muscle contraction. As a result of foot load force, muscle strength imbalance of left and right tend to decrease within 30% during providing the sound recognition feedback, similar to muscle activity and FSR sensor results. We thought that the result of sound recognition feedback on walking was that the user deflects their own strength to one side and distributes the force to the other side. In addition, the most significant effect is in the midfoot area, which is the area where the weight is carried, and the largest imbalance occurs. The behavioral cognitive response is the most effective for sound recognition feedback, which is considered to be an area that reduces the muscle strength imbalance between right and left. We judged that muscle strength imbalance of the left and right in the lower limb is significantly influenced by the weight support, so weight load is the most important reason. Therefore, it is considered that the left and right muscle imbalance can be caused more than the exercise habit due to the movement of the weight in daily life or the wrong walking habit.

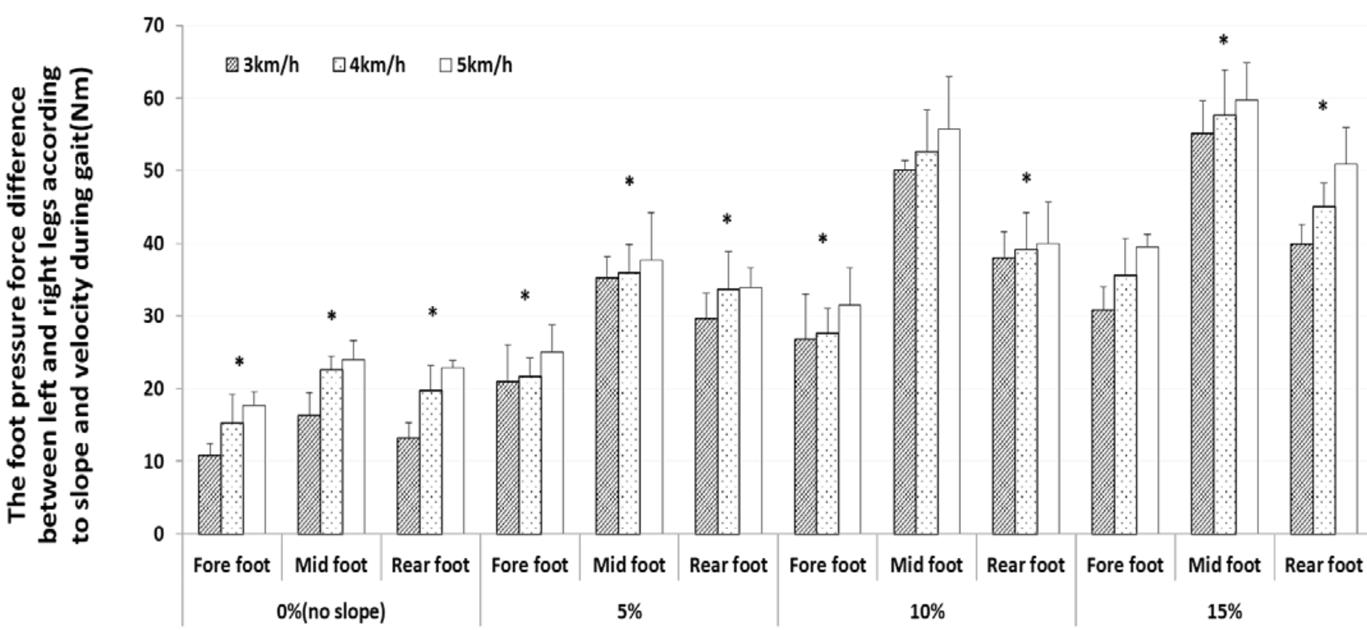

Fig. 11 The foot pressure force difference between left and right according to slope at 0, 5, 10, 15% and velocity at 3, 4, 5 km/h during gait, *p<0.05(*p is the significance of the FSR sensor data between the velocities and angles)

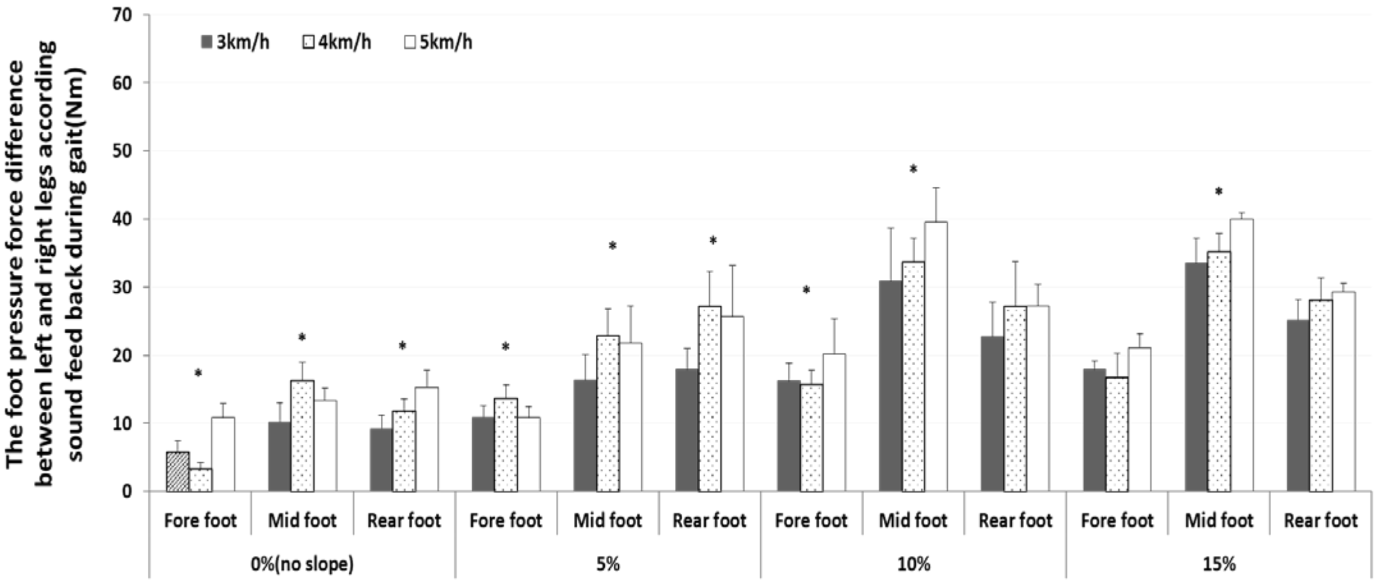

Fig. 12 The foot pressure force difference between left and right legs using sound recognition feedback according to slope at 0, 5, 10, 15% and velocity at 3, 4, 5 km/h during gait, *p<0.05(*p is the significance of the FSR sensor data between the velocities and angles)

IV. CONCLUSION

This study developed a balance insole based on FSR sensor capable of measuring left and right muscle imbalance of the lower and we were to verify the improvement effect of muscle strength imbalance according to sound recognition feedback for evaluating muscular activity and foot pressure in the various gait environment. As a result, we reached the following conclusion below.

First, as the inclination gait slope and velocity increased, the left and right muscle activity, the FSR sensor value, and the foot load force difference between the legs increased, and the muscle strength imbalance tended to increase. This suggests that the larger kinetic energy required for the more inclination gait slope and velocity is due to the more muscle activity mobilization of the dominant muscle group and the induction of rapid muscle contraction, resulting in increased muscle strength imbalance of left and right legs. It is considered that muscle imbalance not only affects the left and right muscle strength but also the function of muscles.

Second, the data of the developed insole based FSR sensor to measure left and right muscle strength imbalance according to gait environment showed resolution difference of muscle activity and foot load force, but it is considered that it is possible to measure the muscle strength imbalance of left and right in lower limbs during gait.

Third, sound recognition feedback could decrease the difference of muscle activity and foot load force and showed improvement of muscle strength imbalance during gait. This leads to the perception response of the sound recognition feedback to the user to recognize and improve the imbalance. We thought that inter-current training between brain cognition and behavioral muscle activity may lead to a greater positive effect in resolving muscle strength imbalance of left and right in lower limbs when minimizing the root cause of imbalance rather than short term rehabilitation training.

Fourth, muscle strength imbalance during gait has the greatest imbalance in the section from the initial folding stage to the weight supporting stage. In other words, weight load is the most important cause of weight gain due to weight support during gait. It is considered that the muscle strength imbalance in the left and right can be caused to occur more than the exercise habit due to the operation in which the weight load is generated in the daily life or the erroneous walking habit. In addition, it is necessary to study not only walking conditions but also muscle strength imbalance due to exercise habit. This suggests that there is a direct or indirect correlation between the left and right muscle imbalance of the lower limb and the imbalance of human body weight distribution during gait.

The results of this study can be applied to basic research on the effects of left and right muscle imbalance on the human body in the future and basic research on development of gait rehabilitation treatment program for the disabled, elderly and patients.

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