

Differences among lower leg muscles in long-term activity during ambulatory condition without any moderate to high intensity exercise

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Abstract

The present study aimed to investigate differences among the soleus (Sol), medial gastrocnemius (MG) and tibialis anterior (TA) in electromyogram (EMG) activities during ambulatory condition without any moderate to high intensity exercise. From 10:00 to 17:00, seven healthy graduate students participated in EMG recordings, which included the measurements during maximal voluntary efforts. During the long-term EMG recording, the subjects were instructed to perform normal daily routines, including desk work and the attendance of lectures. EMG signals from the three muscles were averaged every 0.1 s and expressed as a percentage (%MVE) of those obtained with maximal voluntary efforts, averaged over 1 s. An EMG burst which had an amplitude >2%MVE and a duration >0.1 s was defined as muscular activity. Regardless of muscles examined, the amplitude of the greater part of all bursts observed over the recording time was less than 30%MVE. The summed duration of all bursts over the recording time was significantly greater in Sol than in MG and TA, without a significant difference in the summed number of all bursts among the three muscles. The percentage of the summed duration of bursts at less than 10%MVE to that over the recording time was significantly higher in Sol and TA than in MG, but the corresponding value at $20 \leq \%MVE < 30$ was lower. Thus, EMG responses during ambulatory condition without any moderate to high intensity exercise differed among the three muscles, even between synergists: Sol was predominantly activated with low burst amplitudes as compared to MG.

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1. Introduction

In freely moving ambulatory individuals, major changes in physical activity involve movement of the lower limb (Anastasiades and Johnston, 1990). Therefore, recording the habitual activity patterns of major skeletal muscles located in the lower limbs can be a valuable approach to

monitoring muscle activities that are more directly related to spontaneous physical movements and their variations during daily living.

Recent technological advances have increased the number of studies using long-term electromyogram (EMG) recordings in caged animals performing daily activities (Hodgson et al., 2001). For human muscles, too, this technique has been used to quantify tremors or spasticity in individuals with Parkinson's disease or spinal cord injuries (Scholz et al., 1988; Tepavac et al., 1992). Recently, Mork

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and Westgaard (2005, 2006) have tried to quantify the habitual activity patterns of upper trapezius and low back muscles of healthy individuals at different levels of intensity and presented a substantial amount of data on the repeatability of long-term EMG recordings. For normal ambulatory individuals, however, only two studies have applied this technique to lower limb muscles (Kern et al., 2001; Monster et al., 1978). Among the limited findings available, Kern et al. (2001) reported that, as a result of analysis for EMG bursts exceeding 2% of those during maximal voluntary efforts, the mean amplitude in a 10-h recording is greater in leg muscles than in hand and arm muscles.

Among muscles located in the lower limb, it is known that there are marked differences between plantarflexors and dorsiflexors in twitch responses and susceptibility to fatigue (Belanger et al., 1983). Similarly, although the gastrocnemius and soleus muscles are synergistic muscles as plantarflexors, they differ considerably in physiological cross sectional area (Fukunaga et al., 1992), muscle fiber composition (Johnson et al., 1973), muscle architecture (Kawakami et al., 1998) and contractile properties (Vandervoort and McComas, 1983). These points tempt us to assume that, even in ambulant conditions without any moderate to high intensity exercise, the intensity and/or duration of activities will differ between opposing and/or synergistic muscles. In relation to this assumption, Monster et al. (1978) have shown that, as a result of an 8-h EMG recording with a burst detection threshold set at 8% of maximum, the percentage of total active time over the recording time and average active time per contraction were longer in the soleus muscle than in the gastrocnemius muscle. In any case, with regard to the existence of differences among lower limb muscles in EMG responses during non-restrained daily living, less information is available from previous studies. Notably, it is unknown how the number and/or duration of EMG bursts at a given intensity differs among the lower limb muscles as habitual activity patterns under ambulant conditions.

By using long-term EMG recording technique, therefore, the present study tried to investigate the difference in the activities of lower leg muscles, i.e., the gastrocnemius, soleus and tibialis anterior muscles during ambulant condition without any moderate to high intensity exercise. To this end, we quantified the level and duration of the activity of the three muscles in the daily routines of graduate male students, which was mainly consisted of desk work and the attendance of lectures.

2. Methods

2.1. Subjects

Seven healthy young males voluntarily participated in this study. The means (\pm standard deviation, SD) of age, height, and body mass in the subjects were 24.3 (\pm 1.6) yr, 172.7 (\pm 5.0) cm, and 70.0 (\pm 4.2) kg, respectively. All subjects were graduate students and had no known history of peripheral nerve dysfunction or other

types of neurological disorders. They were either sedentary or mildly active, but none was currently involved in any type of exercise program exceeding 30 min/day and 2 days/week. This study was approved by the National Space Development Agency of Japan and was consistent with their requirement for human experimentation. Each subject was informed of the procedures and purpose of the study, and gave their written informed consent.

2.2. Experimental design

EMGs were recorded from the medial gastrocnemius (MG), soleus (Sol), and tibialis anterior (TA) muscles using a portable EMG device (ME3000P8, Mega Electronics, Finland). Subjects came to the laboratory at 9:00. The EMG recording started at 10:00 and ended at 17:00. Prior to the long-term EMG recordings, the subjects performed isometric contractions with maximal voluntary effort in two movement tasks, i.e., plantarflexion and dorsiflexion. After the completion of the maximal isometric contractions, the subjects left the laboratory. They were instructed to perform normal daily routines, including desk work and the attendance of lectures, without any moderate to high intensity exercise. The subjects came back to the laboratory at 17:00. Each subject performed the experimental procedure two times with an interval of one week to confirm the day-to-day difference of long-term EMG recordings. The first and second sessions were referred to as DAY1 and DAY2, respectively. The EMG recording time not including the EMG measurements during maximal isometric contractions did not significantly differ between DAY1 and DAY2, and averaged 6.5 h a session.

2.3. Measurements

2.3.1. EMG recordings

After careful abrasion of the skin, pairs of disposable surface electrodes (Blue Sensor, Medicotest, Denmark) were placed over the belly of each of the muscles examined on the right leg (20 mm apart between the electrodes). The positions of electrodes were marked with ink to make sure they were the same on both DAY1 and DAY2. To stabilize their location during the recording period including EMG measurements during maximal isometric contractions, the electrodes were fixed with surgical tape and covered with barrel-shaped mesh supporters. The electrodes were connected to a portable EMG device which was protected in a soft case and worn around the subject's waist during the measurements. The EMG signals were amplified (\times 412), filtered (bandwidth 8–500 Hz), sampled at 1000 Hz, full-wave rectified and averaged over 0.1 s. These data were stored on a PCMCIA card for subsequent analysis. The procedure for long-lasting EMG recordings in different days has been already established in our recent study (Kouzaki et al., 2007).

2.3.2. EMG measurements during maximal isometric contractions

The subjects performed maximal isometric contractions of the plantarflexion and dorsiflexion using a dynamometer (VTF-002R/L, Vine, Japan) designed especially for the determination of ankle joint torques. During the maximal isometric contractions, the EMGs from MG, Sol, and TA were recorded under the conditions mentioned above. For each of the two tasks, the subjects sat in an adjustable chair with support for the back and hips with the hip joint flexed 1.57 rad. During the measurements, the back and hips were held tightly to the seat with adjustable lap belts. The rota-

tional axis of the ankle joint was aligned with that of the lever arm of the dynamometer. In the plantarflexion and dorsiflexion, the subject's right ankle was set at 1.57 rad (anatomical position) with the knee joint fully extended and the foot was securely strapped to a foot plate connected to the lever arm of the dynamometer.

After a warm-up procedure with submaximal contractions, the subject performed maximal isometric contractions for each of the two movements. The order of the execution of the two conditions was randomized for each subject. Each of the two movement tasks was repeated at least two times per subject with an interval of 1 min between trials and at least 5 min between the tasks. In each trial, the subjects were required to maintain the maximal isometric contraction for about three seconds. Torque signals were A/D converted at a sampling rate of 100 Hz (PowerLab16SP, AD instrument, Australia) and analyzed by a personal computer (DELL Dimension XPS). The trial in which the highest peak torque was observed was used for the subsequent analysis of EMG during the maximal isometric contractions. The EMGs as well as torque during the maximal isometric contractions were averaged over one second around a data point where the torque peaked. The average EMG value was referred to as MVE and used to normalize EMG activities during long-lasting recording.

2.3.3. Physical activity

Steps and exercise energy expenditure during the long-term EMG recording were measured using a pedometer (Lifecoder, Suzuken, Japan) with a built-in accelerator which counts the acceleration of vertical direction during physical movements (Harada et al., 2001).

2.3.4. Data analysis

After completion of the EMG measurements, the stored data were transferred to a personal computer. Fig. 1 indicates a typical example of a long-term EMG recording in one subject. All data except for those recoded in MVE measurements (about 30 min) were analyzed as long-term EMG data. For the data analysis, an original program written by Real Basic (Real Software) was used. EMG bursts which had an amplitude $>2\%$ of MVE and a duration >0.1 s were defined as muscular activity (Kern et al., 2001). In each EMG burst, two outcome variables were determined as described by Kern et al. (2001): (1) burst duration, an interval that had an amplitude $>2\%$ of MVE, and (2) burst amplitude, mean value of burst amplitude expressed as a percentage of MVE (%MVE). As total indexes representing EMG data over the recording time, two outcome variables were quantified: (1) the summed number of all bursts (TI-SNB) and (2) the summed duration of all bursts (TI-SDB). Furthermore, each EMG burst was stratified into ten levels in accordance with the %MVE; the first level was $2 < \%MVE < 10$ and the remainders were $10 \leq, 20 \leq, 30 \leq, 40 \leq, 50 \leq, 60 \leq, 70 \leq, 80 \leq, 90 \leq \%MVE$. Within each of the ten stratified levels, the summed number (SI-SNB) and duration (SI-SDB) of bursts were quantified as stratified indexes. In addition to the absolute values, SI-SNB and SI-SDB were expressed as a percentage of TI-SNB and TI-SDB, respectively, and referred to as %SI-SNB and %SI-SDB, respectively.

2.3.5. Statistics

Descriptive data were presented as means \pm SDs. A Wilcoxon test was used to test the difference between DAY1 and DAY2 in the variables concerning the physical activity, torque and MVE during the maximal isometric contraction, and the total indexes of

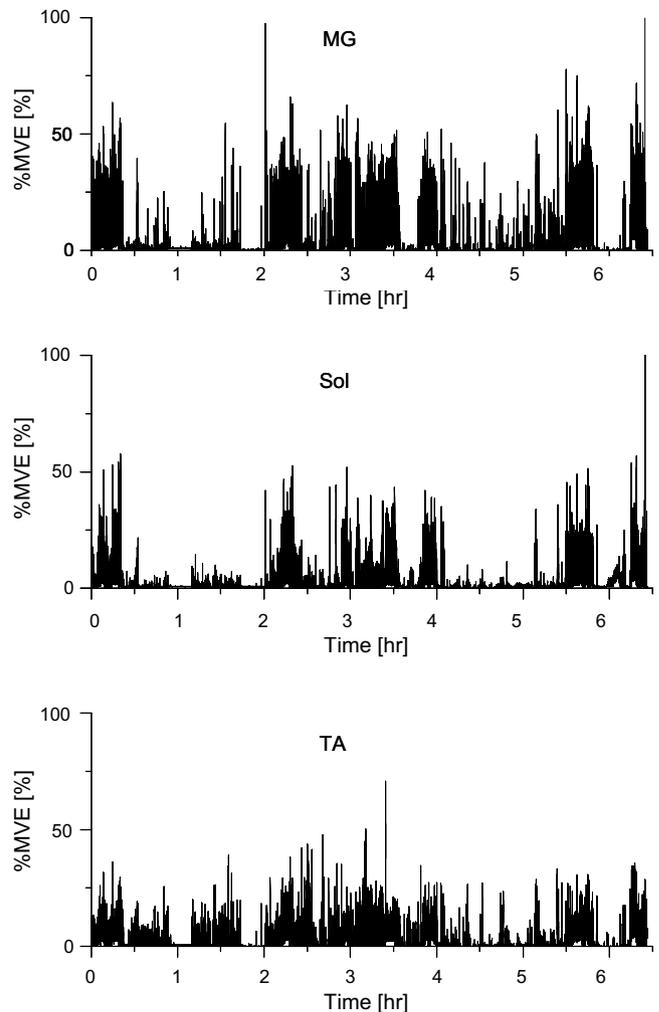


Fig. 1. An example of EMG recordings not including MVE measurements of the three muscles in one subject. The signals were averaged every 0.1 s and expressed as a percentage (%MVE) to those obtained for maximal voluntary contractions, averaged over 1 s.

long-term EMG. The corresponding difference in stratified indexes at each of the ten stratified levels was also examined by Wilcoxon test. Nonparametric one-factor, repeated measures analysis of variance (Kruskal–Wallis) with a post hoc comparison (Steel–Dwass test) was used to compare the total indexes and the stratified indexes at each of the stratified levels of long-term EMG among the three muscles. The probability level for statistical significance was set at $P < 0.05$.

3. Results

3.1. DAY1 versus DAY2

Table 1 summarizes the descriptive data on physical activity, the torque and MVE determined on DAY1 and DAY2. There were no significant differences ($P = 0.208–0.575$) between DAY1 and DAY2 in any of the variables listed in Table 1.

On both DAY1 and DAY2, there were large inter-individual variations in TI-SNB (736–6485 bursts for MG, 765–6472 bursts for Sol, and 785–5418 bursts for TA) and

Table 1
Descriptive data on physical activity, and averaged EMG (MVE) and torque during maximal isometric contractions in the separated 2 days

Variables	DAY1	DAY2
Physical activity		
Steps, <i>n</i>	4561.5 ± 2997.4	4783.6 ± 2858.6
Exercise energy expenditure, kcal	152.3 ± 102.9	158.3 ± 98.3
Torque, Nm		
Plantarflexion	194.6 ± 36.0	193.6 ± 38.5
Dorsiflexion	33.8 ± 15.5	30.6 ± 12.9
MVE, μV		
MG	328.6 ± 125.5	318.5 ± 87.1
Sol	284.3 ± 102.7	303.5 ± 86.2
TA	394.7 ± 71.6	420.5 ± 74.2

Values are means ± SDs.

TI-SDB (2290.3–10515.8 s for MG, 2916.5–11950.3 s for Sol, and 1513.4–8014.9 s for TA). For each muscle, however, there were no significant differences between DAY1 and DAY2 in TI-SNB ($P = 0.237\text{--}0.735$) and TI-SDB ($P = 0.128\text{--}0.735$). As shown in Fig. 1, there were EMG activities exceeding 80%MVE. In relation to the duration of the burst defined as muscular activity, however, there was no burst beyond 80%MVE in all three muscles. The differences between DAY1 and DAY2 in SI-SNB and SI-SDB were also not significant in any of the muscles; $P = 0.128\text{--} >0.999$ for SI-SNB and $P = 0.128\text{--} >0.999$ for SI-SDB. These results indicated that the intra-individual response in the repeated long-term EMG recordings was relatively invariant in spite of large inter-individual variations in the EMG responses. Therefore, data obtained from the 2 days were pooled for all subsequent analyses concerning the muscle-related differences in the long-term EMG responses.

3.2. Muscle-related differences

There was no significant difference in TI-SNB among the three muscles: 2819.7 (±1652.5) bursts for MG, 3262.0 (±1517.7) bursts for Sol and 2968.2 (±1250.0) bursts for TA (Fig. 2). On the other hand, TI-SDB was significantly greater in Sol (7076.1 ± 2911.6 s) than in MG (4450.2 ± 2337.7 s) and TA (4000.0 ± 1805.4 s). The percentage of TI-SDB to the recording time was 30.4 (±12.0)% for Sol, 19.1 (±9.8)% for MG and 17.2 (±7.6)% for TA.

Table 2
Descriptive data on the summed number of bursts (SI-SNB) and its percentage (%SI-SNB) to TI-SNB in each of the stratified levels less than 30%MVE

Variables	Levels	Muscles			Steel–Dwass test*
		MG	Sol	TA	
SI-SNB, <i>n</i>	2 < %MVE < 10	1659.6 ± 659.1	2064.3 ± 775.5	2238.5 ± 991.1	MG, Sol > TA
	10 ≤ %MVE < 20	736.1 ± 589.5	985.8 ± 1000.7	688.4 ± 562.7	
	20 ≤ %MVE < 30	337.9 ± 516.5	193.4 ± 243.7	34.9 ± 30.8	
%SI-SNB, %	2 < %MVE < 10	65.5 ± 17.3	68.0 ± 16.7	75.1 ± 13.7	MG, Sol > TA
	10 ≤ %MVE < 20	23.8 ± 11.0	25.7 ± 13.9	22.7 ± 11.3	
	20 ≤ %MVE < 30	8.5 ± 8.7	5.5 ± 5.8	1.7 ± 2.8	

Values are means ± SDs.

* $P < 0.05$.

The amplitude of most of the bursts obtained here were less than 30%MVE. The percentage of the summed number of all bursts at less than 30%MVE to TI-SNB was 97.8 (±2.7)% for MG, 99.2 (±1.1)% for Sol, and 99.5 (±1.2)% for TA. There was no significant difference among the three muscles ($P = 0.760$) in the summed number of all bursts at less than 30%MVE: 27733.5 (±1455.7) for MG, 3243.5 (±1521.2) for Sol, and 2961.8 (±1254.7) for TA. And so, the examinations on muscle-related difference in the stratified indexes were performed using EMG data of which the amplitude was less than 30%MVE.

Table 2 indicates the mean and SD values of SI-SNB and %SI-SNB at less than 30%MVE, respectively, in each of the three muscles. There was a tendency that Sol and TA showed more EMG bursts than MG at less than 10%MVE (Table 2) and vice versa at $20 \leq \%MVE < 30$. Both SI-SNB and %SI-SNB at $20 \leq \%MVE < 30$ were significantly greater in MG and Sol than in TA.

At less than 10%MVE, Sol showed significantly greater SI-SDB than MG and TA (Table 3). At $20 \leq \%MVE < 30$, SI-SDB was significantly greater for MG and Sol than for

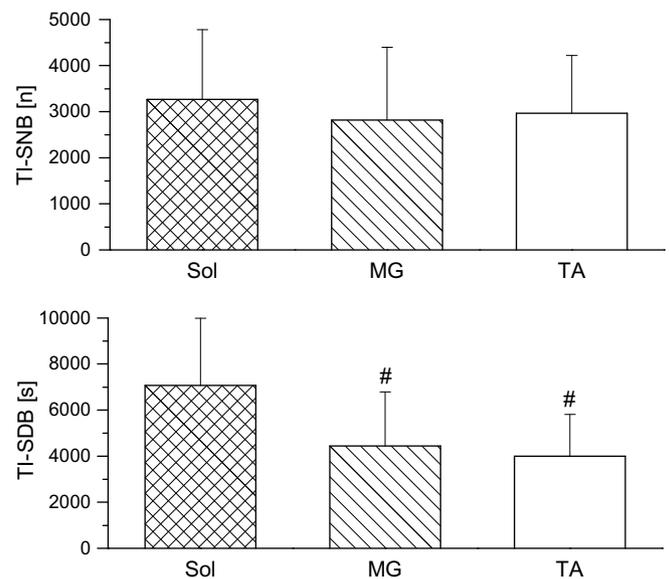


Fig. 2. Comparison among the three muscles of the summed number of all bursts (TI-SNB) and the summed duration of all bursts (TI-SDB) over the recording time. Values are means ± SDs. # denotes that TI-SDB values for MG and TA were significantly ($P < 0.05$) lower than that for Sol.

Table 3
Descriptive data on the summed duration of bursts (SI-SDB) and its percentage (%SI-SDB) to TI-SDB in each of the stratified levels less than 30% MVE

Variables	Levels	Muscles			Steel–Dwass test*
		MG	Sol	TA	
SI-SDB, s	2 < %MVE < 10	1332.8 ± 526.8	3766.6 ± 1809.6	2046.8 ± 943.1	Sol > MG, TA
	10 ≤ %MVE < 20	1539.0 ± 1063.9	2401.4 ± 1405.1	1580.1 ± 1037.5	
	20 ≤ %MVE < 30	928.7 ± 831.9	668.7 ± 430.7	224.59 ± 426.0	MG, Sol > TA
%SI-SDB, %	2 < %MVE < 10	33.8 ± 14.6	52.4 ± 14.1	53.7 ± 19.4	Sol, TA > MG
	10 ≤ %MVE < 20	32.9 ± 13.4	32.7 ± 11.2	36.9 ± 11.6	
	20 ≤ %MVE < 30	18.5 ± 10.5	9.5 ± 5.6	4.9 ± 7.9	MG > Sol > TA

Values are means ± SDs.

* $P < 0.05$.

TA. The %SI-SDB at less than 10%MVE was significantly higher in Sol and TA than in MG. However, the corresponding value at $20 \leq \%MVE < 30$ was higher in MG than in Sol and TA and in Sol than in TA (Table 3).

4. Discussion

The main purpose of the present study was to examine the differences among the three muscles located in the lower leg in the spontaneous activities without any moderate to high intensity exercise. One of the present findings was that Sol had significantly higher value than MG and TA for TI-SDB, despite that TI-SNB was similar among the three muscles. This indicates that Sol is activated more continuously than MG and TA. As described earlier, a prior study has shown that, for human muscle, the duration of total activity during normal daily use can be related to the proportion of type I fibers (Monster et al., 1978). Hensbergen and Kernell (1997), who examined daily spontaneous activities in the ankle muscles of cats, have suggested that differences in the total duration of activity largely reflect differences in the extent to which the various muscles and muscle regions are used for long-lasting stabilizing contractions, which may be related to fiber-type composition. However, Kern et al. (2001) challenged the findings mentioned above on analyzing the daily activities of the human first dorsal interosseus, biceps brachii, vastus medialis, and vastus lateralis. We cannot explain the discrepancies between the findings of the two human studies. From the finding of an autopsy study (Johnson et al., 1973), however, the mean percentage of type I fibers is high for Sol (86% at surface and 89% at depth) than for MG (51%) and TA (73% at surface and depth). When the discussion is limited to the three muscles, therefore, the observed difference in TI-SDB between Sol and the other two muscles support the finding of Monster et al. (1978).

Regardless of muscles, the amplitude of the greater part of all bursts was less than 30%MVE. Especially, the bursts at less than 10%MVE accounted for 66–75% of the summed number of bursts over the recording period (Table 2). Sawai et al. (2004) reported that the integrated EMG per time of lower limb muscles for young adults in various daily actions such as postural maintenance and body transfer actions was less than 20–30% of the maximum voluntary contraction.

Thus, it is reasonable to assume that the present result concerning the burst amplitude can be largely attributed to the fact that the long-term EMG recording was performed during the daily routines of graduate students, which were mainly consisted of desk work and the attendance of lectures. Again, Jonsson (1978, 1982, 1988), who examined the amplitude probability distribution function (APDF) in long-lasting works, indicated that the amplitude probability level reaches around 1.0 at 15–30% of maximum voluntary contraction in works which the worker can complete without discomfort. Therefore, the present result that the amplitude of greater part of all bursts was less than 30%MVE may be also considered to be a pattern of EMG bursts during long-lasting ambulatory condition with less muscular fatigue.

Among the three muscles examined, MG and Sol have a functional linkage as synergists of plantarflexors. In addition to TI-SDB, however, significant differences between the two muscles were found in SI-SDB and %SI-SDB, too, in spite of no significant differences of SI-SNB and %SI-SNB at each level. Namely, the SI-SDB and %SI-SDB at less than 10%MVE was significantly higher in Sol than in MG. On the other hand, %SI-SDB at $20 \leq \%MVE < 30$ for Sol was significantly lower than that for MG. Thus, Sol compared to MG was predominantly activated with lower burst amplitudes and MG compared to Sol with higher burst amplitudes.

In freely moving cats, the profiles of forces produced by MG and Sol during the full range of hindlimb movements in posture, locomotion, and jumping appear to be precisely matched to the different characteristics of the motor-unit populations composing these synergistic muscles (Walmsley et al., 1978). In human experiments, it has been shown that there are differences between MG and Sol in EMG activities during quiet standing (Masani et al., 2003), calf raising (Kinugasa and Akima, 2005), and walking (Gottschall and Kram, 2003). Masani et al. (2003) provided evidence that, compared to Sol, the pattern of EMG activities for MG during quiet standing was more phasic. Borg et al. (2007) suggested that MG is to a large extent responsible for the phasic control of the anterior–posterior balance during quiet standing. In addition, MG compared to Sol showed a greater increment in EMG activity during calf raising (Kinugasa and Akima, 2005) and walking (Gottschall and

Kram, 2003) with increasing exercise intensity. In the present result, the SI-SDB at less than 10%MVE was greater in Sol than MG, but the corresponding difference in that at $20 \leq \%MVE < 30$ was not significant. Taking this into account together with the previous findings cited above, it might be assumed that, in accordance with the different characteristics of the motor-unit populations, the activities of MG would be added to those of Sol in physical actions which require increasing force output of plantarflexors.

The SI-SNB and SI-SDB at $20 \leq \%MVE < 30$ for TA were significantly lower than those for MG and Sol. In addition, SI-SDB at less than 10%MVE was also significantly lower in TA than in Sol, in spite of similar values of SI-SNB and %SI-SNB at the corresponding level. Thus, the present results indicate that TA is predominantly activated with low burst amplitudes as compared to MG and Sol, with shorter duration than Sol. Borg et al. (2007), who analyzed EMG activity and sway data from quiet and perturbed standing, reported that TA EMG was generally quiet except in the beginning of the perturbation trials when the perturbation mass was on the participant while the dorsal flexors resisted the tug. This is because in standing posture the ankle extension torque is continuously required since the center of mass of the body is located in front of the ankle joint (Smith, 1957). Consequently, even if the percentage of type I fibers for TA is more comparable to that for Sol rather than MG (Johnson et al., 1973), TA will not be activated as frequently as Sol to stabilize body posture during quiet standing.

TA is likely the most representative muscle for preparatory adjustment in sit-to-stand movement (Goulart and Valls-Sole, 1999), which might be assumed to be a major action performed by the subjects examined here. From the findings of Goulart and Valls-Sole (1999), however, the activity of TA was greatly diminished after take-off from seat, although TA was the muscle activated first. Conversely, Sol was the last muscle activated, but it remained active during standing. On the other hand, Ericson et al. (1986) reported that TA was activated during the entire walking cycle with greater amplitude of bursts at the time of heel strike and at the beginning of acceleration in the swing phase, in which MG and Sol were less activated. In their results, however, the peak activity of TA was lower than those of MG and Sol. In addition, Gottschall and Kram (2003) showed that TA did not change its activation level during horizontal walking regardless of aiding and impeding forces. In their study, the averaged EMG for MG decreased by 41% and increased by 65% with adding and impeding forces, respectively, corresponding to 10% of body weight. Again, Chiu and Wang (2007) indicated that increased walking speed caused a significant increase in the activity of MG, but did not in that of TA. These points partially explain the observed differences in the stratified indexes between TA and either MG or Sol.

Before summarizing the present results, we should comment the limitations of the present study, in relation to the experimental design taken. First, we have no data concerning not only the muscle fiber composition of the subjects

examined but also their kinetic and kinematic profiles during the EMG recordings. And so, we cannot clear the physiological reasons for the observed differences in EMG responses among the three muscles. Second, the present study examined relatively small number of subjects. In addition, the graduate students were selected as the subjects and their daily routines, which were mainly consisted of desk work and the attendance of lectures, were subjected for collecting EMG data. Hence, the findings obtained here may be considered as a quantitative result of long-term EMG activities during sedentary living. However, there is a possibility that the results on the total and stratified indexes might differ from those obtained here when the EMG data are determined under different ambulatory conditions, or when different populations are selected as subjects. Further study needs to clear whether the muscle-related differences observed in the total and stratified indexes can be generalized as the profile of long-term EMG activities in freely moving ambulatory individuals, regardless of the subjects mentioned above.

In summary, the results of the present study indicated that EMG responses in the daily routine of graduate students among the three muscle groups located in the lower leg: (1) regardless of muscles, the amplitude of greater part of all bursts was less than 30% of maximal voluntary efforts, (2) although there were no significant differences in the summed number of all EMG bursts over the recording time among Sol, MG, and TA, the summed duration of all bursts was greater in Sol than in MG and TA, and (3) Sol and TA are predominantly activated with low burst amplitudes as compared to MG.

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