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Electromyography Study of Forward-stepping Motion

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Abstract. [Purpose] The purpose of this study was to investigate and evaluate the timing and amount of muscle activity during forward-stepping motion. [Subjects and Methods] Seven healthy subjects participated in this study. The task was to step forward from a static standing position. Timing and amount of muscle activity were measured during the task. Muscle activities of the stance leg and the swing leg were measured using surface electromyography (EMG). [Results] A high negative correlation was found between the rate of change in the amount of tibialis anterior muscle activity of the stance leg and the reaction time. High positive correlations were found between the rates of change in the gastrocnemius and soleus muscles and the reaction time of the swing leg. [Discussion] Forward-stepping motion can be accomplished using two strategies. One is to swing the leg out taking a step forward using the gastrocnemius and soleus muscles of the swing leg. The other is to take a step forward using the tibialis anterior muscle of the stance leg. Increasing the activity of the tibialis anterior muscle of the stance leg may lead to taking a step forward rapidly.
Key words: Forward-stepping motion, Tibialis anterior muscle, Electromyography

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INTRODUCTION

When the elderly fall and injure themselves, they may be bedridden and require full-time care. Preventing falls is thus an important issue for health promotion for the elderly[1)]. Various factors contribute to the incidence of falls, including a decreased ability to control posture. Postural control involves the appropriate use of the muscles attached to the hips and ankles and an adequate stepping strategy. Stepping strategies involve movements to form a new base of support in the event of balance disturbances in order to prevent falling[2–6)]. A time delay during stepping has been reported to be associated with a tendency to fall by the elderly[7)]. Many studies have performed motion analyses to contribute toward prevention of falls in this population. More effective exercises can be prescribed for the elderly by identifying the muscles involved in successful stepping strategies. The purpose of this study was to investigate and evaluate the timing and amount of muscle activity in the forward-stepping motion of young persons.

SUBJECTS AND METHODS

Seven healthy subjects (3 males, 4 females; age, 21.3 ± 9 years; height, 164.9 ± 6.5 cm; weight, 56.9 ± 7.2 kg) participated in this study. All subjects were informed of the aims of the study and gave their written informed consent before participation. All test protocols were approved by Heisei College of Medical Technology Ethics Committee [H23-9].

The task was to step forward from a static standing position. Timing and amount of muscle activity were measured during the task. The stepping distances were 50 cm (condition 1) and 80 cm (condition 2) from the center point. A light signaled the start of the task. Subjects were instructed to step forward immediately upon seeing the signal. The task was performed three times for each condition. Subjects practiced a few times before the task.

Muscle activity was measured using surface electromyography (EMG). EMG data were recorded using a telemyosystem G2 EM-601 and Myo Research XP (NORAXON), and data were sampled at 1,000 Hz. Muscle activities of the tibialis anterior, gastronemius lateral head, rectus femoris, biceps femoris, vastus medialis, and soleus of the stance and swing legs were recorded simultaneously. The positions of the electrodes were as described in a previous EMG studiy[8)]. The electrodes were 55 mm in diameter and were positioned on each muscle in line with the fiber direction. Interelectrode distances were 3 cm. Maximal voluntary contraction (MVC) was measured using manual resistance[9)]. EMG data were rectified and the root mean square (RMS) value over 50 ms was determined. All measured waveforms were calculated as %MVC normalized RMS value at the time of MVC for 3 s.

The analysis focused on two parameters of the motion task. The first was the reaction time (RT), the time elapsing from the light signal to the plantar surface leaving the ground (foot-off). The second was the movement time (MT), the time elapsing from foot-off to the plantar surface making contact with the ground again.

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To determine the foot-off time of the plantar surface and the time when it contacted the ground again, a foot switch was used. This switch was pasted to the side of the heel and to the ball of the stepping foot and was synchronized with the EMG.

The paired t-test was used to test the significance of the differences in RT and MT between the two experimental conditions. The rate of change of condition 2 to that of condition 1 (condition 2/condition 1 = rate of change) in RT and MT, and the amount of muscle activity were calculated. Pearson's correlation coefficient was used to examine the relationship between the rate of change in the amount of muscle activity and RT and MT. The alpha level for determining statistical significance was chosen as 0.05.

Table 1. The differences in RT and MT

	condition1(s)	condition2(s)	rate of change [condition2/ condition1]
RT	0.49±0.06	0.54±0.07*	1.09
MT	0.33±0.04	0.40±0.06**	1.21

Values are means±SD
*: p<0.05, **: p<0.01

RESULTS

The results are presented in Tables 1–3. The average value of RT in condition 1 was 0.49 s, while that in condition 2 was 0.54 s, a significant increase. The average value of MT in condition 1 was 0.33 s, and in condition 2 it was 0.40 s, a significant increase. A high negative correlation was found between the rate of change in the amount of tibialis anterior muscle activity of the stance leg ($r = -0.885$) and RT (Table 4). High positive correlations were found between the rates of change in the gastronemius ($r = 0.725$) and soleus ($r = 0.799$) muscles and RT of the swing leg. In contrast, no significant correlations were found for MT (Table 5).

DISCUSSION

The results of this study suggest a relationship between the tibialis anterior muscle of the stance leg, the soleus muscle, the gastrocnemius muscle of the swing leg, and RT. The tibialis anterior muscle of the stance leg moves the leg forward by quickly changing the center of gravity. RT is adequate when the activity of the tibialis anterior muscle is high, as evidenced by the negative correlation between values for this muscle activity and RT.

In contrast, high positive correlations between RT and the gastrocnemius and soleus muscle activities were found for the swing leg. These muscles change the center of grav-

Table 2. Muscle activities at RT

	Stance leg			Swing leg		
	condition1 (%MVC)	condition2 (%MVC)	rate of change [condition2/ condition1]	condition1 (%MVC)	condition2 (%MVC)	rate of change [condition2/ condition1]
Soleus	28.9±8.6	31.4±13.6	1.05	28.9±8.6	32.7±12.5	1.13
Gastrocnemius	21.0±16.0	22.6±13.0	1.18	21.0±16.0	22.8±10.8	1.11
Biceps Femoris	14.3±12.2	14.5±12.6	1.12	14.3±12.2	14.5±10.5	1.17
Tibialis Anterior	110.0±75.4	125.2±93.2	1.11	110.0±75.4	108.6±56.5	1.18
Vastus medialis	23.3±18.0	26.9±21.1	1.15	23.3±18.0	24.5±16.9	1.14
Rectus Femoris	24.3±10.2	28.9±12.7	1.21	24.3±10.2	39.3±26.8	1.24

Values are means±SD

Table 3. Muscle activities at MT

	Stance leg			Swing leg		
	condition1 (%MVC)	condition2 (%MVC)	rate of change [condition2/ condition1]	condition1 (%MVC)	condition2 (%MVC)	rate of change [condition2/ condition1]
Soleus	98.5±19.0	180.4±39.3	1.86	29.3±7.1	36.9±25.9	0.97
Gastrocnemius	79.6±65.3	159.5±100.7	2.15	24.1±10.4	25.7±12.5	1.14
Biceps Femoris	20.8±19.4	24.1±17.4	1.36	47.9±26.0	41.6±27.8	0.75
Tibialis Anterior	82.5±39.8	99.7±41.2	1.26	39.2±16.9	47.1±28.7	1.25
Vastus medialis	27.3±18.3	44.1±37.4	1.47	38.6±15.5	24.5±16.9	1.05
Rectus Femoris	39.1±36.7	31.2±25.5	0.88	45.3±19.2	48.1±18.1	1.13

Values are means±SD

Table 4. Pearson's correlation coefficients for the rates of change in the amounts of muscle activity and RT

	Soleus	Gastrocne-mius	Biceps Femoris	Tibialis Anterior	Vastus medialis	Rectus Femoris
Stance leg	−0.256	−0.406	0.165	−0.886*	−0.378	−0.256
Swing leg	0.725*	0.799*	−0.194	0.044	0.075	0.651

*: $p<0.05$

Table 5. Pearson's correlation coefficients for the rates of change in the amounts of muscle activity and MT

	Soleus	Gastrocne-mius	Biceps Femoris	Tibialis Anterior	Vastus medialis	Rectus Femoris
Stance leg	−0.249	−0.383	0.589	0.417	−0.142	−0.033
Swing leg	0.112	0.323	−0.429	−0.187	0.300	0.125

ity by swinging the leg forward and placing the foot forward. Thus, more RT is required when the activity of these muscles is high.

Forward-stepping motion can be accomplished using two strategies. One is to swing the leg out taking a step forward using the gastrocnemius and soleus muscles of the swing leg. The other is to take a step forward using the tibialis anterior muscle of the stance leg. Increasing the activity of the tibialis anterior muscle of the stance leg may lead to taking a step forward rapidly.

No correlations between MT and muscle activities were found in this study. The initiation of movement and changes in the center of gravity were observed during RT measurements. Therefore, MT can be controlled during forward motion.

We would like to study a large number of subjects who are much older than the participants of the present study in the future, and we would like to conduct exercises for the stance leg during therapy for the elderly.

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