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Soleus H-Reflex Gain in Elderly and Young Adults: Modulation Due To Body Position

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Background. The control of posture and balance in the elderly is a primary health concern. Postural instability directly leads to a greater incidence of falling in the elderly population. One important neuromuscular mechanism instrumental in the control of posture and balance is the reflex system. The purpose of this study was to examine the gain of the soleus H-reflex in young and elderly adults in two different body positions: standing and prone.

Methods. Eighteen neurologically healthy volunteers were categorized by age in two groups: young (n = 9, mean age = 23.3 yr) and elderly (n = 9, mean age = 71.7 yr). In each position, the resting H-max/M-max ratio was determined. The gain of the reflex was also assessed by instructing the subject to perform voluntary contractions of 10, 20 and 30% of their maximum voluntary contraction, using real-time EMG biofeedback. Data were sampled on-line using custom designed software (sample rate = 2 kHz). Dependent variables included the average background EMG of the soleus muscle (40 ms window prior to stimulation) and the peak-to-peak amplitude of the elicited soleus H-reflex. To examine the gain of the reflex, the peak-to-peak amplitude of the H-reflex was plotted against the background EMG activity for each contraction intensity.

Results. Results indicated the following: young subjects significantly depressed the H-max/M-max ratio when standing (69.3% prone, 55.1% standing), whereas elderly subjects increased the ratio (36.1% prone, 54.5% standing). Also, the young subjects modulated the gain of the reflex from prone to standing (3.30 prone, 3.68 standing), and the elderly subjects demonstrated no gain modulation in the different body positions (2.23 prone, 1.91 standing). In both body positions the young subjects demonstrated significantly higher gain than the elderly subjects.

Conclusions. The results demonstrate different control strategies for young and elderly subjects between prone and standing body positions.

THE control of posture and balance in elders is a primary health concern. Postural instability directly leads to a greater incidence of falling in elderly adults, and injury due to falling is a primary health concern of this segment of the population. One neuromuscular system responsible for the maintenance of posture and balance is the reflex system.

The reflex system has been shown to be an important contributor in setting muscle stiffness over a wide range of background forces and muscles lengths. By varying the gain of the stretch reflex, the central nervous system regulates muscle stiffness (1) which, in turn, helps in the complex process of motor control.

New information continues to emerge concerning the manner in which spinal reflexes adapt their activity to varying environmental conditions. Many studies have demonstrated that spinal reflexes are easily modulated depending on the character of the behavior (e.g., static vs dynamic), practice, and complexity of the task. For instance, Capaday and Stein (2,3) demonstrated a clear modulation of the soleus H-reflex in parallel with the action of this muscle during the step cycle. Similar results have been found in other muscles during walking (4). However, when the same levels of muscle activity are generated tonically in a standing position, the amplitude of the H-reflex is larger than during walking, especially at low levels of muscle activity. Edamura, Yang and Stein (5) found that the intention to start walking changes the reflex values from those appropriate to standing to those appropriate for walking. Reflex depression has also been demonstrated in complex beam walking, when compared with normal treadmill walking (6). Reflex depression is also seen in the standing position when compared with the prone position (7). These recent studies suggest that reflexes can be modulated depending on the demands of the behavior and that the amplitude of the reflex decreases as postural instability and/or task complexity increases.

It has been documented that dynamic activity and posture are two important factors that may affect the segmental reflex system (2,3,7). When investigating the segmental reflex system in elders it is important to include a dynamic component. One example of doing so would be to evaluate the gain of the reflex, by observing the change in the amplitude of the reflex at different levels of voluntary muscle activity. Furthermore, it is important to include the effect of varying body positions on the modulation of reflex gain in the elderly, since in young adults the gain of the soleus H-reflex is decreased when standing as compared to prone (7).

The neuromuscular system of the elderly has been characterized as less plastic and, therefore, less adaptive compared to that of young adults. Koceja, Markus, and Trimble (8) demonstrated that the amplitude of the H-reflex in elderly adults increases when standing as compared to prone, in contrast to a decrease found in young adults. To date, no study has evaluated the changes in reflex gain due to prone and standing body positions in the elderly. The purpose of this study was to examine the gain of the soleus H-reflex in prone and standing body positions in a group of elderly subjects and compare it to a group of young adults.

Methods

The subjects were 18 neurologically normal male and female volunteers. There were nine young subjects (mean age = 23.3 yr), and 9 elderly subjects (mean age = 71.7 yr). Each subject signed an informed consent form approved by the University's Committee for the Protection of Human Subjects.

Soleus H-reflex responses were determined in each subject under two experimental conditions: (1) lying prone and (2) standing. In the prone position, subjects were asked to lie on a padded table, with their feet secured to a fixed foot-plate to maintain an ankle angle similar to standing, and to more closely reproduce the cutaneous receptor activity present during the standing condition.

A bipolar surface recording electrode (Therapeutics Unlimited, Iowa City, IA) was attached to each subject's lower right leg over the soleus muscle. The recording electrode was placed longitudinally at the midline of the leg, approximately ≈4 cm below the gastrocnemius. A ground electrode was placed on the lateral malleolus. Two stimulating electrodes (cathode in the popliteal fossa and anode just superior to the patella) were placed on the subject's right leg to elicit soleus H-reflexes following the procedures outlined by Hugon (9). Once in place, the recording and the stimulating electrodes were not removed until the completion of the study.

Initially, the soleus H-reflex and M-wave recruitment curves were mapped for each subject in each body position. From these curves, the H-max/M-max ratio was determined. To examine the gain of the reflex, the stimulus intensity was then adjusted to elicit an H-reflex that was 50% of the maximal H-reflex value. Previous research in our laboratory has shown that the gain of the reflex is relatively independent of the initial amplitude of the H-reflex (10).

To determine each subject's maximal voluntary contraction (MVC), subjects were asked to perform a maximal isometric plantar flexion against the foot-plate. MVC was determined as the peak value of rectified and averaged (40 ms window) EMG activity during the MVC trial. Once the MVC was determined, subjects were asked to perform 28 plantar flexion forces in four randomized conditions: 0 (relaxed, no contraction), 10, 20, and 30% of their MVC. In order to facilitate the match between the required and the actual EMG activity level, subjects received on-line feedback of their EMG via visual feedback on the computer screen. The computer screen was positioned directly in front of the subject (≈ 24 inches) in both body positions, to eliminate any extraneous neck movements by the subject. On each trial, after the voluntary contraction was maintained, an electrical stimulus (1 ms duration square-wave pulse; Grass Instruments, Model S88, Quincy, MA) was delivered to the posterior tibial nerve in the popliteal fossa to elicit an H-reflex. The current delivered on each trial was monitored with a current probe (Tektronix P6021, Beaverton, OR). To ensure that stimulus intensity was similar across the voluntary contraction trials, the trial M-waves in each condition were also recorded. After seven trials were randomly completed in each condition, the above procedures were repeated with the subject in the standing position.

All data were collected on-line using a custom designed computer program running on a 486 PC with a 2 kHz sampling rate. Peak-to-peak amplitude of the EMG wave of the H-reflex and the average background EMG of the soleus muscle (40 ms prior to stimulation) in each condition and position were used to compute the reflex gain. For each dependent variable, a $2 \times 2 \times 4$ (Group × Position × %MVC) analysis of variance (ANOVA) was conducted to examine differences between the groups. When interactions were present, simple main effects (11) were used to isolate specific differences between the independent variables. Furthermore, for each group and each body position (standing vs prone) regression analyses were calculated utilizing H-reflex amplitude and background EMG activity to estimate the gain (slope) and the amplitude (y intercept) of the soleus H-reflex. For all statistical tests, an alpha level of .05 was used.

Results

Figure 1 depicts a raw EMG trace for a young and an elderly subject. It can be seen from this trace that in both subjects, as background EMG increases the amplitude of the H-reflex likewise increases. The group results will be presented in the following sequence: (1) differences in the H-max/M-max ratio at rest; (2) background EMG activity and reflex amplitude at rest; (3) background EMG activity during the voluntary contractions; (4) trial-to-trial M-waves during the voluntary contractions; (5) H-reflex amplitude changes during the voluntary contractions; and (6) changes in the gain of the reflex in the two body positions for each group.

H-max/M-max ratio.—Between the two groups, there was a significant difference in the average amplitude of the H-max/M-max ratio for the prone [$F(1,32) = 15.53$, $p < .05$] but not the standing [$F(1,32) = .03$, $p > .05$] body position (Figure 2). This was the result of the young subjects demonstrating a decrease in H-reflex amplitude when standing compared to prone, whereas the elderly subjects demonstrated an increase in H-reflex amplitude when standing compared to prone. The young subjects demonstrated a ratio of 69.3% prone and 55.1% standing. The elderly subjects demonstrated a 36.1% H-max/M-max ratio when prone and a 54.5% ratio when standing. There was a significant depression of the H-max/M-max ratio when standing in the young subjects [$F(1,16) = 9.69$, $p < .05$] whereas the elderly subjects demonstrated a significant facilitation when standing as compared to prone [$F(1,16) = 15.53$, $p < .05$]. This modulation, similar to that demonstrated in past research, was produced by changes in H-max with no changes in the maximal M-wave between postural conditions (7,8). These results are shown in Figure 2.

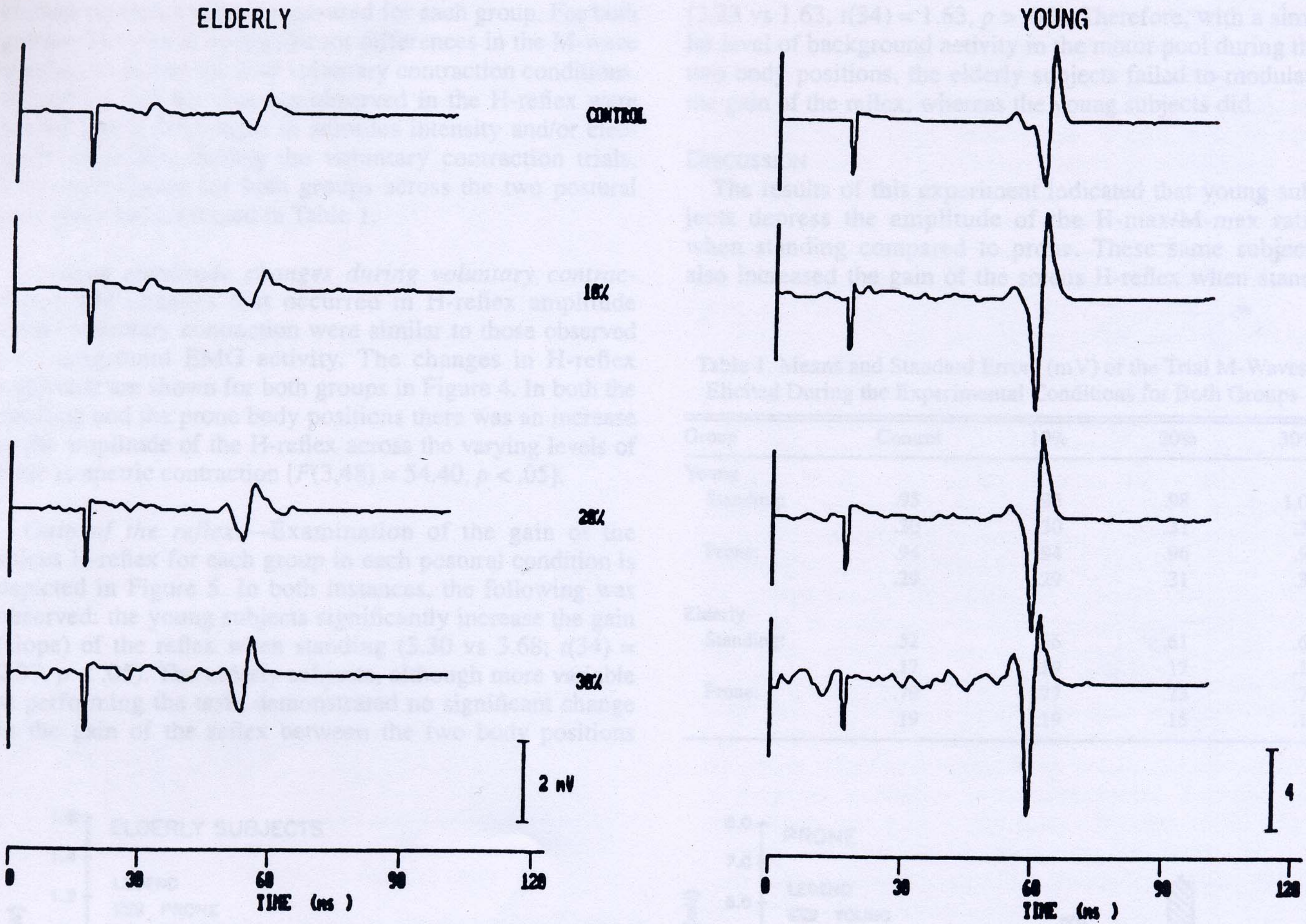


Figure 1. Raw data depicting changes in soleus H-reflex amplitude with changes in voluntary contraction. Both young and elderly subjects depicted in the prone position. Note the differential changes in background EMG activity and H-reflex amplitude as percent of voluntary increases.

Background EMG at rest.—Although there was no significant difference between EMG activity in the standing and prone positions, there was a trend toward increased activity in the standing position. The young group's average background EMG activity was greater when standing (.19 mV) compared to prone (.15 mV), which was similar for the elderly subjects (.29 mV standing and .19 mV prone). These results are shown in the first set of bars in Figure 3.

Background EMG activity during voluntary contraction.—The background EMG activity during the 0, 10, 20, and 30% maximal voluntary contractions is shown for both groups in both body positions in Figure 3. In both groups, there was a significant increase in EMG activity between the conditions [$F(3,48) = 97.76$, $p < .05$], indicating that the task was successfully performed by both groups in both body positions. More importantly, in each group the background EMG activity for the different levels of voluntary contraction (10, 20, and 30% of maximum) were similar in the two body positions, indicating that the level of motor pool activity during voluntary contraction was similar in the two body positions for each group.

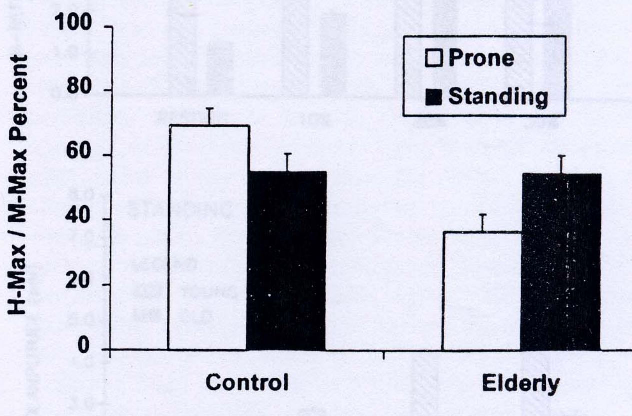


Figure 2. H-max/M-max ratios of young and eldery subjects in the prone and the standing body positions. Note the decrease in the H-max/M-max ratio when standing for young subjects, but an increase for the elderly subjects. Error bars denote the SEM.

Trial-to-trial M-waves.—To ensure that the stimulus intensity did not change across the levels of voluntary contractions, the peak-to-peak amplitude of the small M-wave elicited on each trial was measured for each group. For both groups, there were no significant differences in the M-wave amplitudes across the four voluntary contraction conditions, suggesting that the changes observed in the H-reflex were not the result of changes in stimulus intensity and/or electrode movement during the voluntary contraction trials. These amplitudes for both groups across the two postural conditions are presented in Table 1.

H-reflex amplitude changes during voluntary contraction.—The changes that occurred in H-reflex amplitude across voluntary contraction were similar to those observed for background EMG activity. The changes in H-reflex amplitude are shown for both groups in Figure 4. In both the standing and the prone body positions there was an increase in the amplitude of the H-reflex across the varying levels of tonic isometric contraction [$F(3,48) = 54.40, p < .05$].

Gain of the reflex.—Examination of the gain of the soleus H-reflex for each group in each postural condition is depicted in Figure 5. In both instances, the following was observed: the young subjects significantly increase the gain (slope) of the reflex when standing (3.30 vs 3.68; $t(34) = 2.37, p < .05$). The elderly subjects, although more variable at performing the task, demonstrated no significant change in the gain of the reflex between the two body positions [2.23 vs 1.63, $t(34) = 1.63, p > .05$]. Therefore, with a similar level of background activity in the motor pool during the two body positions, the elderly subjects failed to modulate the gain of the reflex, whereas the young subjects did.

Discussion

The results of this experiment indicated that young subjects depress the amplitude of the H-max/M-max ratio when standing compared to prone. These same subjects also increased the gain of the soleus H-reflex when stand-

Table 1. Means and Standard Errors (mV) of the Trial M-Waves Elicited During the Experimental Conditions for Both Groups

Group	Control	10%	20%	30%
Young				
Standing:	.95	.96	.98	1.00
	.30	.30	.31	.32
Prone:	.94	.94	.96	.94
	.29	.29	.31	.31
Elderly				
Standing:	.52	.56	.61	.64
	.17	.19	.17	.16
Prone:	.79	.77	.73	.72
	.19	.19	.15	.14

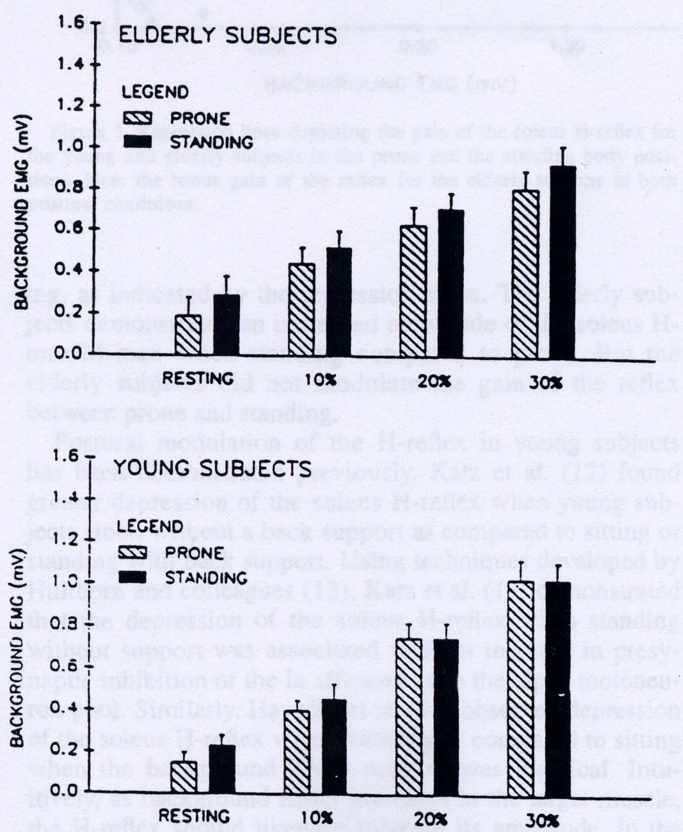


Figure 3. Grouped data depicting the changes in background EMG activity in the soleus muscle (40 ms window prior to stimulation) during voluntary contractions of 10, 20, and 30% of maximum in both the prone and the standing body positions. Error bars denote the SEM.

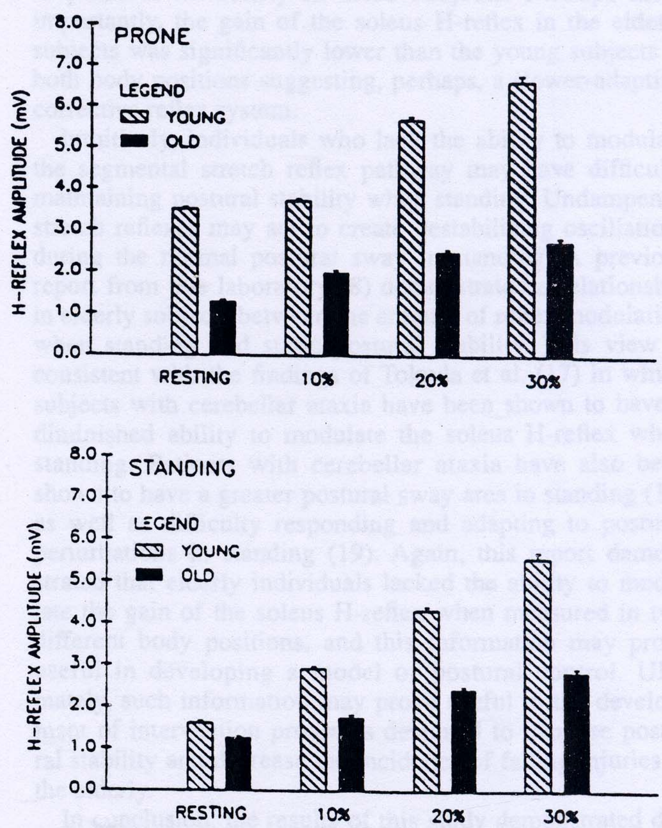
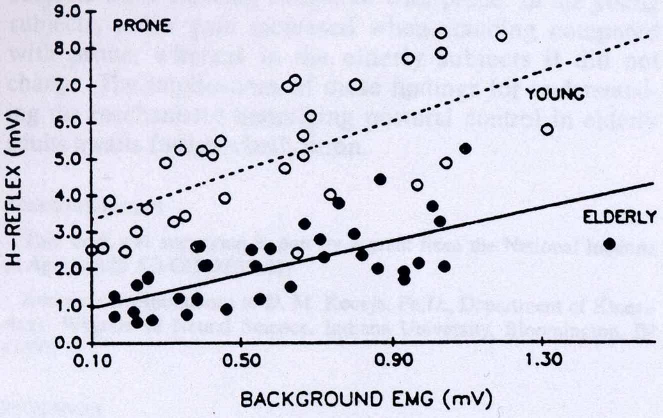


Figure 4. Grouped data depicting the changes in the peak to peak amplitude of the soleus H-reflex during voluntary contractions of 10, 20, and 30% of maximum in both the prone and the standing body positions. Error bars denote the SEM.



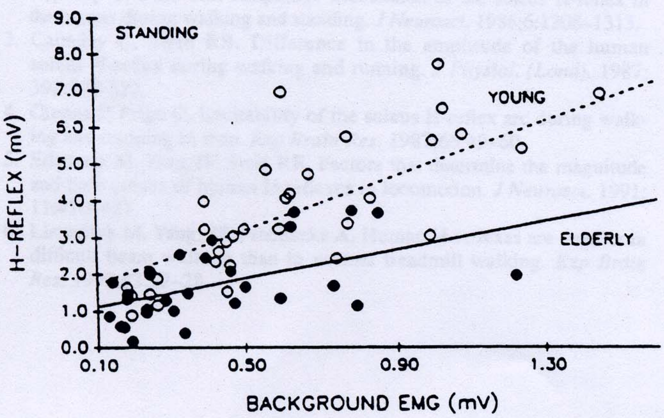


Figure 5. Regression lines depicting the gain of the soleus H-reflex for the young and elderly subjects in the prone and the standing body positions. Note the lower gain of the reflex for the elderly subjects in both postural conditions.

ing, as indicated by the regression slope. The elderly subjects demonstrated an increased amplitude of the soleus H-max/M-max when standing compared to prone. But the elderly subjects did not modulate the gain of the reflex between prone and standing.

Postural modulation of the H-reflex in young subjects has been demonstrated previously. Katz et al. (12) found greater depression of the soleus H-reflex when young subjects stood without a back support as compared to sitting or standing with back support. Using techniques developed by Hultborn and colleagues (13), Katz et al. (12) demonstrated that the depression of the soleus H-reflex when standing without support was associated with an increase in presynaptic inhibition of the Ia afferents onto the alpha motoneuron pool. Similarly, Hayashi et al. (14) observed depression of the soleus H-reflex when standing as compared to sitting when the background EMG activity was identical. Intuitively, as background EMG increases in the target muscle, the H-reflex should likewise increase its amplitude. In the present study, whereas background EMG activity was greater in standing when compared to prone in both the young and elderly subjects, the H-max value was significantly depressed in young subjects, but increased in elderly subjects. Consistent with previous reports (12,14) a likely mechanism to uncouple background EMG activity and the amplitude of the H-reflex is presynaptic inhibition.

An alternative interpretation of these data seems warranted. Perhaps when standing an optimal level of reflex gain is desirable. In this interpretation, to achieve this level of reflex gain, young subjects depressed the reflex whereas elderly subjects, with attenuated resting reflexes, increased the reflex when standing. To do so, young subjects increased presynaptic inhibition when standing whereas elderly subjects decreased presynaptic inhibition when standing.

With respect to the gain of the reflex, investigators have suggested that modulation of the soleus reflex under some postural conditions may prevent saturation of the afferent response from occurring or instability from developing (5,14,15). Llewellyn et al. (6) further proposed that presynaptic modulation of the Ia-motoneuron transmission would prevent the soleus stretch reflex from precipitating postural instability while continuing to allow proprioceptive information to be provided to supraspinal areas. Since muscle groups can be modulated in opposite directions when standing, this postural modulation may represent a presetting of presynaptic interneurons so as to provide reflex action appropriate for the postural or functional task undertaken (12,16). If this is in fact the case, it appears tenable that the inability of elderly subjects to modulate the gain of the soleus reflex in different body positions may contribute to postural instability in these subjects. Perhaps more importantly, the gain of the soleus H-reflex in the elderly subjects was significantly lower than the young subjects in both body positions suggesting, perhaps, a slower-adapting corrective reflex system.

Intuitively, individuals who lack the ability to modulate the segmental stretch reflex pathway may have difficulty maintaining postural stability when standing. Undampened stretch reflexes may act to create destabilizing oscillations during the normal postural sway in standing. A previous report from this laboratory (8) demonstrated a relationship in elderly subjects between the amount of reflex modulation when standing and static postural stability. This view is consistent with the findings of Tokuda et al. (17) in which subjects with cerebellar ataxia have been shown to have a diminished ability to modulate the soleus H-reflex when standing. Patients with cerebellar ataxia have also been shown to have a greater postural sway area in standing (18) as well as difficulty responding and adapting to postural perturbations in standing (19). Again, this report demonstrated that elderly individuals lacked the ability to modulate the gain of the soleus H-reflex when measured in two different body positions, and this information may prove useful in developing a model of postural control. Ultimately, such information may prove useful in the development of intervention programs designed to increase postural stability and decrease the incidence of falling injuries in the elderly.

In conclusion, the results of this study demonstrated differential postural control strategies in young and elderly subjects as they maintained a prone or standing body position. Interestingly, the H-max/M-max ratio was depressed in young subjects when standing, but increased in elderly subjects when standing compared with prone. In the young subjects, reflex gain increased when standing compared with prone, whereas in the elderly subjects it did not change. The implications of these findings for understanding the mechanisms underlying postural control in elderly adults awaits further clarification.

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