Timing and Relative Intensity of Hip Extensor and Abductor Muscle Action During Level and Stair Ambulation

An EMG Study

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The timing and relative intensity of electromyographic activity of hip abductor and extensor muscles were recorded during free and fast velocity walking and during ascent and descent of stairs. Eleven healthy subjects were tested using fine wire electrodes to record the electromyographic activity. Data were quantified by normalizing all electromyographic activity during gait with electromyographic activity occurring during a sustained maximum isometric effort resisted either manually or with a dynamometer. The results indicated that the hip extensor muscles had different phasic patterns and moments of peak activity. During level walking, the semimembranosus and long head of the biceps femoris muscles displayed the greatest swing phase activity (beginning in mid-swing). The adductor magnus muscle followed with its onset in terminal swing. Both this muscle and the gluteus maximus were the principal hip extensors active during the loading response. For ascending stairs, the lower portion of the gluteus maximus muscle proved to be the main hip extensor during the loading response and mid-stance. The findings also showed that the upper portion of the gluteus maximus muscle functioned more like the gluteus medius muscle than the lower portion of the gluteus maximus muscle during both level and stair walking.

Key Words: Electromyography, Gait, Hip, Muscles.

Adequate hip extension and abduction stability is essential for walking; hence, the functional characteristics of the muscles providing such control are a basic clinical concern. Using accepted dynamic EMG techniques to define muscle function, several investigators have studied the action of the abductor and extensor muscles of the hip during walking and stair climbing. Their findings have varied as a result of differences in the techniques used and in the muscles studied. Three investigators chose surface electrodes, both as a convenience and to assure broad representation of the muscle. Five other studies used wire electrodes to gain more accurate delineation of muscle action.

This series of investigations established a clear description of the phasic activity of these muscles during walking and stair climbing. A second, and unanswered concern of the clinician, is the relative intensity of muscular effort required for normal hip abduction and extension control. To determine this, the recorded myoelectric activity must be quantitated and related to a normalizing base that correlates EMG to maximum muscle effort. Only two of the previous studies used this technique, and of the
have any obvious gait abnormalities, and none had a leg length discrepancy of greater than 1 cm.

**Procedure**

Paired fine-wire electrodes (50 µ diameter with 2 mm bared tips) were inserted into each muscle (Tab. 1) using Basmajian's single needle technique. To set the wires in place, the subject strongly contracted each muscle. The electrode placement was confirmed by electrical stimulation. The myoelectric signals were transmitted by FM-FM telemetry to a seven-channel tape recorder for later quantification.

Testing began by recording a resting EMG to establish a threshold for computer signal processing. Next, a series of muscle tests were performed to record the EMG during maximum effort. Both manual resistance and the Cybex dynamometer were used to test each muscle. In addition to using the standard manual muscle test positions, the semimembranosus and the long head of the biceps femoris muscles were tested with resistance to hip extension applied at the ankle while the subject was supine, the hip flexed 30 degrees, and the knee fully extended. A second gluteus maximus muscle test also was conducted in which the subject, while in the side-lying position with the knee flexed 90 degrees and the hip fully extended, hyperextended against maximum resistance applied at the distal thigh. Following the walking and stair climbing trials, the manual muscle tests were repeated to verify that the electrode insertions were intact.

Dynamometer testing was performed with the subjects standing, with the trunk and pelvis stabilized by appropriate strapping to a stationary pillar. For each test, the dynamometer was positioned to align the axis of its resistance arm with that of the hip joint. For hip extension, the joint axis was located at the anterior superior tip of the greater trochanter. The joint axis for abduction was 0.5 in medial to the anterior superior iliac spine at the level of the greater trochanter. All extension tests were done with the hip flexed 30 degrees. Resistance was alternately applied at two locations: just proximal to the knee joint and at the distal one-third of the leg. Hip abduction was tested with the limb in neutral alignment and the resistance placed laterally and proximally to the knee joint line. The tests were conducted in a random order among subjects. Two maximum efforts were performed in each position and held for a four-second recording period. A minimum rest of three minutes was given between trials.

Before conducting the walking and stair climbing series, insole footswitches (containing separate

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**TABLE 1**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Electrode Insertion Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensor fasciae latae</td>
<td>Two fingerbreadths distal to ASIS and two fingerbreadths medial to greater trochanter</td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>Midway between the ASIS and PSIS, approximately two inches inferior to the crest of the ilium</td>
</tr>
<tr>
<td>Upper portion of gluteus maximus</td>
<td>Superior and lateral to a line drawn between the PSIS and the posterior greater trochanter</td>
</tr>
<tr>
<td>Lower portion of gluteus maximus</td>
<td>Inferior and medial to a line drawn between the PSIS and the posterior greater trochanter</td>
</tr>
<tr>
<td>Semimembranosus</td>
<td>One fingerbreadth medial to the medial edge of the semitendinosus muscle at the level of the mid thigh</td>
</tr>
<tr>
<td>Long head biceps femoris</td>
<td>Lateral to semitendinosus muscle at the level of mid thigh on a line drawn between the ischial tuberosity and the distal tendon of the muscle</td>
</tr>
<tr>
<td>Adductor magnus</td>
<td>Three inches inferior and one to two inches medial to the ischial tuberosity, inserting towards the center of the circumference of the thigh</td>
</tr>
</tbody>
</table>

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**METHOD**

The EMG activity of the left semimembranosus, long head of the biceps femoris, adductor magnus, tensor fasciae latae, gluteus medius, and gluteus maximus (upper and lower portions) muscles was recorded as the subjects walked at their free and fast velocities, and then ascended and descended a short staircase.

**Subjects**

Eleven healthy subjects (five men and six women) between 25 and 34 years of age (mean, 27.6 years) volunteered for the study. No one was observed to
## TABLE 2

Means and Standard Deviations of Gait Characteristics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Walk Free</th>
<th>Walk Fast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men n = 5</td>
<td>Men n = 5</td>
</tr>
<tr>
<td></td>
<td>Women n = 6</td>
<td>Women n = 6</td>
</tr>
<tr>
<td></td>
<td>p*</td>
<td>p*</td>
</tr>
<tr>
<td>Velocity (m/min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>83.5 (10.1)</td>
<td>126.8 (21.7)</td>
</tr>
<tr>
<td>Women</td>
<td>77.2 (8.1)</td>
<td>118.9 (16.0)</td>
</tr>
<tr>
<td>Stride length (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>1.49 (.12)</td>
<td>1.81 (.14)</td>
</tr>
<tr>
<td>Women</td>
<td>1.35 (.05)</td>
<td>1.65 (.06)</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>112 (5)</td>
<td>140 (14)</td>
</tr>
<tr>
<td>Women</td>
<td>114 (9)</td>
<td>144 (16)</td>
</tr>
<tr>
<td>Gait cycle duration (sec)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>1.08 (.05)</td>
<td>0.87 (.09)</td>
</tr>
<tr>
<td>Women</td>
<td>1.06 (.09)</td>
<td>0.84 (.09)</td>
</tr>
<tr>
<td>Single limb support (left, % GC)</td>
<td>40.2 (1.8)</td>
<td>43.6 (1.7)</td>
</tr>
<tr>
<td>Swing time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>40.7 (1.7)</td>
<td>43.6 (1.0)</td>
</tr>
<tr>
<td>Women</td>
<td>40.4 (1.9)</td>
<td>44.0 (1.3)</td>
</tr>
</tbody>
</table>

* Two sample t test, α = .05.

 switches for the heel, the 1st and 5th metatarsal heads, and the great toe) were taped to the subjects' feet. All testing was performed on a 15 m (49.2 ft) walkway; the middle 6 m (19.7 ft) was designated by photo electric cells as the steady-state data segment. For the walking trials, the subjects crossed the test area at their self-selected free and fast velocities. Data recordings were made after the subjects had become familiar with the footswitches and had completed a practice run along the walkway.

Stair ascent and descent were performed on a four-step staircase (15 cm riser and 27 cm depth or 5.9 in and 10.6 in). Three runs were recorded to provide three strides for data analysis; only the middle stride of each was used. Each walk and stair trial was repeated once to accommodate our seven-channel recording capability.

All the electronic data (EMG, footswitch, and dynamometer) were stored on a seven-channel analog tape recorder.‡ In addition, these data were recorded simultaneously with the subjects' performance on video tape** for subsequent visual review if data inconsistencies were found. At the end of each experiment, a seven-channel printed record on light-sensitive paper†† was produced.

### DATA ANALYSIS

In preparation for analysis, the EMG and torque data were processed by an analog-to-digital converter and microcomputer.‡‡ After digitizing at a 2,500 sample per second rate, the myoelectric signals were rectified and integrated by summing the sample amplitudes.¹² For the isometric tests, the data intervals were 0.25 second, and 0.02 second intervals were used for the dynamic events. To exclude the data variations created by the inability to control the size of the motor unit pools sampled by the electrodes, all the dynamic EMG test values for each muscle were normalized as percentages of maximum effort. This permitted pooling of the subjects' data. For this purpose, the greatest mean integrated EMG registered over two consecutive seconds in either the manual or dynamometer maximum effort test was selected as that muscle's normalization factor. For the walking and climbing tests, the relative intensity of muscle action occurring in each 2 percent of the gait cycle (GC) was calculated and expressed in 5 percent increments of maximum EMG.

Using the footswitch signals to define the gait cycle variables, the duration of swing and stance was individually identified and adjusted by computer so that the data of all the subjects fitted the same 100 percent scale. The final computer print-outs were histograms displaying, for each dynamic event, the relative intensity and timing of a muscle's activity per stride. Records of both the individual subjects and composites of the entire study group were prepared. Muscle action was defined as representative if it was registered in at least 50 percent of the strides recorded in these data.

From the printed records, the footswitch intervals were hand measured. These data were computer processed to determine gait velocity, cadence, stride length, duration of the GC, and single limb support. The mean and standard deviation for each variable for the subgroups of men and women were calculated. We compared the men's and women's results using two sample t tests.

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‡ Ampex FR 1300, 401 Broadway, Redwood City, CA 94063.
** JVC Model CR 6060U video cassette recording system, 1011 West Artesia Blvd, Compton, CA 90220.
†† Honeywell 2106 Visicorder, 4800 E Dry Creek Rd, Denver CO 80217.
‡‡ Digital Equipment Corporation PDP 11/34, Microcomputer Products Group, MR 2-2/m65, One Iron Way, Marlboro, MA 01752.
RESULTS

Gait Variables

Analysis of the footswitch data for free and fast velocity walking revealed no significant difference between men and women in gait velocity, cadence, and single limb support. The slightly greater stride length of the men than of the women was identified as significant \((p < .01)\) (Tab. 2). Because of the overall similarity in gait, no separation by sex was made for the EMG data analysis.

Muscle Testing

Six muscle samples were excluded from the study because of a significant reduction in amplitude and density of EMG during the repeat muscle tests. In two cases, the wire insertions pulled out as the subjects were ascending the stairs.

The maximum EMG occurred during a manual muscle test in 77 percent of the 73 trials analyzed. Within this group, the EMG was 56 percent greater than that obtained when eliciting a maximum effort test with the dynamometer. In the remaining 17 tests, the dynamometer was slightly more effective, eliciting 18 percent greater EMG than the manual muscle test EMG.

Relative Intensity of EMG

A considerable difference in the intensity and duration of EMG was elicited during the walking and stair climbing activities for all muscles except the tensor fasciae latae. Ascending stairs produced the greatest EMG in the upper and lower portions of the gluteus maximus, gluteus medius, and tensor fasciae latae muscles. Walking fast stimulated the most activity in the semimembranosus, long head of biceps femoris, and adductor magnus muscles. Descending stairs required the least muscle action in all cases.

During free velocity walking, the two hamstring muscles (semimembranosus and long head of the biceps femoris) first became active during swing phase (Fig. 1A). Both began in mid-swing (80% GC) and peaked shortly thereafter (90% GC). Then, the semimembranosus dropped to a minor activity level (10% and 5% of maximum) while the biceps femoris exhibited a second peak during the loading response (30% of maximum). The adductor magnus and lower portion of gluteus maximus muscles also registered...
Fig. 2A (left) and B (right): Walking fast. Timing and relative intensity of EMG. (LR, loading response; SLS, single limb support; PS, pre-swing)

their greatest activity during the loading response (Fig. 1A), but both these muscles exhibited less action and a later onset in swing with the lower gluteus maximus action being minimal. All four muscles reduced their activity below the 5 percent threshold in early stance (10% GC).

A second pattern of action was exhibited by the upper portion of the gluteus maximus and the gluteus medius muscles. Beginning with minimal activity at the end of swing, both had a strong peak during the initial 10 percent GC interval in stance and continued a low level of action for a similar period (Fig. 1B). The tensor fasciae latae muscle registered little activity, which occurred in late- mid- and early-terminal stance (25% through 40% GC). For most muscles, peak activity was about 30 percent maximum. Fast velocity walking demonstrated an earlier onset in swing with higher peak values (50% of maximum) and briefer action in stance (Figs. 2A and B).

During stair ascent (Figs. 3A and B), activity in the upper and lower portions of the gluteus maximus, the gluteus medius, and the adductor magnus muscles began in late swing and continued at a high level through loading response. Activity ceased in the adductor magnus early after single limb support commenced but continued in the other three muscles through mid-stance. The tensor fasciae latae exhibited greater intensity but little change in timing compared with level walking.

Activity of the two hamstring muscles was similar in timing during stair ascent but reversed in intensity. In mid- to terminal-swing, the semimembranosus registered greater EMG, but peak activity for the biceps femoris occurred during two separate stance intervals, the loading response and preswing.

Descending stairs produced low levels of stance phase activity in all the muscles except the hamstrings (Figs. 4A and B). Beginning in terminal swing and continuing through the loading response, the gluteus medius and upper portion of the gluteus maximus muscles registered EMG levels of 20 and 15 percent maximum, respectively. The effort level of the lower portion of the gluteus maximus was only 5 percent of maximum. A period of terminal stance action by the tensor fasciae latae and adductor magnus had similar low intensity. The two hamstring muscles were active only in mid-swing.

**DISCUSSION**

The data from this study identified both the timing and relative intensity of action for the hip extensors...
and abductors. Only minor differences in timing were demonstrated compared with the information already documented in the literature. The intensity data, however, provided several new interpretations on the function of these muscles. The finding that the muscles markedly varied their intensity of action and often produced a major effort for only a brief period of time was of particular significance.

**Phasic Activity**

During free walking in our study, the muscle activity of the long head of biceps femoris and semimembranosus was initiated earlier during swing than previously reported.\(^3,13\) Walking speed may be a factor; in this study, the onset of activity occurred earlier in fast walking.

The stance phase walking data demonstrated more persistent action in the upper portion of the gluteus maximus muscle than Basmajian found.\(^3\) He noted activity only at heel strike, whereas the present study demonstrated peak action during the entire loading response and low level participation into mid-stance. Because the EMG pattern of the upper portion of the gluteus maximus parallels that of the gluteus medius, the data suggests that both muscles are functioning as hip abductors for lateral hip stability during loading response and single limb support. The current data also does not confirm late stance phase action in the gluteus medius muscle as other studies have described.\(^14\)

Comparing the muscle activity patterns recorded during stair ascent in this study with the findings of Joseph and Watson was difficult because the method of documenting the critical events in the gait cycle differed. Such a comparison could lead to possible errors in interpreting when EMG activity was occurring.\(^8\) In addition, Joseph and Watson used surface electrodes and could not differentiate between upper and lower portions of the gluteus maximus muscle or the medial and lateral hamstring muscles. One difference between the findings of the two studies was that the present data did not demonstrate early swing activity in the long head of biceps femoris, semimembranosus, or gluteus medius muscles.

**Relative Intensity of EMG**

Electromyography displays the pattern of motor unit activation. Recent confirmation of the “all-or-
RESEARCH

Fig. 4A (left) and B (right): Descending stairs. Timing and relative intensity of EMG. (LR, loading response; SLS, single limb support; PS, pre-swing)

none™ principle at the single motor unit level provides assurance that each recorded signal correlates with muscle fiber contraction. Desmedt and Godauz have also confirmed that the increasing magnitude of EMG parallels the orderly activation of more and larger muscle fibers. These facts offer assurance that the recorded EMG is proportional to the intensity of occurring muscle action.

Technical inability to control the number of motor units sampled by any electrode application (indwelling wires or surface) denies investigators the opportunity to define directly the intensity of muscle action from a casual recording. If, however, this record is correlated with a known event, such as a maximum effort, the electrode sample variability common to both tests is cancelled, and the EMG record has a relative intensity value. Correlating with a known event is the principle of normalization and must be exercised whenever one wants to define the intensity of muscle action from its myoelectric signals.

A second area of confusion has been the influence of velocity. Both direct muscle fiber studies and strength testing have demonstrated that increasing the speed of contraction reduces a muscle's force. Consequently, a muscle must contract more vigorously (have a higher EMG) when responding to a quick demand than it would exert for a slower effort. This variability in efficiency makes the estimation of muscle force from the EMG more complex, but it does not cloud the interpretation of relative muscle activity. That is, one knows what the muscle is doing, but not necessarily what it is accomplishing.

By identifying the relative intensity of muscle action occurring during walking or other movements, the researcher can better define the specific functions of muscles and the deficits of impaired muscles in disabled persons.

Subtle differences in function of muscles with similar joint action were evident when the intensity of the EMG was examined. During level walking at free and fast velocities, both the semimembranosus and long head of biceps femoris muscles were selectively activated in late mid-swing to decelerate the thigh and shank while the simple hip extensor muscles (lower portion of the gluteus maximus and adductor magnus) remained inactive. Murray's motion data for terminal swing indicates that the hamstring muscles have a greater effect at the hip, where all further flexion is prevented, than at the knee, which evidence no perceptible motion change. This correlation be-
between the EMG and motion data is consistent with an unpublished anatomical finding that the skeletal leverage available to the hamstring muscles is almost twice as great at the hip than at the knee in the walking positions (7 cm vs 4 cm; 2.8 in vs 1.6 in).

The difference in semimembranosus and biceps femoris muscle activity during stance appears related to their rotatory actions at the knee. Heel strike, before stimulating knee flexion, creates subtalar varus in the foot. This varus is reflected in the tibia as external rotation. Active restraint is needed at that time to protect the knee from ligamentous strain. The peak EMG registered by the biceps femoris muscle during the loading response suggests its external rotary leverage protects the knee while the internal rotation effect of the semimembranosus muscle is minimized.

Persistence of any semimembranosus muscle action implies that some knee flexion force is desirable. Immediately after heel strike, the ground reaction vector is anterior to the knee and creates an extensor moment. Because the quadriceps femoris muscle is also active at this time, the knee could experience an undesirable hyperextension thrust if the hamstring muscles did not offer some protection.

The functional significance of adductor magnus muscle action during walking is not clear. Its onset in terminal swing and peak EMG at or just before initial contact suggests terminal deceleration of hip flexion and support as the limb is loaded.

Because the peak activity of the lower portion of the gluteus maximus muscle consistently occurs during the loading response period of stance, isometric extensor support of the flexed hip appears to be this muscle’s role. Both during walking and stair ascent, hip joint posture changes very little in this period of stance.20 The finding of accompanying action by the adductor magnus and biceps femoris muscles may be interpreted two ways. Perhaps the gluteus maximus muscle is incapable of the total task. An alternate view is that asking one muscle to assume the burden of supporting body weight on a flexed hip would be physiologically inefficient. The latter physiological stress is probably the controlling factor, for endurance is required to meet the repetitious demands of walking. By keeping the intensity of muscle action below 50 percent of maximum and generally less than 30 percent of maximum, the dominant source of energy remains aerobic.21 This is important because anaerobic energy production is both limited and only one thirteenth as efficient as aerobic.

Unlike the hip extensor muscles, the abductor muscles did not display a significant change in the intensity of EMG as gait velocity increased. Their similar earlier activation during swing thus suggests a different role. Rather than preparing for a higher demand at the time of floor contact, perhaps the abductor muscles are controlling the swinging limb’s position in space.

The EMG results when ascending stairs also differentiated the actions of the two portions of the gluteus maximus muscle. Although both portions lengthened their period of activity, only the upper portion displayed a notable increase in EMG intensity similar to that of the gluteus medius muscle.

The finding that manually resisted isometric strength tests produced significantly higher integrated EMG activity than dynamometer tests was unexpected. One reason for this may be that manual muscle tests are designed to challenge individual muscles rather than muscle groups. Another reason might be a lack of familiarity of the subjects with dynamometer strength testing. In addition, the stabilizing apparatus imposed an unusual constraint upon the subjects. Although the dynamometer did not prove to be as useful as was anticipated in producing maximum integrated EMG, the results indicated that manual muscle tests do challenge the hip muscles to a high level of function.

**CONCLUSIONS**

1. As a means of deriving a maximum value of electrical activity in the hip abductor and extensor muscles, this study found manual muscle testing to be more effective than testing on a dynamometer.
2. The hip extensor muscles have different functions reflecting the influence of their anatomical attachments. During swing, the two-joint muscles, semimembranosus and long head of the biceps femoris, decelerate the limb. Beginning in late swing and continuing in stance phase, the adductor magnus, gluteus maximus, and biceps femoris muscles provide support during limb loading.
3. The gluteus maximus muscle is functionally divided, with the upper portion responding as an abductor like the gluteus medius and the lower portion providing hip extension.
4. Gluteus medius muscle action is primarily during loading response with weak activity in mid-stance.
5. Walking fast increases the intensity and duration of muscle action.
6. The primary hip extensor for ascending stairs is the lower portion of the gluteus maximus muscle. The long head of the biceps femoris muscle, but not the semimembranosus muscle, contributed support during loading response.
7. Limb support in descending stairs is dependent on some hip abductor action but not on hip extension action.
REFERENCES