Soleus Muscle Electromyographic Activity and Ankle Dorsiflexion Range of Motion During Four Stretching Procedures

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Volitional muscle contractions are used frequently in some combination with muscle stretching to promote muscle relaxation and to increase range of motion. In this study, muscle lengthening procedures were evaluated in the ankle plantar flexors. Four soleus muscle stretching procedures—static stretch (SS), hold relax (HR) (isometric plantar flexor contraction before stretch), agonist contract (AC) (dorsiflexor contraction assisting stretch), and hold relax-agonist contraction (HR-AC)—were performed in the sagittal plane by 12 physically active adults. The dorsiflexion angle, soleus muscle electromyogram, and soleus muscle motoneuron excitability as determined by the Hoffmann-reflex (H-reflex) amplitude were measured throughout the duration of each stretch. The range of dorsiflexion achieved at the end of the stretch did not differ significantly between stretching procedures, although in 8 of the 12 subjects and in the subject group as a whole, the AC and HR-AC procedures were associated with higher levels of soleus muscle EMG than the levels in the SS and HR procedures (p < .01). The H-reflex amplitudes during the AC and HR-AC procedures were smaller than the amplitudes during the SS and HR procedures (p < .001), suggesting the possibility of reciprocal inhibition during the agonist contraction. Increased tonic EMG levels produced by input from other neural pathways affecting alpha motoneurons in the AC and HR-AC procedures may have masked this inhibitory reflex. In healthy adults, a complicated procedure, involving muscle contractions for decreasing active resistance to stretch, may be unnecessary because 1) active resistance to stretch is minimal and 2) muscle relaxation during stretch appears to have little or no direct effect on the ROM achieved.

Key Words: Electromyography, Movement, Muscles, Physical therapy.
contractions are thought to facilitate an eventual agonist contraction\textsuperscript{11}. Moore and Hutton\textsuperscript{7} questioned the premise that an isometric antagonist contraction preceding muscle stretch produces a more relaxed muscle as a result of presumed "successive induction" or "autogenetic inhibition."\textsuperscript{1,5,6,10} They hypothesized instead that the isometric antagonist contraction would promote continued antagonist muscle activity through the mechanism of postcontraction sensory discharge (ie, the potentiation of muscle afferent discharge after an isometric contraction\textsuperscript{12}). They found that static contraction and relaxation of the hamstring muscles followed by voluntary activation of the hip flexors produced significantly greater EMG activity in hamstring musculature than did the static stretch (SS) procedure (passive) alone. They found no significant difference in acute ROM between the two stretching procedures, suggesting that the level of muscle activation and ROM achieved may be unrelated. They did not investigate a procedure involving active contraction to assist muscle stretching without a preliminary isometric contraction. The mechanism of the greater hamstring muscle EMG activity during muscle stretching, therefore, could have been related to the preliminary isometric contraction of the hamstring muscles, the assisting contraction of the hip flexors, or both. Several authors theorize that an assisting contraction might promote relaxation of the muscles stretched through alphagamma linkage in reciprocal inhibition.\textsuperscript{13–18}

In this investigation, we expanded on the observations of Moore and Hutton.\textsuperscript{7} A stretching procedure involving an isometric antagonist contraction followed by relaxation and an agonist contraction assisting SS can be divided into components, each of which may affect the results by different mechanisms and may add to or detract from any beneficial effects of the procedure as a whole. Our purpose, therefore, was to compare the effects of such a procedure and each of its component parts on alpha motoneuron excitability and active resistance of the muscle stretched, on the ROM achieved, and on the subject's perception of the stretch. We hypothesized that 1) an antagonist contraction performed before an SS would result in increased antagonist alpha motoneuron excitability, more antagonist muscle activity, and less ROM than performance of an SS alone; 2) an agonist contraction assisting SS would result in decreased antagonist alpha motoneuron excitability, less antagonist muscle activity, and more ROM than an SS alone; and 3) an antagonist contraction followed by a SS assisted by an agonist contraction would result in increased antagonist alpha motoneuron excitability, more antagonist muscle activity, and less ROM than an SS assisted by an agonist contraction alone. In testing these hypotheses, we also assessed the relationship between active muscle resistance and improved ROM.

**METHOD**

**Subjects**

Six men and six women (aged 22–34 years) with no known history of neuromuscular disorders or ankle injury volunteered to participate in the study. The experimental procedures and guidelines explained in the informed consent forms signed by each subject conformed to standards approved by the University of Washington Human Subjects Committee. Subjects qualified for participation if their right ankle ROM with knee flexion was greater than 45 degrees (measured as the angle formed by the intersection of lines parallel to the longitudinal axis of the fibula and the longitudinal axis of the fifth metatarsal, that is, the ankle angle decreasing with dorsiflexion) during extreme passive muscle stretching. According to this criterion, all subjects reported ROM limitations because of shortness of calf musculature compared with structural mobility of the ankle joint.

**Apparatus and Subject Positioning**

Subjects were seated in a straight-back chair mounted on an elevated platform. Attached to the platform were a footplate and torque device for producing dorsiflexion of the right ankle (Fig. 1). The height and depth of the footplate were adjusted to align the subject's medial malleolus with the axis of rotation of the torque device. Through seat angle adjustments, the right knee was set in 60 degrees of flexion from full extension to relieve stretch on the gastrocnemius and plantaris muscles. The torque device consisted of two circular and rotational plywood disks, joined by a wooden footplate and heel stop. The device could be locked into a resting position with the ankle angle at 90 degrees. A steel chain, extending from a bolt on the elevated platform to a bolt on one of the disks, prevented rotation of the device during a maximal voluntary contraction (MVC) of the plantar flexors. Running in a groove over the top of each disk was a rope attached to a weight. When the device was unlocked, the smaller of the two weights applied dorsiflexion torque of 9.0 Nm. So that an increased dorsiflexion torque could be applied, the free end of the rope was raised and attached to a metal rod, thus suspending the weight. Constant applied torques were calculated to

![Fig. 1. Experimental condition for applying stretch and recording soleus and tibialis anterior muscle electromyographic activity and H-reflexes.](image)
be 35.5 N·m during the stretching procedures. For four subjects (before a minor modification was made in the device to make the applied torques constant), the small applied torque was 7.5 N·m, and the large applied torque varied between 31 and 33 N·m.

**Range-of-Motion Data**

Ankle angle was measured by an electrogoniometer containing a linear potentiometer (±1% accuracy). The electrogoniometer axis was aligned with the medial malleolus with one arm taped in alignment with the head of the first metatarsal, and the other arm taped in alignment with the medial tibia (Fig. 1). Output from the electrogoniometer was monitored on a storage oscilloscope and stored on FM tape.

**Electromyographic Data**

Electromyographic activity in the soleus and tibialis anterior (TA) muscles was recorded using 1-cm-diameter, bipolar, silver-silver chloride surface electrodes (Fig. 1). The skin at the electrode sites was shaved when necessary, rubbed with fine-grained sandpaper until pink, and cleansed with alcohol. The electrode cups were filled with electrolytic paste, and the electrodes were secured to the skin with adhesive disks and surgical tape. Electrodes for the soleus muscle were spaced 1.5 cm apart along the midline of the calf, 4 cm below the attachment of the gastrocnemius muscle heads to the Achilles tendon.19,20 The TA muscle electrodes were 1.5 cm apart at a point 5 cm distal and 2 cm lateral to the tibial tuberosity. The lateral tibial condyle was the site of the ground electrode. Input skin resistances were judged acceptable if less than 5 kΩ. Electromyographic activity was amplified differentially (half-amplitude at 1 Hz-3 kHz). For low-level measurements, EMG activity was amplified further (1 µV = 10 mV). All EMG activity was monitored on storage oscilloscopes and stored on FM tape (0–2.5 kHz ± 1 dB).

Methods of eliciting and measuring the Hoffmann reflex (H-reflex) have been reported previously.19,20 The H-reflex is an electrically elicited monosynaptic and oligosynaptic reflex (IA afferents to alpha motoneurons) that provides a measure of the excitability of the alpha motoneuron pool. The stimulating electrode sites were prepared in the manner described for the recording electrodes. A silver-silver chloride plate anode electrode was taped in place just proximal to the patella. A cathode disk electrode was located in the popliteal fossa with an adjustable elastic band and Velcro strap. A constant voltage stimulator delivered rectangular pulses (1-msec duration) through an isolation unit. The largest diameter axons, the IA afferents, have the lowest resistance to external electrical stimulation and reach threshold first, resulting in the propagation of action potentials and facilitory input to triceps surae muscle alpha motoneurons. If the facilitative input is sufficient to cause the motoneurons to fire, the result will be an H-reflex, which is recorded by electrodes over the soleus muscle. If the intensity of the electrical stimulation also is sufficient to cause the propagation of action potentials in motoneural axons, an M-response (wave) will occur before the H-reflex. A 1.1 × H-reflex threshold voltage was calculated for use as the experimental stimulus intensity. This intensity has been shown to be optimal in demonstrating both facilitation and inhibition of motoneuron excitability21 and was sufficient to produce consistently small M-responses. The H-reflexes were identified on the basis of latency (≈30 msec) and their characteristic triphasic waveform.20 Control and experimental H-reflexes were elicited every 10 seconds, avoiding depression of the H-reflex amplitude that occurs at shorter interstimulus intervals (ISIs).22 Stimulus artifacts were recorded on FM tape and used in triggering and timing the samples of H-reflex and EMG data.

**Stretching Procedures**

The four stretching procedures were 1) SS, 2) AC, 3) HR, and 4) HR-AC. All stretching procedures were performed in the sagittal plane and began with the application of a low-level dorsiflexion torque to achieve position of the ankle closer to its extreme of dorsiflexion to minimize the known effects of muscle length on reflex EMG amplitudes.20,23 The large dorsiflexion torque then was applied to stretch the soleus muscle.

For the SS procedure, the subject was instructed to relax while the ankle was subjected to the light dorsiflexion torque for 11 seconds, followed by the application of the large dorsiflexion torque for 50 seconds. The AC procedure was the same as the SS procedure with the addition of a low-level voluntary contraction of the dorsiflexors during the entire application of the large dorsiflexion torque. For the HR procedure, the light dorsiflexion torque was applied for 5 seconds, followed by a 5-second isometric plantar flexion MVC, 1 second of relaxation, and a 50-second application of the large dorsiflexion torque. The HR-AC procedure was the same as the HR procedure with a low-level voluntary contraction of the dorsiflexors added throughout the application of the large dorsiflexion torque. We used a submaximal, low-level voluntary contraction (assisting active stretch) because cocontraction of antagonistic muscle pairs regularly occurs as subjects perform contractions approximating 100% of a static MVC.24-26

**Testing Procedure**

All subjects participated in each of the four stretching procedures. The order of the presentation of the stretching procedures was determined using a Latin square design.27 Each of the four stretching procedures was tested as follows: 1) 10 control H-reflexes were elicited with the small dorsiflexion torque; 2) 3 stretching trials were performed with two-minute rest intervals between each trial; during each trial, 5 H-reflexes were elicited during the application of the large dorsiflexion torque; and 3) 10 control H-reflexes were elicited with the small dorsiflexion torque in place. Rest intervals between procedures were five minutes in length. After the completion of all four stretching procedures, all subjects completed a written questionnaire in which they ranked each of the stretching procedures according to associated discomfort and perceived effectiveness in increasing the ROM.

**Electromyographic Data Reduction**

To analyze the levels of EMG activity during stretching, TA and soleus muscle EMG data were transmitted from FM tape through a full-wave rectifier and a low-pass filter (25-msec time constant, cutoff frequency 6 Hz)28 and then analog/digital converted (sampling rate 50 Hz) for input into a PDP 11-34 computer. Baseline EMG levels with the ankle resting at 90 degrees were sampled for a 1-second period at the beginning of each trial. The first four H-reflex stimulus artifacts of each trial (ISI = 10 sec) served as a signal for the computer to begin sampling EMG activity during muscle stretching. No EMG activity was sampled 1 second before or 1 second after the stimulus artifact. Digitized and smoothed EMG activity then was sampled for an 8-second period. Thus, four
8-second periods of both soleus and TA muscle EMG activity were sampled for each trial. A second computer program was used to integrate the sampled rectified and filtered EMG data over 1-second time segments. The integrated value of the baseline EMG sample was subtracted from the integrated values of the EMG activity sampled during the stretch. Only the last seven 1-second time segments of each period were included; the first was omitted because it was frequently an extreme value.

For H-reflexes, the stimulus artifact served as a signal for the computer to sample (at 2 kHz) the raw soleus muscle EMG activity for 100 msec. The minimum and maximum amplitudes of each M-response and H-reflex were measured with the use of a computer program.

Data Analysis

The ROMs achieved during the four stretching procedures were compared using an analysis of variance (ANOVA). Stretching conditions (4 levels) and trials (3 levels) were within factors. Sex (2 levels) was a between factor. Effects of the order of performance of the stretching conditions were compared using the ANOVA with order (4 levels) and trials (3 levels) as within factors and sex (2 levels) as a between factor.

Parametric comparisons of quantified EMG activity are not valid across subjects because of individual differences in skin resistance, input impedance, amount of subcutaneous tissue, and muscle anatomy. Intrasubject parametric comparisons of integrated soleus muscle EMG data, therefore, were performed to obtain information on individual responses to the stretches. A separate ANOVA was performed on the integrated soleus muscle EMG data of each subject. Stretching conditions (4 levels), trials (3 levels), and periods (the time intervals between H-reflexes, 4 levels) were treated as between factors. Because the levels of the random factor in an ANOVA are assumed to be independent observations,29 the one-second time segment values were tested for independence and determined to be the appropriate random variable.

For subjects showing a significant stretch condition main effect, Scheffé post hoc tests (paired condition comparisons) were used to determine the two conditions with the highest mean soleus muscle EMG level of activity and the two conditions with the lowest mean soleus muscle EMG level of activity. Tukey's pair wise post hoc tests then were used to determine the significance of the differences between the two conditions with the highest level and the two conditions with the lowest level of soleus muscle EMG activity.

Electromyography

As instructed, the subjects generally obtained a resting level of TA muscle EMG activity during the SS and HR procedures and a low-level TA muscle contraction during the AC and HR-AC procedures (Fig. 2). Fluctuations in the intensity of the low-level voluntary contractions, however, were evidenced by relatively large standard deviations of the integrated TA muscle EMG data. Nine of the 11 subjects had higher mean TA muscle EMG values in the HR-AC procedure than in the AC procedure (Fig. 2).

All subjects showed significant differences (p < .001) in the mean integrated soleus muscle EMG activity across the stretch conditions (Tab. 1). Relative magnitudes of mean soleus muscle EMG activity for each subject and across stretch conditions are summarized in Figure 3. The results of the post hoc analyses are summarized in Table 1. All Scheffé post hoc tests were significant (p < .001), and the SS and HR procedures were associated with significantly lower levels of soleus muscle EMG activity than the AC and HR-AC procedures in 8 of the 12 subjects. Using Tukey's tests for pair wise comparisons, we found that, in 6 of these 8 subjects, soleus muscle EMG activity was higher in the HR-AC procedure than in the AC procedure (p < .05), whereas in 7 of the 8 subjects no significant differences existed between the SS and HR stretch procedures. Four of the 12 subjects (Subjects 1, 3, 5, 6) demonstrated unique patterns of soleus muscle EMG values for the different stretching procedures. The TA muscle EMG values for Subjects 5 and 6 indicated that they performed the stretch procedures incorrectly.

A significant difference in the relative magnitudes of integrated soleus muscle EMG activity between stretching conditions across subjects was revealed by the performance of a Friedman two-way ANOVA by ranks (p < .01). These results confirmed those of the individual ANOVAs performed on the integrated soleus muscle EMG data. The subjects as a group had lower levels of soleus muscle EMG activity during the SS and HR procedures than during the AC and HR-AC procedures.

The effects of the trials on the integrated soleus muscle EMG values were significant in 10 of the 12 subjects for individual ANOVAs (p < .01). We found four different patterns in the relative magnitudes of EMG activity. A

RESULTS

Range of Motion

The results of the ANOVAs showed that stretching procedures and their order of presentation had no significant effect on the degree of dorsiflexion achieved (range, 76–54 degrees). We found a significant trials-by-sex interaction (F = 8.75; df = 2.20; p < .005) because the women tended to achieve less ROM with successive trials than the men. Examination of electromyometer traces showed that the maximum amount of dorsiflexion was achieved within about 10 seconds of the application of the stretching weight.
Friedman two-way ANOVA, performed on the ranking of soleus muscle EMG values by trials across subjects, also showed a significant trials effect \((p < .05)\). The cumulative rankings for trials 1, 2, and 3 were 18, 30, and 24, respectively. The subjects as a group demonstrated the highest integrated soleus muscle EMG values during the second trial.

A significant period effect (time between successive H-reflexes) was found for soleus muscle EMG activity in 10 of 12 subjects (Tab. 2). Exchange post hoc tests revealed the H-reflex amplitudes to be significantly larger during the SS and HR stretching procedures than during the AC and HR-AC procedures \((p < .001)\). No significant differences were found between these respective pairs using Tukey’s post hoc tests. We found significant differences among the five H-reflex amplitudes \((F = 11.38; df = 4.40; p < .001)\). The results of the Scheffé post hoc tests showed that the H-reflex amplitude increased progressively after the onset of the stretch \((p < .001)\). A tendency for M-response amplitudes to increase progressively during muscle stretching was nonsignificant.

Normalized M-response amplitudes varied across stretching conditions, but not significantly (Tab. 2). Because stable M-responses are considered indicative of stable electrode positioning relative to the posterior tibial nerve, this procedural difficulty is discussed further in the Discussion section.

**TABLE 1**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Stretching Condition</th>
<th>(\bar{X}) (µV·sec)</th>
<th>(F)</th>
<th>Post Hoc Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SS</td>
<td>HR</td>
<td>AC</td>
<td>HR-AC</td>
</tr>
<tr>
<td>4</td>
<td>0.68</td>
<td>1.90</td>
<td>3.07</td>
<td>3.67</td>
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<td>7</td>
<td>0.05</td>
<td>0.09</td>
<td>1.22</td>
<td>1.69</td>
</tr>
<tr>
<td>8</td>
<td>0.02</td>
<td>0.20</td>
<td>11.36</td>
<td>14.37</td>
</tr>
<tr>
<td>9</td>
<td>−0.19</td>
<td>0.11</td>
<td>8.51</td>
<td>9.94</td>
</tr>
<tr>
<td>11</td>
<td>−0.57</td>
<td>−0.29</td>
<td>5.69</td>
<td>23.71</td>
</tr>
<tr>
<td>10</td>
<td>1.89</td>
<td>1.01</td>
<td>9.58</td>
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<tr>
<td>12</td>
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<td>−0.45</td>
<td>5.20</td>
<td>5.93</td>
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<tr>
<td>2</td>
<td>0.20</td>
<td>−0.07</td>
<td>19.25</td>
<td>16.77</td>
</tr>
<tr>
<td>6</td>
<td>4.85</td>
<td>2.61</td>
<td>7.34</td>
<td>1.74</td>
</tr>
<tr>
<td>1</td>
<td>0.67</td>
<td>1.27</td>
<td>−0.02</td>
<td>1.59</td>
</tr>
<tr>
<td>5</td>
<td>3.02</td>
<td>1.59</td>
<td>0.42</td>
<td>0.69</td>
</tr>
<tr>
<td>3</td>
<td>0.11</td>
<td>0.32</td>
<td>. . .</td>
<td>0.03</td>
</tr>
</tbody>
</table>

\(a\) Negative values indicate electromyographic activity below baseline. For Subject 3, \(df = 2,216\); for all others, \(df = 3,288\).

\(b\) SS = static stretch; HR = hold relax; AC = agonist contraction; HR-AC = hold relax-agonist contraction.

\(c\) All \(F\) ratios were significant at \(p < .001\).

\(d\) Scheffé tests for paired condition comparisons were significant \((p < .001)\). Tukey tests for pair-wise comparisons denoted by ‘>’ were significant \((p < .05)\).
hamstring musculature,\textsuperscript{7} the PNF procedure of HR-AC was ineffective in minimizing EMG activity through putative “successive induction” or “autosynaptic inhibition.”\textsuperscript{4,5,6,10} Unlike the findings in the previous study by Moore and Hutton,\textsuperscript{7} our results revealed no significant differences across stretch conditions for ROM achieved, and the HR technique was associated with soleus muscle EMG activity similar in magnitude to that produced during the SS procedure. Combined, the SS and HR procedures evidenced significantly less soleus muscle EMG activity than the AC and HR-AC procedures. Cocontractions of the soleus muscle, therefore, predominated during the stretch procedures involving intended voluntary and isolated activation of dorsiflexors.

The H-reflex testing provided a means to test soleus muscle motoneuron excitability during the application of the stretch procedures. A significantly smaller H-reflex during the AC and HR-AC procedures than during the SS and HR procedures may reflect lower excitability from the subliminal fringe\textsuperscript{11} because of alpha-gamma linkage in reciprocal inhibition from voluntarily active dorsiflexors.\textsuperscript{13-18} Active reciprocal inhibition to soleus muscle motoneurons, therefore, may have occurred but was masked by excitatory input from other pathways. These possible explanations are tempered, however, by a tendency toward larger M-responses during the AC and HR-AC procedures than in the SS and HR procedures (Tab. 2), thereby suggesting the alternative explanation that differences in H-reflex responses may have been caused by antidromic collision.\textsuperscript{20} Similar problems with variations in M-response amplitudes were encountered in the Space Lab 1 experiment.\textsuperscript{30} These investigators dismissed the problem by arguing that the variations were not statistically significant; that is, the variations were nonsystematic. Likewise, in our study, the normalized M-responses were not significantly different across stretch conditions. We, nevertheless, advise caution in interpreting our H-reflex data.

Even though the AC and HR-AC procedures did not produce increased ROM, they were associated with more discomfort than the HR and SS procedures. Possibly, the greater cocontractions in the AC and HR-AC procedures were responses to pain or a protective response to guard against excessive stretch. The subjects in the Moore and Hutton study\textsuperscript{7} also associated an HR-AC stretch with the most discomfort.

The HR and SS procedures were similar in all variables measured. If the hypothesized potentiating effects of an isometric MVC\textsuperscript{11,12,19} were of short duration, the resultant effects on the EMG activity of the soleus muscle would have been masked by integrating the EMG activity in 1-second time segments. If the effects were of such short duration, however, we would not expect them to have functional significance in a 40-second stretch. Also, if changes in the dynamic sensitivity of the stretch reflex had occurred, they would not have been detected by H-reflex testing, which bypasses direct activation of the receptor. Another experimental approach is necessary to test the potentiating effects of a previous contraction.\textsuperscript{19}

**CONCLUSIONS**

The type of stretching procedure performed was found to have no significant differential effect on the ROM achieved, although in 8 of the 12 subjects and in the subject group as a whole, the SS and HR procedures were associated with lower levels of antagonist EMG activity than the levels found in AC and HR-AC procedures. Thus, muscle relaxation was unrelated to the degree of ROM achieved. The HR stretch was similar to the SS stretch in EMG activity levels and H-reflex amplitudes in addition to ROM achieved. The assumed postactivation potentiation in association with the HR procedure was not manifested, although stretch reflexes were not tested systematically. The H-reflex amplitudes during the SS and HR procedures were larger than during the AC and HR-AC procedures, suggesting that reciprocal inhibition may have been present during the agonist contraction. High tonic EMG activity levels in the AC and HR-AC conditions showed that, if reciprocal inhibition had been operational, the effects were masked by other neuronal input. Two factors must be considered when generalizing our results to clinical settings: 1) Our subjects were healthy young adults, and 2) EMG and ROM measurements were limited to the du-

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**TABLE 2**

<table>
<thead>
<tr>
<th>EMG Ratios</th>
<th>Stretch Conditions*</th>
<th>Post Hoc Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-reflex\textsuperscript{b}</td>
<td>SS 0.53 0.48 0.24 0.25</td>
<td>(SS ≈ HR) &gt; (AC ≈ HR-AC)\textsuperscript{d}</td>
</tr>
<tr>
<td>M-response\textsuperscript{d}</td>
<td>AC 1.83 2.27 3.36 2.76</td>
<td>1.63</td>
</tr>
</tbody>
</table>

* SS = static stretch; HR = hold relax; AC = agonist contract; HR-AC = hold relax-agonist contraction.  
\textsuperscript{b} Experimental amplitude divided by precondition control amplitude.  
\textsuperscript{c} df = 3, 30; p < .001.  
\textsuperscript{d} Scheffé test for paired comparisons, p < .001.

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**Fig. 3.** Mean integrated soleus muscle electromyographic (EMG) data (µV·sec) plotted for each subject across stretch procedures (same as Fig. 2). Negative values indicate EMG activity below baseline. Data unavailable for Subject 3 for the AC procedure.

**Fig. 4.** Group mean normalized H-reflex amplitudes plotted across stretch procedures (same as Fig. 2).
ration of the stretch. Our findings suggest that the procedure of choice for increasing ROM is the passive SS procedure. The SS procedure produced a level of ROM comparable to that achieved with the more complicated procedures, and it elicited little or no active resistance. This finding is in agreement with the findings of Moore and Hutton. An antagonist contraction before muscle stretching did not decrease myoelectric activity to stretch, and an agonist contraction assisting the stretch significantly increased EMG activity. Furthermore, healthy adults may not require a complicated procedure to decrease active resistance to stretch because 1) active resistance to SS is minimal, and 2) muscle relaxation during stretch appears to have little or no direct effect on ROM achieved, although muscles that are elongated when undergoing tonic EMG activity may be predisposed to stretch-induced injury.

Acknowledgments. We express our gratitude to Mr. Ronald Palmatier for his electronic assistance, to Professor Beth Kerr for her statistical assistance and comments on an earlier version of the manuscript, and to Ms. Chien Ng and Ms. Karen Bryce for typing the manuscript.

Postscript. Subsequent to the acceptance of this article for publication, an article by B. R. Etnyre and L. D. Abraham was published in *Electroencephalography and Clinical Neurophysiology*, in which data were presented corroborating our findings of depressed H-reflexes in muscles undergoing stretch during the voluntary agonist contraction component of the HR-AC procedure. The authors, however, misquote the findings reported by Moore and Hutton. As in our study, Moore and Hutton did not show the HR-AC procedure, which they termed the “CRAC stretch,” to be superior to the SS procedure in increasing ROM (the differences were statistically insignificant), as reported by Etnyre and Abraham. They also implied erroneously from the work of Smith and associates that Golgi tendon organs evidence persistence of firing (“lingering influences”) in muscles that previously were contracted isometrically. Smith and associates reported that the stretch sensitivity of Golgi 1b receptors were depressed transiently after a static contraction. The degree and duration of depression vary with the duration of the maximal isometric contraction. Golgi tendon organ activation and autogenetic inhibition, therefore, are not the likely mechanisms causing the depression initially found in H-reflexes during stretch. Rather, this depression more likely is caused by reciprocal inhibition occurring through voluntary alpha-gamma co-activation of the agonist muscles assisting in the stretch.7,13,17,23

REFERENCES

9. Tanigawa MC: Comparison of the hold-relax procedure and passive mobilization on increasing muscle length. Phys Ther 52:725–735, 1972