

Activity of lower limb muscles during treadmill running at different velocities

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Abstract. [Purpose] The present study aimed to determine changes in muscle activity while moving on a treadmill at various speeds. [Subjects] The activities of the left vastus lateralis, vastus medialis, hip adductors, lateral head of gastrocnemius, medial head gastrocnemius, soleus, and tibialis anterior of 10 healthy male university students were analyzed. [Methods] University students walked, jogged, and ran for 10 minutes each in random order, and then myogenic potentials were measured 10 minutes later for 30 seconds. The flexion angle of the lower limb upon initial contact, mid stance, and toe off were measured. [Results] The average walking, jogging, and running speeds were 3.6 ± 0.4 , 6.7 ± 0.6 , and 10.4 ± 1.3 km/h, respectively. The average electromyographic activities of the vastus medial, tibialis anterior, medial head of gastrocnemius, and lateral head of gastrocnemius significantly differed. All muscles were more active during jogging and running than walking. Only the soleus was more active during running than walking, and the activities of the hip adductors and vastus lateralis did not significantly differ. [Conclusion] Velocity is faster and the angles of the lower limbs and ground reaction force (GRF) are larger during running than walking. The vastus medialis and soleus worked more easily according to the angle of the knee joint, whereas the tibialis anterior worked more easily at faster velocities and the medial and lateral heads of the gastrocnemius worked more easily with an increased GRF.

Key words: Walking, Running, Skeletal muscle

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INTRODUCTION

Human movement can be classified into walking and running, the latter of which easily fatigues the lower limb muscles¹⁻⁴⁾. During running, the lower limbs must cope with the repeated transient impact of vertical ground reaction force (GRF), which is an abrupt collision force equal to about 1.5- to 3-fold the body weight⁵⁾. Such repeated impacts are considered to cause lower limb muscle fatigue via chronic irritation. The incidence of running injury is affected by the running velocity and distance ran. Cheng et al. investigated 17,000 patients⁶⁾ and found a significantly higher incidence of osteoarthritis in men who were involved in running > 20 miles per week. Koplán et al. found that the risk of injury increased with increasing weekly distance³⁾. On the other hand, Imai et al.⁷⁾ found that the number of marathon athletes who stopped running within four hours was significantly high. Thus, running long distances imposes a burden on the lower limbs. However, enhanced velocity is thought to improve running ability. Running faster generally produces greater

ground reaction force (GRF) and imposes greater stress on various parts of the body^{8, 9)}. Running injuries occur most frequently in the knee, foot/ankle, and lower leg according to Taunton, et al.¹⁰⁾, who found that the most common overuse injuries included patellofemoral pain syndrome, iliotibial band friction syndrome, and plantar fasciitis.

Running velocity is affected by various conditions including individual running ability. We postulated that the load imposed on the lower limbs would change at different running velocities. Furthermore, because portion failure differs among individuals, the load applied to each muscle is probably not uniform. Therefore, we analyzed muscle activity at various speeds. According to Hreljac¹¹⁾, the boundary between walking and running velocities is 8.64 km/h. Therefore, we analyzed muscle activity under free walking, jogging (≤ 8.7 km/h), and running (≥ 8.8 km/h) conditions on a treadmill.

SUBJECTS AND METHODS

Ten male students without leg injuries (age, 23.2 ± 6.5 y; height, 170.4 ± 5.7 cm; weight, 67.6 ± 11.1 kg; BMI, 23.3 ± 3.2) provided written informed consent to participate after receiving an oral and written explanation of the study and its purpose. The Ethics Review Board at Heisei College of Health Sciences approved this study (No. H23-17). The participants did not routinely run but participated in recreational sports once or twice each week. Muscle activity was

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Table 1. Average %MVC of muscles (n=10)

	Walking	Jogging	Running
Vastus medialis	12.5±2.7	35.8±5.3*	38.8±4.6*
Vastus lateralis	17.1±6.1	36.3±8.1	37.7±6.8
Hip adductors	31.2±6.7	41.0±7.2	50.1±7.1
Tibialis anterior	14.3±1.3	29.3±3.8*	37.6±3.0*
Lateral head of the gastrocnemius	16.0±3.0	42.6±8.5*	40.8±6.2*
Medial head of the gastrocnemius	30.8±3.7	58.1±7.6*	63.3±5.3*
Soleus	18.4±5.0	39.6±7.8	44.8±6.2*

Values are means±SE. *p<0.05, vs. walking.

Table 2. Maximum %MVC of muscles (n=10)

	Walking	Jogging	Running
Vastus medialis	54.8±7.6	105.9±15.2*	135.7±11.5*
Vastus lateralis	68.1±29.0	103.1±17.0	134.4±23.6
Hip adductors	147.2±31.5	98.6±20.2	137.3±20.0
Tibialis anterior	54.1±6.3	85.8±20.7	87.8±7.9
Lateral head of the gastrocnemius	69.0±14.4	125.5±27.7	136.5±15.1
Medial head of the gastrocnemius	129.9±21.6	190.4±27.8	224.2±26.0*
Soleus	103.3±51.8	113.6±25.9	179.0±28.6

Values are means±SE. *p<0.05, vs. walking.

measured by surface electromyography using a TeleMyo G2 and MyoResearch XP (Noraxon USA Inc., Scottsdale, AZ, USA) with disposable M-00-S Blue Sensor polymer electrodes (Ambu A/S, Ballerup, Denmark) attached to the belly of the muscle while the participants moved on a Gait Trainer System 2 treadmill (Biodex Medical Systems Inc., Shirley, NY, USA). Muscle output was recorded at 30 frames/sec using a video camera to synchronize the movements with the electromyographic data. Activity was assessed at the left vastus medialis, vastus lateralis, hip adductors, tibialis anterior, lateral head of gastrocnemius, medial head gastrocnemius, and soleus.

Maximum voluntary isometric contraction (MVC) was determined as manual resistance against a maximally contracted muscle. The participants walked, jogged, and ran for 10 minutes in random order, and the myogenic potentials were measured for 30 seconds 10 minutes later. Analog signals of myogenic potential were processed using a band-pass filter (10–500 Hz) at a sampling frequency of 1,000 Hz.

The greater trochanter, lower limb joint space, and lateral malleolus of the left hip, knee, and ankle were marked with tape to measure the range of motion. One 30-second cycle of walking, jogging, and running recorded with the video camera was selected, and then initial contact, mid stance, toe off, and the range of motion of hip flexion, knee flexion, and ankle dorsiflexion were measured on printouts. In addition, using the time required for one cycle, stride was calculated.

Electromyographic data were analyzed using the average value of each muscle output and central frequency. The average activity was calculated from 30-second cycles of walking, jogging, and running, including both the swing and stance phases. These output values were divided by the MVC to determine the %MVC of each muscle. In addition,

lower limb joint angles on printouts were measured using a protractor. The data were analyzed using a one-way analysis of variance, and statistical significance was accepted at $p < 0.05$.

RESULTS

The average walking, jogging, and running speeds were 3.6 ± 0.4 , 6.7 ± 0.6 , and 10.4 ± 1.3 km/h, respectively.

The average electromyographic activities of the vastus medial, tibialis anterior, medial head of the gastrocnemius, and lateral head of the gastrocnemius were significantly higher during jogging and running compared with walking. The value was higher during running than walking only for the soleus. The hip adductors and vastus lateralis did not significantly differ (Table 1).

The maximal electromyographic activities of the vastus medialis during jogging and running and medial head of the gastrocnemius during running were significantly higher than during walking (Table 2).

The central frequency did not significantly differ (Table 3).

The angle of the knee at initial contact, mid stance, and toe off significantly differed, with the knee being more flexed during jogging and running than walking the knee being more flexed during running than jogging at mid stance and toe off (Table 4).

The average lengths of the running stride were significantly longer than those of jogging and walking. Also, that of jogging was significantly longer than that of walking (Table 5).

Table 3. Average central frequency of muscles (n=10)

	Walking	Jogging	Running
Vastus medialis	23.1±6.4	37.9±5.9	32.4±6.4
Vastus lateralis	29.7±5.8	40.3±5.6	41.8±6.9
Hip adductors	15.2±4.1	20.4±4.1	23.3±3.4
Tibialis anterior	59.8±6.0	66.0±6.5	66.1±7.4
Lateral head of the gastrocnemius	34.3±7.1	42.7±7.2	55.7±6.0
Medial head of the gastrocnemius	50.0±7.3	62.5±9.9	63.1±9.2
Soleus	61.2±7.6	45.1±8.2	59.7±11.8

Values are means±SE

Table 4. Average left lower limb joint angles (n=10)

		Walking	Jogging	Running
Hip joint flexion	IC	20.5±2.4	24.5±2.2	28.0±2.9
	MS	10.5±1.6	23.5±1.5*	28.5±1.7*
	TO	-6.0±2.2	3.0±2.6*	5.5±1.9*
Knee joint flexion	IC	4.2±2.1	14.8±2.2*	17.2±2.0*
	MS	15.0±2.1	41.5±1.5*	48.0±1.5**, **
	TO	57.1±1.3	38.9±2.4*	25.4±2.4**, **
Ankle joint dorsiflexion	IC	-2.2±3.6	4.0±2.0	6.2±1.1
	MS	6.5±1.3	20.0±1.7*	22.0±1.3*
	TO	-14.8±2.2	-14.8±2.7	-20.1±3.5

Values are means±SE. *p<0.05, vs. walking. **p<0.05, vs. jogging.

IC: initial contact, MS: mid stance, TO: toe off

DISCUSSION

Hreljac identified training, anatomy, and biomechanical factors as risk factors associated with running, since fast running generates considerable GRF and training to run stresses the joints, muscles, and ligaments¹²). The present study investigated differences in the amount of muscle activity during walking, jogging, and running. All participants walked freely at their own pace and then jogged at ≤ 8.7 km/h and ran at ≥ 8.8 km/h.

The central frequency of each muscle seemed to remain essentially unchanged between running and jogging compared with walking, and fatigue did not arise. The vastus lateralis and vastus medialis of the quadriceps not only act on the lower limb during running or walking but also suppress damage to the knee during weight-bearing in the stance phase. Therefore, we speculated that the amount of muscle activity would increase as the GRF increases. The averaged values of the vastus medialis were significantly higher during running and jogging compared with walking. Brownstein et al.¹³) found that a knee position that is more flexed than extension is due to the amount of activity of the vastus medialis. The present study found that the knees were flexed significantly more during running and jogging compared with walking at initial contact and during mid stance. These findings support the notion that the vastus medialis works easily during jogging and running. In addition, Kim et al.¹⁴) showed that the amount of activity in the vastus medialis rose in response to an elevated walking speed. Furthermore,

Table 5. Average length of stride (n=10)

	Walking	Jogging	Running
Stride (m)	1.24±0.04	1.46±0.06*	2.14±0.08*, **

Values are means±SE. *p<0.05, vs. walking. **p<0.05, vs. jogging.

in a previous study¹⁵), we compared the muscle activity during jogging and walking at the same velocity. In this study, the activity of the vastus medialis during jogging was significantly higher, and the knee joints exhibited significant flexion during jogging. Furthermore, the lower legs exhibited external rotation and internal rotation during running¹⁶). Load was especially applied in the direction of internal rotation in the stance phase. A study by Ono et al.¹⁷) showed that the output of the vastus medialis was increased in the lower leg during internal rotation. On the other hand, the output at 90° of flexion between knee extension from the vicinity of the vastus lateralis muscle did not significantly change¹³). In addition, the activity of the vastus lateralis muscle during walking was significantly higher, which could account for the small difference between walking and running. We considered that the influence of knee flexion was small. The average values of the adductor muscles did not significantly differ among walking, jogging, and running. Along with the outer muscles of the hip joint such as the gluteus medius, the adductor muscles maintain the inner-outer intermediate position of the lower limb during running. The types of hip movement involved in running are primarily flexion and extension, with minimal adduction and abduction. In addition, because the treadmill floor is horizontal, the trunk is also likely to become upset. Therefore, we considered that the adductor muscles do not play significant roles in walking, jogging and running.

The averages values for the tibialis anterior muscle were significantly higher during running and jogging compared with walking. The tibialis anterior muscle contracts either centrifugally or isometrically before and after initial contact to control the foot to prevent falling^{18, 19}). This muscle was significantly more contracted during running and jogging, perhaps because movement was faster.

The average values of the lateral and medial heads of the gastrocnemius were significantly higher during running and jogging compared with walking. The gastrocnemius works from the loading response to the terminal stance between

the stance phase¹⁸). The knee joint extends in the late stance phase of the running stride via plantar flexion of the ankle joint. The force exerted on the Achilles tendon during running exceeds 12-fold the weight of the runner²⁰). A large output by the gastrocnemius is required to advance the body during running.

The average value of the soleus muscle was significantly higher during running than during walking. The soleus is a single joint muscle that runs from the proximal portion of the tibia and fibula to the Achilles tendon. Thus, the amount of muscle activity is not affected by the angle of the knee joint. Because the knee flexes deeply in mid stance during running, more extension is required at toe off, and thus a large force is required for the triceps surae muscle. Under such conditions, the soleus muscle works more easily than the gastrocnemius, which is a biarticular muscle.

According to Mann et al.²¹), the angle of the lower limbs and the amount of muscle activity increases during running at higher velocities compared with walking. The stance phase is longer than the swing phase during walking but is shorter during running. According to Kluitenberg et al.²²), GRF on a treadmill and on the ground increases in the same way when the running speed is increased. Arampatzis et al.²³) reported that the mechanical power of the knee joint and ankle joint increases with increasing running velocity, and the present study found that, the stride was extended in accordance with the increase in velocity. We considered that exercise load is greater during running compared with walking due to these factors. The present study found that the amount of activity in the soleus muscle was significantly higher during running and jogging compared with the amounts of activity in the vastus medialis, tibialis anterior, and gastrocnemius muscle, which are involved in walking. Therefore, it was suggested that an increase in velocity causes these muscles to carry a heavier load.

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