Long-term activity in upper- and lower-limb muscles of humans

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Kern, Drew S., John G. Semmler, and Roger M. Enoka. Long-term activity in upper- and lower-limb muscles of humans. J Appl Physiol 91: 2224–2232, 2001.—Despite limited data on humans, previous studies suggest that there is an association between the duration of daily muscle activity and the proportion of type I muscle fibers. We quantified the activity of limb muscles in healthy men and women during normal use and compared these measurements with published reports on fiber-type proportions. Seven men (age range = 21–28 yr) and seven women (age range = 18–26 yr) participated in two 10-h recording sessions. Electromyogram (EMG) activity of four muscles in nondominant upper (first dorsal interosseus and biceps brachii) and lower limbs (vastus medialis and vastus lateralis) was recorded with surface electrodes. Hand and arm muscles were active for 18% of the recording time, whereas leg muscles were active for only 10% of the recording time. On average, upper-limb muscles were activated 67% more often than lower-limb muscles. When lower-limb muscles were activated, however, the mean amplitude of each burst was greater in leg muscles (18 and 17% maximum voluntary contraction [MVC]) compared with arm (8% MVC) and arm (6% MVC) muscles. Temporal association in activity between pairs of muscles was high for the two lower-limb muscles ($r^2 = 0.7$) and relatively weak for the two upper-limb muscles ($r^2 = 0.09$). Long-term muscle activity was only different between men and women for the biceps brachii muscle. We found no relation between duration of muscle activity in 10-h recordings and the reported values of type I fibers in men and women.

The amount of daily activity in the muscle, however, does not appear to be solely determined by the proportion of type I fibers. Monster et al. (23), for example, found for 24% (8/33) of comparisons between pairs of muscles that the muscle with the greater proportion of type I fibers was active for a lesser percentage of the recording time. Although Monster et al. studied only men, one factor that might influence this association is the sex of the individual. This possibility was suggested by sex differences that were observed in long-term EMG recordings during baseline measurements in a study on the effects of limb immobilization (30). In this study, several features of EMG activity recorded in the elbow flexor muscles was greater in a group of subjects that was comprised mainly of women (6/7 subjects) compared with a group of five men. Because the statistical power of these comparisons was marginal and the study involved a single muscle group, we decided to expand our comparison of muscle activity.

The purpose of the study was to quantify and compare long-term muscle activity in upper- and lower-limb muscles of men and women. We recorded the concurrent activity of four muscles for 10 h and performed a detailed analysis of the EMG to assess differences between muscles and effects of an individual’s sex on the level of muscle activity. Results of most previous studies (16, 19, 23, 32) predicted that we should find a significant relation between the amount of EMG activity and the fiber-type proportions of selected muscles but not between the sex of the individual. In contrast, we found no relation between the amount of EMG activity and the reported fiber-type proportions of the muscles. However, there were modest sex differences in EMG levels. A preliminary report of these data has been presented (18).

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METHODS

Subjects

Seven men (age = 21–28 yr) and seven women (age = 18–26 yr) participated in the study. All subjects were right-hand dominant and had no known history of peripheral nerve dysfunction or other types of neurological disorders. Subjects were administered the Paffenbarger Physical Activity Questionnaire (25) to obtain a self-report of their weekly energy expenditure related to physical activity. Most participants were college students and reported being moderately active. The Human Research Committee at the University of Colorado approved the procedures, and subjects gave their informed consent before participation in the study.

Muscles Examined

Experiments were performed on two upper-limb (first dorsal interosseus and biceps brachii) and two lower-limb (vastus medialis and vastus lateralis) muscles. These muscles were selected because they perform a range of functions and are reported to comprise from 41 to 57% of type I muscle fibers. The first dorsal interosseus is an intrinsic hand muscle that contributes to abduction and flexion forces exerted by the index finger. It is active during many manipulative functions performed by the hand (7, 35). The biceps brachii is a proximal arm muscle that is used primarily to transport the hand throughout its workspace. It exerts a supination torque about the long axis of the forearm and a flexion torque about the elbow joint (4, 10, 37). The vastus lateralis and vastus medialis muscles are thigh muscles that contribute to, among other actions, upright stance and locomotion. Although both muscles exert an extensor torque about the knee, they may be activated independently (12, 15, 27).

Experimental Arrangement

EMG. Long-term EMG activity was recorded from selected muscles on a subject’s left (nondominant) side. Pairs of disposable surface electrodes (5-mm diameter Meditrace pellet electrodes, Graphic Controls, Buffalo, NY) were attached over the bellies of the four muscles. Electrodes over the first dorsal interosseus were positioned ~1.5 cm apart, whereas those over the biceps brachii, vastus medialis, and vastus lateralis muscles were 2.0 cm apart. To stabilize electrode location during the recording period, subjects wore a modified breathable mesh glove (E-Force, San Diego, CA) covering the electrodes of first dorsal interosseus and a flexible wrapping (Co-Flex, Andover Coated Products, Salisbury, MA) over the electrodes of biceps brachii, vastus medialis, and vastus lateralis muscles. The electrodes were connected to a portable EMG device (ME-3000 Professional, Mega Electronics, Kuopio, Finland) that was protected in a hip sack. EMG signals were pass filtered (20–500 Hz), then averaged every 0.1 s, and stored for subsequent analysis.

Maximum voluntary contractions. Subjects performed maximum voluntary contractions (MVCs) with the first dorsal interosseus muscle while seated in a chair with the forearm resting on a table. This task involved exerting an abduction force with the index finger. The hand was positioned in an apparatus containing a plastic restraint that conformed to the radial side of the index finger and a metal support aligned to the palmar side of the thumb. For MVCs performed with elbow flexor and knee extensor muscles, the subject was seated and secured with waist straps to the back of a chair. The elbow joint was flexed to 1.57 rad (90°) for elbow flexor MVCs with hand supinated, forearm strapped to an armrest, and elbow resting on a padded armrest. Knee extensor MVCs were performed on the same apparatus with the knee flexed to 1.57 rad and an adjustable strap that connected the ankle to the base of the chair.

Experimental Procedures

Subjects were required to participate in two 10-h recording sessions, each separated by 2 to 4 wk. Each subject reported to the laboratory at ~7:00 AM for the initial application of the recording electrodes and the performance of MVCs for each muscle. When subjects left the laboratory at ~8:00 AM, they were instructed to maintain normal daily routines, including moderate exercise, without performing activities that would potentially damage the recording device or dislodge the surface EMG electrodes (e.g., swimming). Subjects reported back to the laboratory at ~8:00 PM to return the recording equipment and to perform another set of MVCs for each muscle. The two sessions were used to determine the reliability of the recordings as a measure of typical long-term EMG activity.

Three MVCs were performed in the morning and three in the evening to measure the maximum EMG for each muscle and check the integrity of the recording electrodes. Data were discarded if there was a significant difference between the maximum EMG recorded in the morning and evening sessions. MVC comprised a ramp-and-hold protocol that involved gradually increasing force from baseline to maximum over 2–3 s and then holding the maximum force for an additional 2–3 s. Participants were verbally encouraged to achieve maximum force during each MVC trial. Subjects were given a 30-s rest between each MVC. For first dorsal interosseus MVCs, subjects were instructed to keep the palmar surface of their hands flat on the support surface and to abduct the index finger against the plastic restraint while minimizing activity in other hand and arm muscles. Similarly, subjects were encouraged to relax the hand, forearm, and shoulder muscles while pulling up with the wrist to perform an MVC with the elbow flexor muscles. For knee extensors MVCs, the task was to pull against the ankle restraint.

Data Analysis

The 10-h recording sessions were stored on a RAM card at a sampling frequency of 10 Hz and downloaded to a computer hard disk. Data were analyzed by using custom-designed software written in MATLAB (Mathworks, Natick, MA). Comparison of EMG activity for selected muscles was based on the number of EMG bursts that were identified. An EMG burst was defined as an interval that had an amplitude >2% of the maximum EMG (obtained during the MVCs) and a duration of >0.1 s (Fig. 1). Peak EMG observed during MVCs, either in the morning or the evening, was used to normalize long-term EMG recordings. EMG activity was quantified with nine outcome variables: 1) number of bursts; 2) burst duration: total number of bursts during the recording period; 2) burst duration: mean duration of all bursts; 3) burst amplitude: mean amplitude of bursts as a percentage of maximum EMG activity measured during MVCs; 4) burst area: mean area of each burst; 5) burst rate: mean number of bursts per second; 6) summed duration: total summed duration of all bursts; 7) total burst time: summed duration of all bursts as a percentage of total recording time; 8) summed area: summed area of

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all bursts; and 9) mean activity: summed area of all bursts as a percentage of total recording time.

Statistical analysis. A paired t-test was performed to compare MVCs obtained in morning and evening sessions. An unpaired t-test was used to compare weekly energy expenditure reported from the Paffenbarger Physical Activity Questionnaire between men and women. A three-factor, repeated-measures ANOVA (session × muscle × sex) for each EMG-dependent variable was used to test differences between sessions. Absence of a session effect enabled us to collapse data across sessions and perform a two-factor, repeated-measures ANOVA (muscle × sex) to examine the effect of sex on EMG data. Fisher’s post hoc test was performed as required. Significance was set at a P value <0.05. Data are reported as means ± SD unless otherwise stated.

RESULTS

EMG activity was recorded from two upper-limb (first dorsal interosseus and biceps brachii) and two lower-limb (vastus medialis and vastus lateralis) muscles for a 10-h period on two separate occasions. All subjects, with one exception, were university students. Subjects were predominantly involved in educational activities for the duration of each recording session, which included attending lectures and performing computer work. All subjects performed some mild physical activity during the recording sessions, such as walking and climbing stairs. None of the subjects performed activities that damaged the equipment. Self reports from subjects indicated that the recording equipment did not limit their activities.

Average Energy Expenditure

Average energy expenditure (means ± SD) related to physical activity for the 14 subjects, as assessed by the Paffenbarger Physical Activity Questionnaire, was 8,921 ± 7,669 kcal/wk (range = 2,460 to 26,745 kcal/wk). These values suggest that the population of subjects studied was moderately active (26). An unpaired t-test revealed no significant difference (P > 0.05) in energy expenditure between men (7,866 ± 5,875 kcal/wk) and women (9,976 ± 9,504 kcal/wk).

MVC EMG

To assess the reliability of MVC EMG, we performed a two-factor ANOVA (session × muscle) on the coefficient of variation [(standard deviation/mean) × 100]. The coefficient of variation did not differ statistically between muscles, across sessions, or for interaction term. The coefficient of variation averaged 16.3% for session 1 and 17.6% for session 2, with average values ranging from 15.0 to 18.7% for individual muscles. Similarly, a two-factor ANOVA (muscle × time of day) indicated that the coefficient of variation did not differ statistically for muscle, time of day (morning and evening), or interaction term. The coefficient of variation averaged 23.6% for morning and 20.7% for evening, with average values ranging from 15.1 to 30.6% for individual muscles.

A paired t-test for each muscle determined that there was no significant difference (P values from 0.4 to 1.0) between peak EMG recorded during MVCs performed in the morning and evening sessions. This suggests that the integrity of the electrodes remained intact for the duration of the recording period. Peak EMG for MVCs performed in the two sessions was used to normalize EMG data obtained from each muscle in that recording session. Because there was no significant difference between peak EMG for each muscle between sessions 1 and 2 (two-factor ANOVA), these EMG data were averaged between sessions. Peak EMG averaged across sessions for each subject was largest for the biceps brachii muscle, intermediate for the first dorsal interosseus muscle, and least for the vastus medialis and vastus lateralis muscles (Table 1).

Sessions

Long-term EMG recordings were obtained from 14 subjects on two separate occasions. A two-way ANOVA (session × muscle) for each dependent variable in the burst analysis revealed no significant difference between sessions (P values from 0.12 to 0.98), which indicated that the subjects activated the four muscles to a similar extent on each day. Hence, data were pooled across sessions for all subsequent analyses. Similarly, mean MVC EMG for all muscles was not different between sessions (P = 0.15).
EMG Activity in Upper and Lower Limbs

A representative example of a long-term (9.7 h) EMG recording obtained from the first dorsal interosseus, biceps brachii, vastus medialis, and vastus lateralis muscles in one woman is shown in Fig. 2. For this subject, the number of bursts was 11,397 for the first dorsal interosseus, 7,393 for the biceps brachii, 4,247 for the vastus medialis, and 4,575 for the vastus lateralis muscle. The first dorsal interosseus and biceps brachii muscles were active for 22% (2.2 h) and 15% (1.4 h) of the total recording time, respectively, whereas the vastus medialis and vastus lateralis muscles were both active for 9% (0.9 h) of the recording time. Although leg muscles were activated less often, amplitude of EMG activity was greater when activated. Mean burst amplitude for the vastus medialis and vastus lateralis muscles was 20% of maximum, whereas mean amplitudes for the first dorsal interosseus and biceps brachii were 9 and 6% of maximum, respectively.

Burst analysis data obtained during long-term EMG recordings in upper- and lower-limb muscles of all subjects are shown in Table 1. Activity in upper-limb muscles was significantly greater ($P < 0.05$) than in lower-limb muscles for number of bursts, burst rate, and total burst time. Furthermore, summed duration of activity for upper-limb muscles was significantly greater than the vastus medialis muscle, and summed duration for the biceps brachii muscle was greater than for the vastus lateralis muscle. Differences in summed duration of EMG activity between the first dorsal interosseus muscle and the vastus lateralis muscle just failed to reach statistical significance ($P = 0.05$). On the basis of the four significantly different outcome

<table>
<thead>
<tr>
<th>First Dorsal Interosseus</th>
<th>Biceps Brachii</th>
<th>Vastus Medialis</th>
<th>Vastus Lateralis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recording time, h</td>
<td>10.1 ± 1.1</td>
<td>10.3 ± 0.9</td>
<td>10.0 ± 1.4</td>
</tr>
<tr>
<td>MVC, $\mu$V</td>
<td>872 ± 263*†‡</td>
<td>1,148 ± 582*†‡</td>
<td>265 ± 160</td>
</tr>
<tr>
<td>Number of bursts</td>
<td>9,327 ± 6,658*†‡</td>
<td>8,897 ± 3,470*†‡</td>
<td>5,411 ± 2,722</td>
</tr>
<tr>
<td>Mean burst duration, s</td>
<td>0.66 ± 0.11</td>
<td>0.76 ± 0.24</td>
<td>0.67 ± 0.19</td>
</tr>
<tr>
<td>Mean burst amplitude, %MVC</td>
<td>7.8 ± 1.2†‡</td>
<td>5.6 ± 1.2†‡</td>
<td>18.2 ± 6.7</td>
</tr>
<tr>
<td>Burst area, %MVC·s</td>
<td>2.79 ± 0.50</td>
<td>2.81 ± 1.41</td>
<td>3.58 ± 2.93</td>
</tr>
<tr>
<td>Burst rate, no./s</td>
<td>0.26 ± 0.09†‡</td>
<td>0.24 ± 0.09†‡</td>
<td>0.15 ± 0.07</td>
</tr>
<tr>
<td>Summed duration, h</td>
<td>1.6 ± 0.9†</td>
<td>1.9 ± 1.0†‡</td>
<td>1.0 ± 0.6</td>
</tr>
<tr>
<td>Total burst time, %RT</td>
<td>17.5 ± 7.4†‡</td>
<td>18.4 ± 9.5†‡</td>
<td>10.0 ± 5.2</td>
</tr>
<tr>
<td>Summed area, %MVC·h</td>
<td>7.5 ± 3.5</td>
<td>7.2 ± 4.6</td>
<td>5.1 ± 4.0</td>
</tr>
<tr>
<td>Mean activity, %MVC</td>
<td>0.74 ± 0.31</td>
<td>0.62 ± 0.43</td>
<td>0.51 ± 0.37</td>
</tr>
</tbody>
</table>

Values are means ± SD. RT, total recording time of the averaged sessions; EMG, electromyograph; MVC, maximum voluntary contraction.

* $P < 0.05$ compared with biceps brachii. † $P < 0.05$ compared with vastus medialis. ‡ $P < 0.05$ compared with vastus lateralis.

Fig. 2. EMG activity recorded continuously for ~10 h in 1 woman. All data are represented as a percent of maximum EMG obtained during MVCs performed for each muscle. For this subject, FDI and biceps brachii were active for 22 and 15% of total recording time, respectively. The vastus medialis and vastus lateralis (VL) were both active for 9% of recording time.
variables from burst analysis, upper-limb muscles were activated 67% (range = 41–90%) more often than lower-limb muscles. No significant differences in EMG activity were observed between the two upper-limb muscles (first dorsal interosseus compared with biceps brachii) and the two lower-limb muscles (vastus medialis compared with vastus lateralis).

Although lower-limb muscles were activated less often, EMG amplitude was greater in these muscles when activated (Table 1). Mean burst amplitude was 170% (range = 118–225%) greater in lower-limb muscles compared with upper-limb muscles. No significant difference in mean burst amplitude was observed within the two upper- and two lower-limb muscles.

A frequency distribution plot of mean burst amplitudes in the first dorsal interosseus and vastus lateralis muscles of all subjects is shown in Fig. 3. For the first dorsal interosseus muscle, 79% (7,558/9,527) of bursts had an amplitude <10% MVC EMG, whereas only 55% (3,338/6,051) of bursts were <10% MVC EMG in the vastus lateralis muscle (Fig. 3A). In contrast, the vastus lateralis muscle had more bursts above 90% MVC EMG than the first dorsal interosseus muscle (Fig. 3B). The small number of bursts above 100% MVC EMG in the vastus lateralis muscle is a reflection of the protocol used to measure MVC EMG. For experimental purposes, the MVC EMG was obtained during an isometric contraction that was performed in a controlled manner, whereas EMG during normal, everyday activities included anisometric contractions obtained at varying muscle lengths and contraction velocities. A comparison of burst amplitude distribution between the first dorsal interosseus and vastus lateralis muscles (Fig. 3) suggests that relative distribution is concentrated at higher burst amplitudes in lower-limb muscles and lower burst amplitudes in upper-limb muscles. The behavior of the two upper-limb muscles was quantitatively similar, as was the behavior of the two lower-limb muscles.

**EMG Activity Between Muscles**

The degree of correlated activity between pairs of muscles for a 10-h duration is shown for one subject in Fig. 4. These graphs were created from data shown in Fig. 2 by comparing moment-to-moment EMG activity...
in one muscle with EMG activity in a second muscle when recorded concurrently. Each data point represents EMG activity averaged over 0.1 s in each muscle. For this subject, EMG activity in the two lower-limb muscles was highly correlated (Fig. 4B) with the coefficient of determination ($r^2$ values), indicating that 83% of EMG activity in the vastus lateralis could be accounted for by activity in the vastus medialis muscle. In contrast, EMG activity in the two upper-limb muscles (Fig. 4A) was relatively independent of each other, with activity in the biceps brachii muscle only accounting for 4% of EMG activity in the first dorsal interosseus muscle. For all subjects and muscle comparisons, the greatest relation in EMG activity was observed between the vastus lateralis and vastus medialis muscles ($r^2 = 0.70$; range = 0.10–0.93). The next strongest association was for the first dorsal interosseus and biceps brachii muscle ($r^2 = 0.09$; range = 0.0001–0.243). Weak associations were obtained for all four comparisons of one upper- and one lower-limb muscle ($r^2$ values from 0.008 to 0.024).

**EMG Activity in Men and Women**

A comparison of 10-h EMG recordings between men and women are shown for the upper limb in Table 2 and for the lower limb in Table 3. For the biceps brachii muscle (Table 2), women had a significantly longer ($P < 0.05$) summed duration and total burst time of EMG activity compared with men. No significant differences were observed between men and women for any other muscle. However, the women had slightly greater EMG activity in all muscles for number of bursts (35–38% greater in women; $P$ values of 0.1 to 0.3), burst rate (30–39% greater; $P$ values of 0.1 to 0.3), summed duration (46–71% greater; $P$ values of 0.02 to 0.30), total burst time (16–67% greater; $P$ values of 0.02 to 0.48), and summed area (19–77% greater; $P$ values of 0.05 to 0.50).

**DISCUSSION**

The purpose of the study was to quantify muscle activity in upper- and lower-limb muscles of men and women during normal activities of daily living. We found that upper-limb muscles were more active during 10-h recording compared with lower-limb muscles. Although lower-limb muscles were activated less often, mean burst amplitude was greater for these muscles. A high temporal association existed between activity of the two thigh muscles, which was not observed in the two upper-limb muscles. Furthermore, we found only modest differences in 10-h EMG activity between men and women.

**Muscle Activity and Fiber-Type Composition**

There are numerous reports of long-term activity in muscles of rats and cats during normal daily use. From 24-h recordings in spontaneously moving cats, it has been shown that there are substantial differences in EMG activity between different ankle muscles (13). There is also evidence that relative activity of synergistic muscles (soleus and medial gastrocnemius) is altered depending on the particular task that is performed (14, 16, 36). Furthermore, there is evidence of a differential activation of specific regions of muscles in the cat hindlimb, which seems to be related to a non-uniform fiber-type distribution throughout the muscle (6). Nevertheless, the general consensus from these studies is that duration of daily activity within a given muscle depends on its role during various postural tasks, which is related to its fiber-type composition (13, 19).

A major application of chronic EMG recordings has been to quantify muscle activity during chronic interventions, such as hindlimb suspension, spinal cord transection, and limb immobilization. These studies have shown that hindlimb suspension significantly decreases the quantity of EMG activity (5, 28), but this occurs in some muscles and not in others (2). Although substantial changes in neuromuscular properties occur after hindlimb suspension, these changes do not seem to be related to the extent of muscle activity during the intervention (34). One factor that could be responsible for this discrepancy is the differences in fiber-type proportion of the muscles under examination. For example, transformation of slow-twitch fibers to fast-twitch fibers after spinal cord transection may be reversible.

**Table 2. Long-term EMG of arm muscles during normal everyday use for men and women**

<table>
<thead>
<tr>
<th></th>
<th>First Dorsal Interosseus</th>
<th>Biceps Brachii</th>
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<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td>Recording time, h</td>
<td>9.7 ± 1.1</td>
<td>10.5 ± 1.1</td>
</tr>
<tr>
<td>MVC, μV</td>
<td>801 ± 278</td>
<td>943 ± 247</td>
</tr>
<tr>
<td>Number of bursts</td>
<td>8,116 ± 3,829</td>
<td>10,939 ± 3,111</td>
</tr>
<tr>
<td>Mean burst duration, s</td>
<td>0.68 ± 0.13</td>
<td>0.63 ± 0.08</td>
</tr>
<tr>
<td>Mean burst amplitude, %MVC</td>
<td>8.1 ± 1.6</td>
<td>7.7 ± 0.9</td>
</tr>
<tr>
<td>Burst area, %MVC-s</td>
<td>3.0 ± 0.6</td>
<td>2.6 ± 0.4</td>
</tr>
<tr>
<td>Burst rate, no/s</td>
<td>0.23 ± 0.10</td>
<td>0.30 ± 0.08</td>
</tr>
<tr>
<td>Summed duration, h</td>
<td>1.3 ± 1.0</td>
<td>1.9 ± 0.7</td>
</tr>
<tr>
<td>Total burst time, %RT</td>
<td>16.2 ± 8.8</td>
<td>18.8 ± 6.1</td>
</tr>
<tr>
<td>Summed area, %MVC-h</td>
<td>6.9 ± 3.7</td>
<td>8.2 ± 3.3</td>
</tr>
<tr>
<td>Mean activity, %MVC</td>
<td>0.69 ± 0.34</td>
<td>0.80 ± 0.30</td>
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</table>

Values are means ± SD for 7 men and 7 women. %Δ, differences of relative values in women compared with men. *P < 0.05 compared with women.
related to the total level of spontaneous daily activity, where reduction in EMG activity is greater in slow-twitch muscles (1). Unfortunately, we do not know how these data apply to humans because of the lack of long-term recordings of muscle activity in humans and the differences in fiber-type proportions and muscle morphology between animals and humans.

It has been shown in both animal (19) and human (23) studies that the percentage of type I fibers is typically higher for muscles with greater levels of daily activity compared with muscles that are more quiescent. More importantly, these studies have suggested that the fiber-type proportion of a muscle can be reasonably predicted based on the duration of daily muscle activity. We examined this issue by matching recorded EMG activity from four muscles during normal activities of daily living with estimates of fiber-type compositions as reported in the literature. As indicated in Fig. 5, there was no association between the amount of EMG activity in a 10-h period and the approximate proportion of type I muscle fibers.

**EMG Activity in Upper and Lower Limbs**

From 38 recordings of different muscle pairs over an 8-h period, it has been reported previously that upper-limb muscles are more active than lower-limb muscles (23). With a burst detection threshold set at 8% of maximum, Monster et al. (23) found that the biceps brachii muscle was active for ~18% of recording time, the first dorsal interosseous muscle for 13% of recording time, and the vastus lateralis muscle for 8% of recording time. (The vastus medialis muscle was not measured.) Although we used a burst detection threshold set at 2% of maximum, we obtained similar findings. From concurrent recordings of these muscles, we found that the biceps brachii and first dorsal interosseous muscles were active for 18% of recording time, whereas the vastus lateralis muscle was active for 10% of recording time (Table 1).

The most striking difference in muscle activity between upper and lower limbs was the greater mean burst amplitude in the vastus lateralis and vastus medialis muscles (Fig. 3). Although activated less often, we found that mean burst amplitudes of lower-limb muscles were two to three times greater than those of upper-limb muscles. These data were not reported by Monster et al. (23) because they were unable to compare EMG amplitude between muscles when they were recorded at different times. Between-muscle and between-subject comparisons of EMG amplitude was possible in the present study because we used a procedure of normalizing EMG activity to the value obtained during a controlled MVC performed at the beginning and end of each recording period. As such, this is the first study to report greater EMG amplitude in lower-limb muscles during normal, everyday use. This finding is to be expected, as lower-limb muscles are used to support body weight during postural control and are often subjected to high-impact forces during locomotion.

On the basis of a qualitative examination of long-term EMG patterns, it has been suggested that there is a strong temporal similarity between muscles of the lower limb but not between muscles of the upper limb. For example, Monster et al. (23) noted a strong functional linkage in concurrent recordings of muscle ac-

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**Table 3. Long-term EMG for leg muscles during normal everyday use for men and women**

<table>
<thead>
<tr>
<th></th>
<th>Vastus Medialis</th>
<th>Vastus Lateralis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
<td><strong>Women</strong></td>
<td><strong>%Δ</strong></td>
</tr>
<tr>
<td>Recording time, h</td>
<td>9.9 ± 0.6</td>
<td>10.0 ± 2.0</td>
</tr>
<tr>
<td>MVC, μV</td>
<td>316 ± 179</td>
<td>213 ± 130</td>
</tr>
<tr>
<td>Number of bursts</td>
<td>4,607 ± 2,901</td>
<td>6,275 ± 2,453</td>
</tr>
<tr>
<td>Mean burst duration, s</td>
<td>0.60 ± 0.18</td>
<td>0.73 ± 0.20</td>
</tr>
<tr>
<td>Mean burst amplitude, %MVC</td>
<td>15.8 ± 3.8</td>
<td>20.5 ± 8.4</td>
</tr>
<tr>
<td>Burst area, %MVC</td>
<td>3.8 ± 3.9</td>
<td>3.4 ± 1.8</td>
</tr>
<tr>
<td>Burst rate, no./s</td>
<td>0.13 ± 0.08</td>
<td>0.18 ± 0.06</td>
</tr>
<tr>
<td>Summed duration, h</td>
<td>0.8 ± 0.5</td>
<td>1.3 ± 0.6</td>
</tr>
<tr>
<td>Total burst time, %RT</td>
<td>7.5 ± 4.4</td>
<td>12.5 ± 4.9</td>
</tr>
<tr>
<td>Summed area, %MVC</td>
<td>4.2 ± 3.7</td>
<td>6.0 ± 4.4</td>
</tr>
<tr>
<td>Mean activity, %MVC</td>
<td>0.41 ± 0.35</td>
<td>0.60 ± 0.39</td>
</tr>
</tbody>
</table>

Values are means ± SD for 7 men and 7 women.

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tivity in four leg muscles, with the strongest correlation being observed between the biceps femoris and tibialis anterior muscles. In contrast, no strong temporal association was observed between four muscles of the wrist and arm (wrist flexor and extensor, biceps and triceps brachii). We used a correlational technique to quantify functional coupling between muscles and found a high temporal similarity between the vastus lateralis and vastus medialis muscles of the leg (Fig. 4B) but not for the first dorsal interosseus and biceps brachii muscles of the upper limb (Fig. 4A).

Sex Differences in Muscle Activity

The major catalyst for the present study was a previous observation of possible sex differences in the activity of the elbow flexor muscles (30). From 24-h recordings obtained before limb immobilization, we found that the biceps brachii muscle was active for a total duration of 2.9 h in a group of subjects consisting mostly of women (6/7 subjects), compared with 1.2 h for a group of five men. Because a direct comparison of long-term EMG patterns in men and women has never been performed, we examined muscle activity in men and women by using concurrent recordings from upper- and lower-limb muscles.

The largest differences between men and women were detected in the biceps brachii muscle (Table 2) where the summed duration and total burst time were ~70% greater in women. No significant differences were observed for any other dependent variable from EMG between men and women. Based on this finding and our previous observation (30), we now have convincing evidence that sex differences in muscle activity exist for the biceps brachii muscle, at least in the non-dominant arm of university students. Although no significant sex differences were observed for the other muscles, many EMG-dependent variables just failed to reach statistical significance. A larger sample size may provide additional support for sex differences in muscle activity, particularly in lower-limb muscles.

There are conflicting reports in the literature regarding sex differences in fiber-type composition. The lack of consensus on this issue is presumably due to the inherent variability in obtaining a biopsy sample from different sites within the same muscle. Furthermore, the sex differences in fiber-type composition appear to exist in some muscles but not in others. For example, there is substantial evidence suggesting that fiber-type proportions are similar in the biceps brachii muscle for men and women (3, 22, 24, 29). Interestingly, it was in the biceps brachii muscle where we found the largest sex differences in long-term EMG activity. This dissociation suggests that long-term EMG activity in different muscles is related more to other physiological characteristics of each muscle, such as muscle strength, muscle mass, or endurance capacity, rather than to fiber-type proportions. However, it is possible that the amount of long-term EMG activity for men and women could be different on the dominant side, especially in upper-limb muscles.

In summary, we found greater average amplitudes but less frequent bursts of EMG in lower-limb muscles compared with upper-limb muscles of nondominant limbs of young men and women. The duration of long-term muscle activity was not related to the reported fiber-type composition of the muscle. Furthermore, modest sex differences were observed in EMG activity of the biceps brachii muscle. It appears that factors other than fiber-type distribution influence the extent of EMG activity in a muscle during normal activities of daily living performed by young men and women.

REFERENCES