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Analysis of Changes in Electrical Signals and Ground Reaction Force in Muscles According to Exercise Method

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With an increasing aging population and improved standards of living, more attention has been paid to health. Although walking exercise is known as an aerobic exercise, it imposes repeated and continuous impacts on the joints of the lower extremities. Therefore, when overweight gives a burden to the lower extremity or there is a joint disease, exercise limit occurs. The articular cartilage, weakened with age, also makes it difficult for the elderly to perform walking exercises. Accordingly, this study conducted a comparative analysis between regular walking using only the lower extremity and Nordic walking, which has been known as stable. For analysis, electromyography (EMG) was performed and the ground reaction force of the upper and lower extremities were measured in the same exercise. Integrated EMG (iEMG) revealed that the upper extremity muscles were more active in Nordic walking than in regular walking, where lower extremity muscles were relatively more inactive. In addition, when EMG measurements were performed at each measurement point during walking exercise, the pattern was different. Nevertheless, the result was the same as in iEMG. The load that occurs in each exercise was measured using the ground reaction force system. As a result, Nordic walking had a lower load than regular walking. Therefore, it was found that Nordic walking minimized the load on the lower extremities owing to the effect of whole-body exercise and was a safer and more efficient exercise method.

Keywords : Nordic walking, Regular walking, EMG, Ground reaction force

1. INTRODUCTION

With the improved standard of living, more attention has been focused on health. Walking exercise is used for health improvement, because it is easy to perform in everyday life. However, the exercise brings repeated and continuous impact to the lower extremity joints. Accordingly, using an inappropriate degree of intensity and an incorrect exercise method can cause damage.

Persons who have joint problems and the elderly generally have great difficulty when walking. Nordic walking is a walking exercise method that uses two ski poles on both hands. As it is similar to Nordic skiing, it is called Nordic walking.

In Europe, the exercise method has been widely applied since 1997 [1] and is now popular in North Europe [2]. In the United States, it is known to be an exercise method developed by Tom Rutlin in 1988, which is called Exerstriding. In Nordic walking, the body is pushed forward by using the ground friction of the sticks on both hands. It is a dynamic walking exercise method. In walking, the poles on both hands are used to activate the muscles of the upper limbs, including

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the arms, shoulders, and breast, active. For this reason, more calories and oxygen are consumed in Nordic walking than in regular walking [3]. As such, to maximize metabolism, Nordic walking uses more muscles of the upper extremities than regular walking, which uses only the lower extremities. In addition, as Nordic walking is like four-foot walking, it is safe, maintains walking balance, and secures constant stability in exercise [4]. In North Europe, the United States, Japan, and other advanced countries, Nordic walking is regarded as an approved and effective whole-body exercise method for health improvement [5]. In Finland, 30% of the population do Nordic walking. In Switzerland, those who do Nordic walking have insurance discount. In Austria, medical doctors recommend Nordic walking to patients who have high blood pressure, diabetes, osteoporosis, and depression [6]. Nordic walking is an effective and rhythmical exercise method for the upper and lower extremities. In particular, using walking sticks can improve the muscular force of the arms, shoulders, upper extremity, breast, and abdomen, and increase stride distance, walking speed, and oxygen consumption. In addition, the exercise method helps to alleviate pain in the joints of the lower extremities and improve muscular function [7], and is applied to rehabilitation training for Charcot syndrome, Parkinson's disease, depression, and sports injury [8]. In addition, the exercise method is reported to be effective for weight control, backache, and cardiovascular diseases [9]. In foreign countries, various effects of Nordic walking have been researched. Domestically, research on the field is lacking. Most relevant studies focus on the physiological change through the analysis of walking patterns [10].

Therefore, this study compared regular walking with Nordic walking in the same condition by analyzing electromyography (EMG) signals to measure the electric signals of the main muscles. EMG analysis allows for comparison of muscular activities quantitatively to analyze an accurate quantity of motion. This study also analyzed ground reaction force as a dynamic analysis on the exercise methods. On the basis of the analysis results, we determined the influence of Nordic walking on the human body and its effects.

2. EXPERIMENTS

EMG is a quantitative method of amplifying at a microvolt level electrical signals that occur in muscle cell contraction. It is used to analyze the degree of muscular contraction activity electrically and physiologically. Currently, EMG is widely applied to kinematic analysis in clinical practice. To quantitatively measure the activities of the main muscles of the human body in regular and Nordic walking, this study used an EMG device. Figure 1 illustrates the EMG device used in this test.

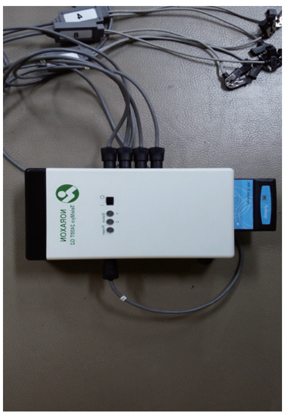

Fig. 1. Electromyographic device.

In this study, the EMG device used was TeleMyo 2400T G2 of Noraxon Inc. The EMG device uses eight units of surface EMG signals to analyze muscular activities at each measurement point. In addition, as the device can remove unnecessary noise in measurement, the measured data can be transmitted wirelessly and has no restriction of motion.

To analyze the changes caused by the exercise methods, this study selected as a test participant a 27-year-old man who had no problem with the myoneural system and had no damage of the musculoskeletal system over the last 6 months. To evaluate muscular contraction, the present researcher used the EMG device to attach each surface EMG unit to the left triceps brachialis, rectus abdominis, right gluteus medius, right biceps femoris, and right rectus femoris muscles. To analyze the amplitude-change of the EMG depending on the change in muscular contraction, this study applied integrated EMG (iEMG), which is a value calculated by integrating muscular contraction potential signals with time. With iEMG, the active mass in muscular contraction can be analyzed.

To measure the magnitude of the ground force of the feet in walking, the present researcher installed a ground reaction force device (AMTI OR6-7-2000, USA) in line with the floor height. Figure 2 illustrates the ground reaction force device installed for analysis.

Regarding measurement accuracy, the ground reaction force device has ±0.1% of applied load as a resolution ratio. With regard to the measurement of ground reaction force, at the moment the soles of the feet are grounded to the ground reaction force recorder, vertical reaction force (Fz), anteroposterior ground reaction force (Fy), and mediolateral ground reaction force (Fx) were measured.

A measured value was sampled with 1,000 Hz. Matlab (Mathworks, USA) was applied to analyze the moment of motion. Figure 3 presents the mimetic diagram of EMG and ground reaction force measurement points for checking the change in the motion pattern.

Fig. 2. Ground reaction force recorder.

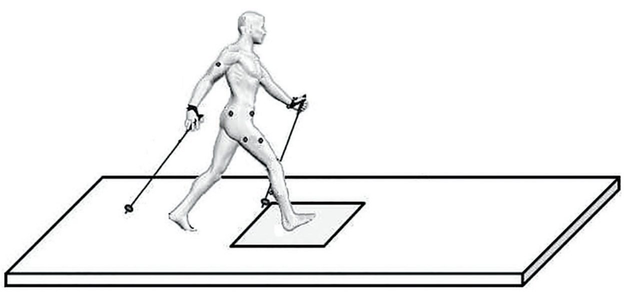

Fig. 3. A set of experimentation.

3. RESULTS AND DISCUSSION

By analyzing the muscular activity of the main muscles and the difference in ground reaction force between regular and Nordic walking at the same speed, this study determined the advantages and stability of Nordic walking. EMG and ground reaction force values were measured 20 times in regular walking and 20 times in Nordic walking in the same condition.

For the muscular activity in each exercise method, an iEMG value was measured. The differences in iEMG in each measured region between regular and Nordic walking are presented in Table 1.

For iEMG analysis, a measured EMG signal was sampled with 1,200 Hz. The signal was smoothed (20–200 Hz) through rectification, baseline offset adjustment, and band-pass filter, and then an iEMG value was calculated.

In this study, an iEMG is a value calculated by integrating a muscular activity potential signal in the stance period, during which the feet contact the ground in walking. The mean iEMG value was calculated for comparison. According to the measurement, the gluteus medius muscle had a relatively lower EMG measurement in Nordic walking than in regular walking, but the difference was not statistically significant. The biceps femoris, gluteus medius, rectus femoris, and triceps brachialis muscles had a lower EMG measurement in Nordic walking than in regular walking, whereas the rectus abdominis muscle had a higher EMG measurement in Nordic walking than in regular walking. In addition, all the muscles, except the triceps brachii muscle, showed statistically significant changes at $P < 0.001$. The purpose of using walking poles in Nordic walking is to use the muscles of the upper extremity, which are not used in regular walking. Therefore, EMG revealed that the muscles of the lower extremity, including the rectus femoris, gluteus medius, and biceps femoris, had relatively lower EMG measurements in Nordic walking than in regular walking. The muscles of the upper extremity, including the rectus abdominis and triceps brachialis, had higher EMG measurements in Nordic walking than in regular walking. This means that although the perceived exercise intensity of the human body is relatively low, the use of all muscles of the whole body leads to an efficiency improvement in energy metabolism. As a result, Nordic walking is more effective than regular walking.

The measurement results of ground reaction force in the exercise methods are presented in Table 2.

Table 1. iEMG analysis between Nordic and regular walking (unit: mV-sec).

Variables	Nordic walking	Regular walking	Δ Difference	T	p
Rectus femoris	604.56±351.24	695.38±358.87	90.82±123.16	-5.99	0.0000
Gluteus medius.	1010.39±346.99	1052.03±328.47	41.63±206.33	-1.64	0.0529
Biceps femoris	750.73±316.22	3177.44±2032.54	2426.72±1724.27	-11.43	0.0000
Rectus abdominis	3955.39±1229.13	3439.03±1161.71	516.37±1130.95	-3.71	0.0002
Triceps brachialis	8557.13±6665.02	7672.52±5984.13	884.60±3207.97	-2.24	0.0142

Table 2. Paired t test between Nordic and regular walking in ground reaction force (unit: BW ratio).

Variables	Nordic Walking	Regular Walking	Δ Difference	T	p
Ground reaction force	0.7366±0.3057	0.8274±0.3392	0.0908±0.0929	-7.94	0.0000

Regarding ground reaction force, the load generated by the ground reaction force recorder in each exercise method was calculated. To minimize the variable through repeated motion, the load was first divided by body weight (BW) and then standardized.

As a result, with regard to ground reaction force, Nordic walking had a smaller pressure than regular walking overall, with a statistically significant difference at $P < 0.001$. Nordic walking had a relatively lower ground reaction force value than regular walking. This indicates that the use of walking sticks helps to distribute the impact generated in walking.

The motion that occurs in walking has stance and swing periods. The stance period is the time during which the feet contact the ground in walking. Generally, given that a walking period taken for one foot to touch the ground and retouch it is set to 100%, the stance period becomes 60% roughly. In this study, the measurement of EMG changes and ground reaction force was based on the stance period of the ground reaction force recorder.

The EMG changes in the rectus femoris muscle during Nordic and regular walking were analyzed. The analysis results are presented in Fig. 4.

According to the analysis in Fig. 4, in the 10% band, the muscular activity value was lower in Nordic walking than in regular walking. In the stance period (approximately 10~20% band), no significant difference was found between the exercise methods. In the 20~40% band, the EMG value was lower in Nordic walking than in regular walking.

The EMG change in the gluteus medius muscle during Nordic and regular walking was analyzed. The analysis results are presented in Fig. 5.

The gluteus medius muscle had similar EMG patterns in regular and Nordic walking. However, the gluteus medius muscle had lower maximum voluntary contraction (MVC) in Nordic walking than in

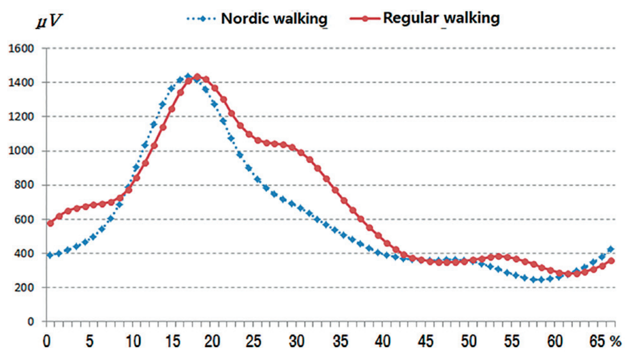

Fig. 4. EMG changes in the rectus femoris muscle.

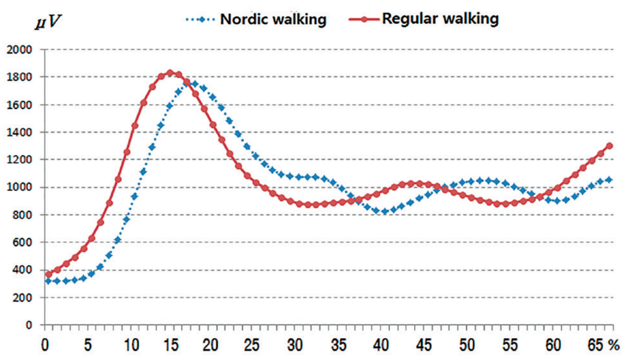

Fig. 5. EMG changes in the gluteus medius muscle.

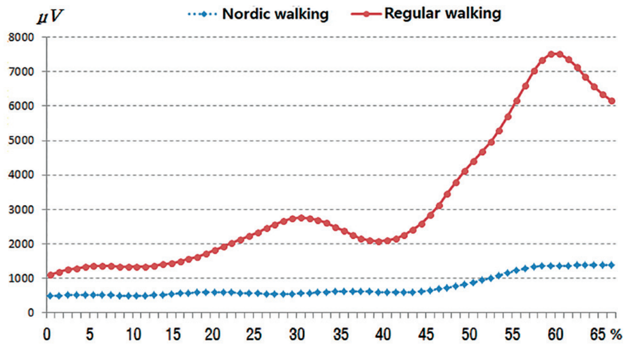

Fig. 6. EMG changes in the biceps femoris muscle.

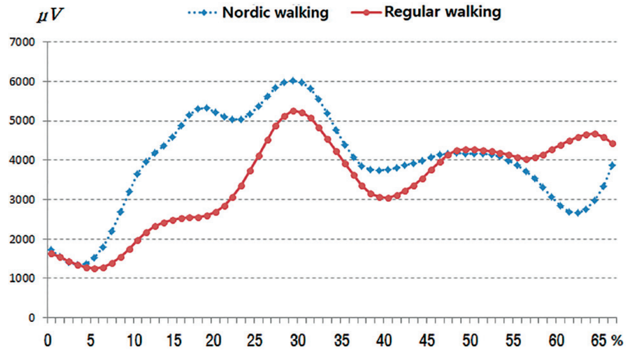

Fig. 7. EMG changes in the rectus abdominis muscle.

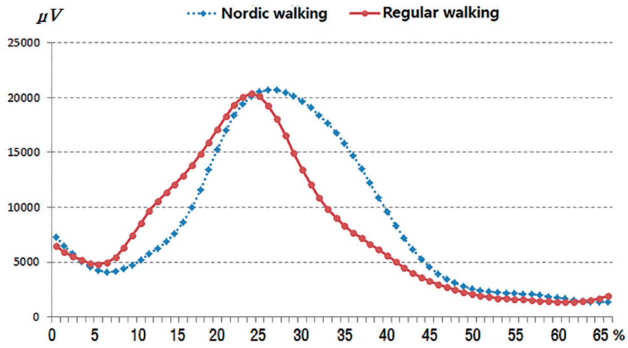

Fig. 8. EMG changes in the triceps brachialis muscle.

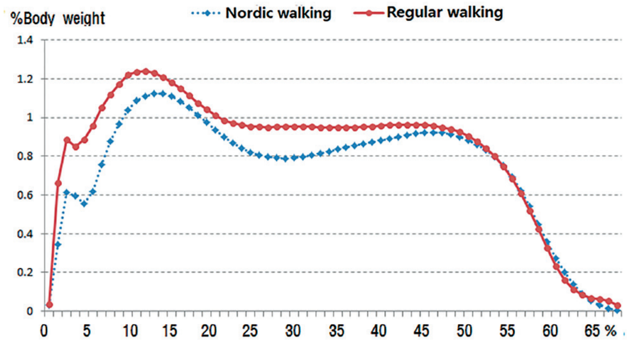

Fig. 9. Difference in ground reaction force.

regular walking. In addition, the MVC and EMG patterns were found later in Nordic walking than in regular walking. This indicates that the use of sticks leads to late exercise of the gluteus medius muscle.

The EMG change in the biceps femoris muscle during Nordic and regular walking was analyzed. The analysis results are presented in Fig. 6.

The EMG change in the rectus abdominis muscle during Nordic and regular walking was analyzed. The analysis results are presented in Fig. 7.

According to the analysis, in the approximately 50% band, the EMG measurement was far higher in Nordic walking than in regular walking. Around the end of the stance period, the EMG measurement was higher in regular walking than in Nordic walking.

The EMG change in the triceps brachialis muscle during Nordic and regular walking was analyzed. The analysis results are presented in Fig. 8.

The triceps brachialis muscle had no marked EMG change in MVC. However, in the approximately 25% band, the EMG measurement was lower in Nordic walking than in regular walking. After the 25% band, the EMG measurement was higher in Nordic walking than in regular walking. On the basis of the approximately 45% band, a similar pattern was observed. The difference in ground reaction force between Nordic and regular walking was analyzed. The results are shown in Fig. 9.

According to the analysis of ground reaction force, on the basis of the maximum point, regular walking had a load approximately 1.2 times heavier than the test participant's weight and Nordic walking had a load approximately 1.1 times lighter. In the approximately 50% band, the ground reaction force device had a smaller load in Nordic walking than in regular walking. At the end of the stance period, after 50%, no marked difference was found between the two exercise methods. This indicates that the load imposed on the lower extremities is generally reduced in Nordic walking as compared with that in regular walking.

4. CONCLUSIONS

This study compared regular walking with Nordic walking, which is an exercise method that uses walking sticks, and analyzed the differences in EMG measurements and ground reaction force between the two methods. The EMG analysis system used in this test exploits is TeleMyo 2400T G2 (Noraxon), which uses surface EMG for quantitative analysis of the noninvasive muscular activities of the human body. To analyze ground reaction force, this study measured the magnitude of the ground force of the feet in each exercise to analyze the load imposed on the lower extremities.

According to the analysis of iEMG signals, the rectus abdominis and triceps brachialis of the upper extremities had higher EMG measurements in Nordic walking than in regular walking. The rectus femoris, gluteus medius, and biceps femoris of the lower extremity had lower EMG measurements in Nordic walking than in regular walking. This indicates that Nordic walking, which involves using walking sticks, changed the muscular activities of the upper and lower extremities and made whole-body exercise possible.

According to the analysis of the EMG variation in each exercise, different patterns were displayed depending on the analysis points. The lower extremities had a higher EMG measurement in Nordic walking than in regular walking; the upper extremity had a lower measurement generally. The biceps femoris had a remarkably low measurement in Nordic walking. Nordic walking is considered able to reduce the risk of hamstring damage, which occurs at the end of walking exercise.

According to the analysis of ground reaction force, the lower extremities had a relatively lower load imposed in Nordic walking than in regular walking. This result attributed to the use of walking sticks, which helped distribute the load imposed on the lower extremities. Therefore, Nordic walking is considered to minimize the weight load imposed on the waist, knees, and ankles, and to be effective for patients who have difficulty walking.

Given the result that Nordic walking produces more activities for the upper extremity muscles than regular walking, it can be used as a good exercise method for the whole body.

Nordic walking was found to minimize the load of the lower extremity than regular walking and helped to distribute the load to the whole body. It means that Nordic walking improves walking efficiency and prevents damage as an exercise method with high stability. Therefore, Nordic walking was found to be effective as a whole-body exercise for ordinary people and for preventing damage. It has become a stable walking exercise for those with functional difficulty with the lower extremity joints.

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