A comparative study of the electromyographic activities of lower extremity muscles during level walking and Pedalo riding

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Abstract. [Purpose] To analyze the electromyographic (EMG) activities of several lower extremity muscles during ground walking and pedaling using the Pedalo Reha-Bar device. [Subjects and Methods] Fifteen healthy adults aged 20–29 year participated in this study. The subjects’ surface EMG signals while walking and Pedalo Reha-Bar riding were recorded. The subjects performed 20 steps on flat ground and 20 cycles on the Pedalo Reha-Bar. During the tasks, EMG signals of the rectus femoris, biceps femoris, tibialis anterior, soleus, and gastrocnemius within a 20-second period were recorded. The mean EMG signals within the 10 seconds from 6 to 15 seconds were used for the data analysis. [Results] There was a significant increase in the bilateral use of the rectus femoris and a significant decrease in the use of the left tibialis anterior and left soleus in pedaling using the Pedalo Reha-Bar device compared to ground walking. [Conclusion] Level walking and the Pedalo Reha-Bar riding utilize different types of muscles activities. These results suggest that Pedalo Reha-Bar riding may be used for neuromuscular activation, especially of the rectus femoris.

Key words: Pedalo, Walking, Electromyography

INTRODUCTION

Activities such as walking and cycling are the two most common exercises performed for maintaining good health or recovering condition1). Previous studies have reported a decrease in blood pressure after ground walking2, 3). Other studies have suggested there are improvements in the balance and gait abilities, and muscle strength of stroke patients after stationary cycling exercise or walking training in stroke patients4–6). In addition, a study demonstrated that patients with diabetes who practiced 30 minutes walking for 3 months showed decreased blood pressure and blood glucose levels, and physical changes such as improved muscle strength and stability7). Furthermore, another study reported that patients who underwent pneumonectomy showed a decreased incidence of complications, improved motor skills, and a decreased length of hospital stay when they performed walking exercises for a specific amount of time and intensity8).

The recreational device, Pedalo Reha-Bar, is becoming more popular. This device is designed for children, adults, and the elderly to enjoy recreation. However, a few countries are using this device in rehabilitation. Thorpe and Valvano utilized the device as an intervention tool in order to investigate the effect of different types of feedback on motor learning among children with cerebral palsy9). Also, Chen et al. analyzed the movement of healthy adults using the Pedalo Reha-Bar10).

The Pedalo Reha-Bar provides a weight shift between the lower limbs and allows movement similar to walking. Thus, this device may be beneficial not only for healthy adults but also for the elderly and disabled patients. In addition, because the Pedalo Reha-Bar was originally designed for play or recreation, it could provide interest and motivation. Although a few
studies have been conducted on the Pedalo Reha-Bar, the number of studies conducted to analyze the movement and force while using the device is limited.

Therefore, the present study aimed to investigate the electromyographic activities of the lower extremity muscles while using the Pedalo Reha-Bar, and compare them with the electromyographic muscle activities while walking.

SUBJECTS AND METHODS

In the present study, healthy adult volunteers aged between 20 and 29 years from a university were enrolled. The university message board was used for the recruitment of volunteers, and subjects were enrolled if they fulfilled the inclusion criteria: healthy adults without musculoskeletal, neuromuscular, cardiovascular, pulmonary, or integumentary pathological conditions that might have affected physical performance. Fifteen subjects participated in this study. The subjects included 2 male and 13 female healthy adults whose mean age was 21.3 years, mean height was 162.1 cm, mean weight was 52.9 kg, and dominant side was the right side, except one subject. The subjects provided their informed consent. The study was approved by the Ethics Committee of Kyungnam University.

This was a cross-sectional study. After the subjects had been interviewed to collect general information (gender, age, height, and weight), they participated in the experiment in which surface EMG signals were recorded while the subjects walked or performed Pedalo Reha-Bar riding. Before the experiment, the maximum voluntary isometric contraction (MVIC) of five muscles (rectus femoris, biceps femoris, tibialis anterior, soleus, and gastrocnemius) were measured. Measurements were taken in the sitting position for the rectus femoris, soleus, and gastrocnemius in the standing position for the tibialis anterior and in the prone position for the biceps femoris\(^1\). Each muscle was measured for 10 seconds in three trials, with a 2-minute break between each trial. MVIC was calculated based on the 5 seconds of data, between 3 to 7 seconds of the 10-second trial. Subjects were shown how to use the Pedalo Reha-Bar, and they were allowed to practice until they were comfortable with it. After a 10-minute break, EMG electrodes were placed on the rectus femoris, biceps femoris, tibialis anterior, soleus, and gastrocnemius. The subjects were then asked to perform 20 steps on a flat ground and 20 cycles on the Pedalo Reha-Bar. For the Pedalo Reha-Bar riding, all subjects began from the starting position on the Pedalo Reha-Bar. Starting with the left foot, in the raised position subjects were allowed to move at a comfortable speed for 20 cycles. Alternation from the left to the right foot was measured as one cycle. During the Pedalo Reha-Bar riding, EMG signals of a 20-second period were recorded. The mean EMG signals of three trials, the 10 seconds from 6 to 15 seconds of the 20-second period, were used for the data analysis. Three trials of ground walking and Pedalo Reha-Bar riding were performed and the subjects were allowed to take a 5-minute break after each trial.

In the present study, a surface EMG system (Trigno\textsuperscript{TM} Wireless EMG, Delsys Inc., Boston, MA, USA) was used to collect muscle activity data. This system has small wireless EMG sensors and an integrated amplifier. Prior to attaching the electrodes, skin impedance was reduced by shaving excess body hair, gently scrubbing the skin with sandpaper, and wiping the skin with alcohol swabs. The EMG electrodes were placed on the rectus femoris, biceps femoris, tibialis anterior, soleus, and gastrocnemius, on both sides of the body. In total, 10 channels were recorded. The EMG electrodes were placed according to SENIAM (Surface EMG for Noninvasive Assessment of Muscles) guidelines\(^2\). The electrodes were placed at the midpoint of the line from the anterior spina iliaca superior to the superior part of the patella for the rectus femoris, at the medial position on the line between the ischial tuberosity and the lateral epicondyle of the tibia for the biceps femoris, at one-third the distance between the tip of the fibula and the tip of the medial malleolus for the tibialis anterior, at two-thirds the distance on the line between the medial condyles of the femur to the medial malleolus for the soleus, and at the one-third the distance on the line between the head of the fibula and the heel for the gastrocnemius. The data was processed using standard filtering and rectifying methods. The sampling frequency was 2,000 Hz. A 60 Hz high-pass filter and a 10 Hz low-pass filter were applied (all filters, zero-lag 4th order Butterworth). The root mean square (RMS) value of the raw EMG data was calculated. The EMG data of each muscle was normalized by calculating the RMS of the 5-second MVIC of the muscle. The EMG data collected during the ground walking and the Pedalo Reha-Bar riding were expressed as %MVIC.

SPSS 18.0 (IBM Corporation, Endicott, NY, USA) was used for the statistical analysis. Data were analyzed using the paired t-test for the comparison of values between walking and the Pedalo Reha-Bar riding. The level of statistical significance was chosen as 0.05.

RESULTS

The electromyographic activities of each muscle measured during ground walking and Pedalo Reha-Bar riding are summarized in Table 1. Significant differences were observed between ground walking and the Pedalo Reha-Bar riding in the electromyographic activities of the rectus femoris, left tibialis anterior, and left soleus (p<0.05). The electromyographic activity of the right rectus femoris showed a significant difference between ground walking and Pedalo Reha-Bar riding (44% vs. 59%, respectively). Moreover, the left rectus femoris showed a electromyographic activity of 37% during ground walking and 55% during Pedalo Reha-Bar riding. Meanwhile, the left tibialis anterior showed a electromyographic activity of 20% while ground walking and 16% while Pedalo Reha-Bar riding, and the left soleus showed electromyographic activities of 63% and 45%, respectively, indicating a significant decrease in electromyographic activity during the Pedalo Reha-Bar riding.
DISCUSSION

In the present study, the electromyographic activities of the lower extremity muscles during Pedalo Reha-Bar riding were recorded and compared with those of ground walking. The results show that the rectus femoris on both sides demonstrated a significant increase in electromyographic activity during the Pedalo Reha-Bar riding compared to ground walking. However, the electromyographic activities of the left tibialis anterior and left soleus decreased during the Pedalo Reha-Bar riding compared to ground walking.

Romkes et al. reported that Masai walking, which is walking slowly with short strides, elicited maximum activity in the tibialis anterior in the toe off and swing phases, and the gastrocnemius at mid stance compared to normal walking with ordinary shoes. Kim et al. reported that as the load increases, the soleus and tibialis anterior showed increased activity compared to the other muscles. Hallal et al. reported that the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, gastrocnemius, tibialis anterior, and soleus showed increased activities while walking, and even greater muscle activities were observed in the rectus femoris, vastus medialis, vastus lateralis, and biceps femoris when the muscles were tensed while stepping over an obstacle. Miller et al. used the step-and-go cycle as a three-wheel cycle that repeats vertical motion to investigate the muscle activity of the power levels in the three different stages between standing and sitting. They reported that standing with the lowest power level elicited major muscle activities in the gluteus maximus, vastus medialis, vastus lateralis, rectus femoris, and tibialis anterior. Moreover, the study by Lopes et al., which was not relevant to this study because the subjects performed recumbent pedaling and upright pedaling, indicated that only the rectus femoris was activated during upright pedaling. The Pedalo Reha-Bar used in the present study was not the same device as that used in the studies of Miller et al. and Lopes et al., but it has sufficient similarity for comparison. The increased activity of the rectus femoris reported in the previous studies may support the findings of the present study. In the present study, electromyographic activity of the rectus femoris was greater during the Pedalo Reha-Bar riding than during ground walking. This result, as previous studies showed, indicates that the rectus femoris is used to propel the body forward in the upright position. That is, cycling uses the rectus femoris to push the pedals forward while sitting down and during knee extension, and the Pedalo Reha-Bar uses a similar motion to perform the knee-extension position, which requires more force to be applied by the rectus femoris.

Previous studies of muscle activities while riding and bicycling have reported rectus femoris activation. In this study, the observed bilateral rectus femoris activation was statistically significant. Although it is different from a bicycle, the Pedalo Reha-Bar may induce similar muscle activation, but via a different method and position of using the device. In addition, the present study compared the EMG data obtained during the Pedalo Reha-Bar riding and those obtained during ground walking. Thus, the results from the present study alone cannot confirm the similarity between the Pedalo Reha-Bar and a bicycle. Therefore, follow-up studies are required to compare muscle activities between Pedalo Reha-Bar riding and bicycle riding.

The present study showed the electromyographic activities of the tibialis anterior and soleus decreased while using the Pedalo Reha-Bar compared to their values during ground walking. This may be due to the propulsion characteristics of the Pedalo Reha-Bar, which uses the knee and hip joints, rather than the ankle, in the standing position. Although no direct investigation was conducted, the angle of the ankle joint did not change much while Pedalo Reha-Bar riding. Moreover, ground walking requires tibialis anterior activation at heel strike and soleus activation at heel off, rather than a powerful knee extension. The present study confirmed that walking and Pedalo Reha-Bar riding utilize different types of muscles. In particular, Pedalo Reha-Bar riding has a positive influence on electromyographic activation of the rectus femoris. Furthermore, the Pedalo Reha-Bar may be used as an exercise device for neuromuscular activation of the lower extremities, especially the rectus femoris. The results suggest that the Pedalo Reha-Bar may be utilized as an optional device for exercise.

Table 1. Comparison of EMG data between walking and Pedalo riding

| Muscles          | Side | Walking | Pedalo riding |
|------------------|------|---------|---------------|
| Rectus femoris (%) | Right | 44      | 59*           |
|                  | Left  | 37      | 55*           |
| Biceps femoris (%) | Right | 19      | 20            |
|                  | Left  | 21      | 23            |
| Tibialis anterior (%) | Right | 18      | 15            |
|                  | Left  | 20      | 16*           |
| Soleus (%)       | Right | 51      | 44            |
|                  | Left  | 63      | 45*           |
| Gastrocnemius (%) | Right | 40      | 36            |
|                  | Left  | 58      | 54            |

The values are presented as %MVIC.

*significant difference between the two tasks, p<0.05.
or recreation. However, the present study had a few limitations. First, the number of subjects was small and the subjects were limited to those in their twenties. Thus, the results are difficult to generalize. Also, electromyographic activities of only a few muscles in the lower extremity were recorded. Finally, motion analyses during Pedalo Reha-Bar riding were not conducted.

Thus, future studies should include analysis of other muscles, such as core muscles, motion analysis, and recording of electromyographic activities of muscles while Pedalo Reha-Bar riding. Through such studies, the Pedalo Reha-Bar can be suggested as an optional device for exercise or recreation.

REFERENCES

1) Kim SJ, Cho HY, Kim YL, et al.: Effects of stationary cycling exercise on the balance and gait abilities of chronic stroke patients. J Phys Ther Sci, 2015, 27: 3529–3531. [Medline] [CrossRef]
2) Whelton SP, Chin A, Xin X, et al.: Effect of aerobic exercise on blood pressure: a meta-analysis of randomized, controlled trials. Ann Intern Med, 2002, 136: 493–503. [Medline] [CrossRef]
3) Sohn AJ, Hasein M, Sinacore JM: Impact of exercise (walking) on blood pressure levels in African American adults with newly diagnosed hypertension. Ethn Dis, 2007, 17: 503–507. [Medline]
4) Lee DG, Jeong SK, Kim YD: Effects of underwater treadmill walking training on the peak torque of the knee in hemiplegic patients. J Phys Ther Sci, 2015, 27: 2871–2873. [Medline] [CrossRef]
5) Park BS, Kim MY, Lee IK, et al.: The effects of a progressive resistance training program on walking ability in patients after stroke: a pilot study. J Phys Ther Sci, 2015, 27: 2837–2840. [Medline] [CrossRef]
6) Yamada S, Tomida K, Tanino G, et al.: How effective is the early fast treadmill gait speed training for stroke patients at the 2nd week after admission: comparison with comfortable gait speed at the 6th week. J Phys Ther Sci, 2015, 27: 1247–1250. [Medline] [CrossRef]
7) Tiwari S, Gehlot S, Tiwari SK, et al.: Effect of walking (aerobic isometric exercise) on physiological variants with special reference to Prameha (diabetes mellitus) as per Prakriti. Aya, 2012, 32: 44–49. [Medline] [CrossRef]
8) Souza Possa S, Braga Amador C, Meira Costa A, et al.: Implementation of a guideline for physical therapy in the postoperative period of upper abdominal surgery reduces the incidence of atelectasis and length of hospital stay. Rev Port Pneumol, 2014, 20: 69–77. [Medline] [CrossRef]
9) Thorpe DE, Valvano J: The effects of knowledge of performance and cognitive strategies on motor skill learning in children with cerebral palsy. Pediatr Phys Ther, 2002, 14: 2–15. [Medline] [CrossRef]
10) Chen HH, Liu YT, Mayer-Kress G, et al.: Learning the pedalo locomotion task. J Mot Behav, 2005, 37: 247–256. [Medline] [CrossRef]
11) Kendall FP, McCreary EK, Provance PG, et al.: Muscles: testing and function with posture and pain, 5th ed. Baltimore: Lippincott Williams and Wilkins, 2005.
12) Hermens HJ, Freriks B, Desselhorst-Klug C, et al.: Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol, 2000, 10: 361–374. [Medline] [CrossRef]
13) Romkes J, Radmann C, Brunner R: Changes in gait and EMG when walking with the Masai Barefoot Technique. Clin Biomech (Bristol, Avon), 2006, 21: 75–81. [Medline] [CrossRef]
14) Kim SG, Nam CW, Yong MS: The effect of increase in baggage weight on elderly women's lower extremity muscle activation during gait. Arch Gerontol Geriatr, 2014, 59: 574–576. [Medline] [CrossRef]
15) Hallal CZ, Marques NR, Spinoso DH, et al.: Electromyographic patterns of lower limb muscles during apprehensive gait in younger and older female adults. J Electromyogr Kinesiol, 2013, 23: 1145–1149. [Medline] [CrossRef]
16) Miller MS, Peach JP, Keller TS: Electromyographic analysis of a human powered stepper cycle during seated and standing riding. J Electromyogr Kinesiol, 2001, 11: 413–423. [Medline] [CrossRef]
17) Lopes AD, Alsouche SR, Hakansson N, et al.: Electromyography during pedaling on upright and recumbent ergometer. Int J Sports Phys Ther, 2014, 9: 76–81. [Medline]
18) Cappellini G, Ivanenko YP, Poppele RE, et al.: Motor patterns in human walking and running. J Neurophysiol, 2006, 95: 3426–3437. [Medline] [CrossRef]
19) den Otter AR, Geurts AC, Mulder T, et al.: Speed related changes in muscle activity from normal to very slow walking speeds. Gait Posture, 2004, 19: 270–278. [Medline] [CrossRef]