

## ORIGINAL ARTICLE

# Changes in Motoneuron Excitability in Hemiplegic Subjects After Passive Exercise When Using a Robotic Arm

Sheila Patel, DO, Jeffrey T. Ho, DO, Rajeswari Kumar, MD, Khang Lai, DO, Brian Ahangar, MD, Charles G. Burgar, MD, Antonia E. Scremin, MD

**ABSTRACT.** Patel S, Ho JT, Kumar R, Lai K, Ahangar B, Burgar CG, Scremin AE. Changes in motoneuron excitability in hemiplegic subjects after passive exercise when using a robotic arm. *Arch Phys Med Rehabil* 2006;87:1257-61.

**Objective:** To test the hypothesis that motoneuron excitability in stroke subjects is influenced by peripheral sensory input through passive exercise to the hemiplegic upper extremity.

**Design:** Case-control prospective study.

**Setting:** Physical medicine and rehabilitation inpatient and outpatient clinic at a tertiary Veterans Affairs medical center.

**Participants:** Nineteen hemiplegic adult subjects with a history of a cerebrovascular event.

**Intervention:** A standardized passive exercise program was performed on the right upper extremity by using a robotic arm. Nerve conduction study of the median nerve was obtained before and after the exercise. Maximum onset and peak amplitudes of the Hoffmann reflex (Hmax) and motor response (Mmax) wave were recorded.

**Main Outcome Measures:** Hmax, Mmax, and Hmax/Mmax ratio.

**Results:** Immediately after passive exercise, there was no significant alteration in the Hmax ( $P=.94$ ), Mmax ( $P=.60$ ), or Hmax/Mmax ratio ( $P=.53$ ) as compared with pre-exercise evoked responses.

**Conclusions:** Peripheral proprioceptive input with passive exercise does not cause appreciable change in the Hmax/Mmax ratio, suggesting that motoneuron excitability of the affected upper extremity in stroke subjects is not influenced by passive robotic intervention.

**Key Words:** Cerebrovascular accident; H-reflex; Rehabilitation; Robotics.

© 2006 by the American Congress of Rehabilitation Medicine and the American Academy of Physical Medicine and Rehabilitation

**C**EREBROVASCULAR ACCIDENTS (CVAs) result in a variety of neurologic deficits. Immediately after an acute cerebrovascular event, there is generally a reduction in muscle

tone and reduced or absent reflexes in the affected extremities. This period is followed by an increase in tone with various degrees of motor recovery. If the increase in tone overcomes the motor function, it is difficult to obtain purposeful movement of the limb. Increased tone can also lead to joint contractures. Passive range of motion (ROM) is a commonly prescribed therapeutic modality for the affected extremities to maintain ROM in all the joints. The question exists whether passive exercise alone is adequate to reduce the tone in the extremities after CVAs.

An increase in muscle tone or spasticity is associated with hyperactive tendon stretch reflexes. It has been documented in the past that subjects with spasticity and increased muscle tone have increased motoneuron excitability as represented by an enhanced maximal amplitude of the Hoffmann reflex (Hmax) and motor response (Mmax) ratio (Hmax/Mmax ratio).<sup>1</sup>

Muscle tone is influenced by a variety of factors. Alpha motoneurons are under inhibitory influence from the supraspinal input and similar impulses from interneurons, which can account for 99% of the neurons in the spinal cord.<sup>2</sup> This inhibitory control influences the alpha motoneuron excitability and motoneuron output. When there is an upper motoneuron lesion, as in CVAs or spinal cord injuries, there is an increase in motoneuron excitability that is clinically manifested as increase in tone and increased tendon reflexes. Hyperexcitability implies that increased motoneuron recruitment could result from lower than normal excitatory inputs via electrical (by excitation of Ia afferent fibers) or mechanical stimulation (ie, the Hoffmann reflex [H-reflex] or muscle stretch reflex, respectively).<sup>3</sup>

Daily ROM exercises are important to prevent contractures in the extremities with muscle weakness. These exercises help to prevent contractures in early stages of stroke and to maintain ROM in later stages. Maintaining ROM is important in stroke patients in early stages so that functional activities can be restored when the patients regain motor function. There is evidence that at later stages of stroke stretching of the joints in addition to passive exercise results in reduction of hyperactive stretch reflexes.<sup>3,4</sup> A slow sustained stretch is recommended to manage painful contractures<sup>3,4</sup> to avoid sudden stretching that may cause pain and may increase muscle excitability. Although stretching is important in later stages of stroke, studies have shown that there are changes in muscle tone with exercise, which does not involve stretching.<sup>5,6</sup>

Our working hypothesis was that passive exercise performed by using a robotic arm apparatus would change the motoneuron excitability in the upper extremity as measured by Hmax/Mmax ratio. In 1940, Renshaw<sup>7</sup> postulated that inhibitory influences on the motoneurons can be affected by peripheral stimulus such as massage or icing. Previous studies have noted that exercises like cycle ergometry and active contraction of muscles cause changes in the muscle tone and motoneuron excitability of healthy subjects.<sup>8</sup>

Muscle tone is commonly tested by subjective methods, such as passively ranging the extremity through the range of the joint and eliciting tendon reflexes on examination. A com-

From the Department of Physical Medicine and Rehabilitation, VA Greater Los Angeles Healthcare System/University of California, Los Angeles, CA (Patel, Ho, Kumar, Lai, Ahangar, Scremin); and Central Texas Veterans Health Care System, Temple, TX (Burgar).

Presented as a poster to the American Academy of Physical Medicine & Rehabilitation, October 2004, Phoenix, AZ.

Supported by the Department of Veterans Affairs Rehabilitation Research and Development Service (project no. B26951).

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the author(s) or upon any organization with which the author(s) is/are associated.

Reprint requests to Antonia E. Scremin, MD, Dept of PM&R, 11301 Wilshire Blvd, Bldg 500, Mailcode 117, Los Angeles, CA 90073-1003, e-mail: Antonia.Scremin@va.gov.

0003-9993/06/8709-1024\$32.00/0

doi:10.1016/j.apmr.2006.05.026

monly used quantitative measurement of tone is the H-reflex and Hmax/Mmax ratio. The H-reflex is the electrical equivalent of the tendon stretch reflex and bypasses the muscle spindle complex. Although some controversy exists between correlating muscle tone, spasticity, and the H-reflex, it is a commonly used method to document changes in transmission of the spinal pathways.<sup>9</sup> Little and Halar<sup>1</sup> noted an increase in H/M ratio and H-reflex amplitude in spinal cord-injured patients with hyper-reflexia. Funase<sup>10</sup> and Higashi<sup>11</sup> and colleagues noted that motoneuron pool excitability could be documented by the ratio of maximum amplitude of the H wave to the maximum amplitude of the M wave (Hmax/Mmax).

Previous studies<sup>11,12</sup> have used the Hmax/Mmax ratio to document spinal motoneuron pool excitability in hemiplegic subjects. Other studies<sup>13-15</sup> have documented changes in Hmax/Mmax after electric stimulation and after intense bouts of active exercise. Even though passive movement of joints through the normal ROM is a common modality of exercise that is prescribed in stroke patients with hemiplegia, no previous studies have documented changes in Hmax/Mmax, and thus changes in motoneuron excitability, in stroke patients as a result. A previous study<sup>16</sup> reported no change in motoneuron excitability, as measured by the H-reflex, after sustained passive stretching in hemiparetic arms. Our study included repeated movement of the arm through a defined ROM by the robotic arm.<sup>17</sup> The exercise protocol did not include sustained stretching of muscles or isolated movement of a person's joint; thus, the effect of passive exercise on specific muscles or joints could not be determined. Our objective was to study the effect of a set of passive exercises on the motoneuron excitability. The upper extremity was chosen because increased tone occurs more commonly in the upper extremity than the lower extremity in this population.

## METHODS

Subjects were recruited from the VA Greater Los Angeles Healthcare System inpatient rehabilitation ward, Nursing Home Care Unit, and the outpatient rehabilitation clinics. A convenience sample of patients who had a stroke documented by magnetic resonance imaging and computed tomography scans were included. All subjects underwent a physical examination by the same investigator. Subjects enrolled in this study represent patients seen in acute, subacute, and outpatient rehabilitation settings. No persons with flaccid hemiplegia, complete hemisensory loss, or severe dysphasia were included, however. Overall, the study population is believed to represent patients generally regarded as appropriate, at their stage of recovery, for continued upper-limb rehabilitation. The passive motion performed by the robotic arm targeted shoulder and elbow movements. We therefore assessed the more proximal (shoulder abduction and elbow flexion, collectively) and distal (wrist extensors and finger flexion) strength by manual muscle testing by using a 0 to 5 scale.<sup>18</sup> Severity of spasticity was quantified by using the Modified Ashworth Scale (MAS). However, to ease the statistical analysis, the 1+ on the scale was replaced by 2 and each higher score increased by 1 resulting in a 0 to 5 range of scores. Subjects with normal muscle tone and normal strength (5/5) in the affected upper extremity were excluded from the study. All participant subjects had residual weakness in the upper extremity, as described in the Results section. All subjects gave informed consent. The study was approved by the institutional review board. Medical records were reviewed to rule out any other neurologic conditions. In addition, patients with symptoms suggestive of cervical radiculopathy were excluded. All patients underwent cognitive evaluation by Folstein Mini-Mental

**Table 1: Mean Amplitude Difference (in mV) Between Paired Values of H-Reflex, M Response, and H/M Ratio**

Measures	Mean Difference	95% CI
H-reflex	.0136	-.36 to .39
M response	.142	-.28 to .56
H/M ratio	.037	-.11 to .05

NOTE. None of the differences were statistically significant. Abbreviation: CI, confidence interval.

Status Examination,<sup>19</sup> and those with scores less than 24/30 were excluded. Similarly, patients with previous trauma or surgery to the elbow were also excluded. Patients were also excluded, regardless of the cause, if the elbow could not be fully extended passively or the shoulder MAS score was greater than 4. Patients with severe upper-extremity edema were also excluded because of the difficulty in placement of the electrodes. Twenty-three adults with a history of stroke who met the inclusion criteria were initially enrolled in our study. All patients had residual weakness and spasticity.

All subjects started with documentation of pre-exercise H-reflex studies of the median nerve in the supine position. Subjects were transported in a wheelchair to participate in the robotic arm study. The postexercise H-reflex study was done again in the supine position.

## Exercise Intervention

Robot-assisted exercise was provided by a Mirror Image Movement Enabler (MIME) system provided by the Palo Alto Veterans Affairs Rehabilitation Research and Development Center. It allows the application of force, via the robotic arm, to the hemiparetic upper limb during goal directed movements, much as a therapist would apply. Subjects sat in a wheelchair, at a height adjustable table, with their affected forearm and hand placed on a splint that was attached to the robotic arm. The forearm was secured in the splint with self-adhesive (Velcro) straps. Sensors measured interaction forces between the robot and the subject's limb and motion during assisted arm movement. Subjects performed a series of standardized, pre-programmed movements in the passive mode for 20 minutes. The exercises included a set of 3 reaching tasks, including forward reaching (shoulder flexion, elbow extension), outward diagonal (shoulder external rotation, flexion, abduction, elbow extension), and diagonal crossing midline reaching (shoulder internal rotation, flexion, adduction, elbow extension) (fig 1).<sup>17</sup> Of note, each of the 3 tasks was performed both at the tabletop level and from tabletop to shoulder level, with 15 repetitions each. These continuous exercises passively placed the shoulder and elbow through a functional ROM, without sustained stretch. The starting position for forward-reaching movements was with the shoulder at 40° to 45° of flexion, neutral rotation, and approximately 20° of abduction. Elbow extension was -60° to 40°. During the forward-reaching exercise at the tabletop level, the shoulder increased in forward flexion an average of 18° and the elbow increased in extension by an average of 12°. The resulting forward translation of the hand was approximately 25cm.

The starting position for outward diagonal movements was with shoulder at approximately 35° of flexion, 40° of internal rotation, and 20° of abduction. Elbow extension was -94° to 81°. During outward diagonal movement to shoulder level, the shoulder increased in forward flexion by an average of 9.6°, external rotation increased by 62.3°, and elbow extension increased an average of 18.4°. All movements were of 10-second duration.

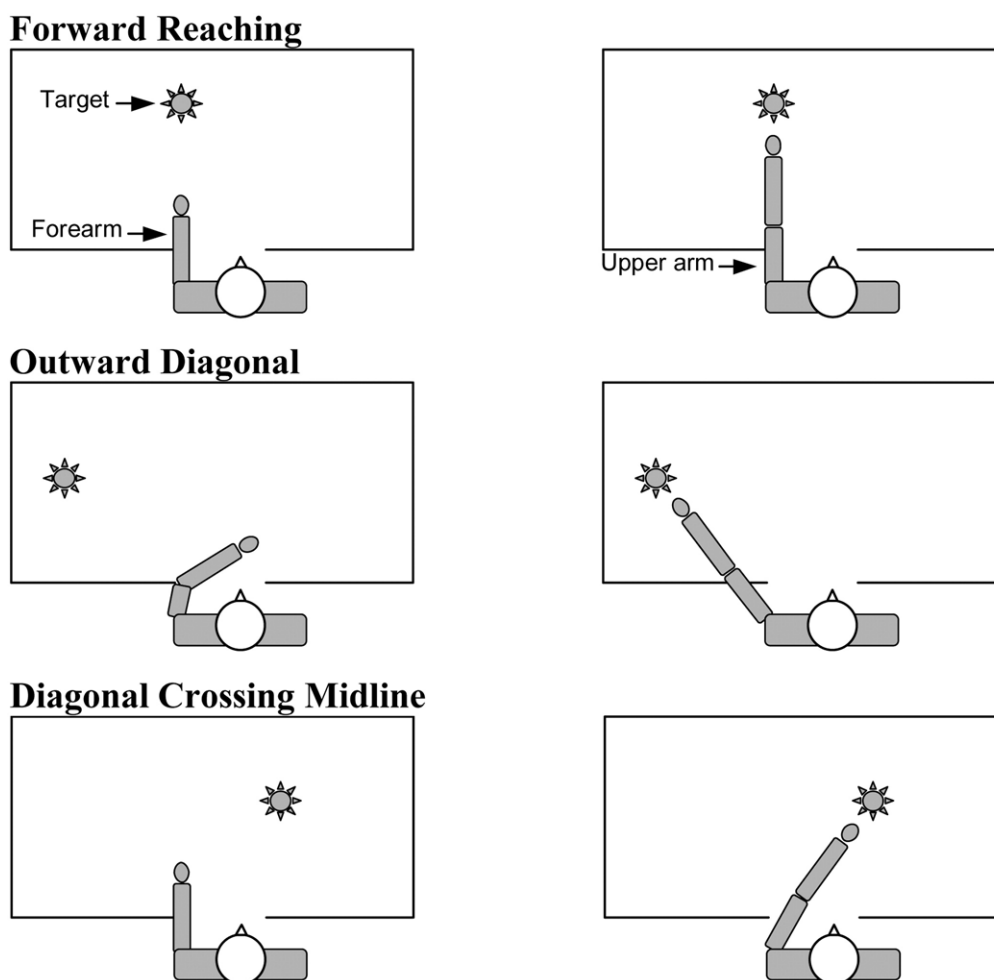


Fig 1. Exercise intervention on the MIME robotic arm. Exercise was performed in each of the above trajectories, with 15 repetitions each, both at the tabletop level and from tabletop to shoulder level height for a total of 20 minutes.

Subjects and the examiner had visual feedback to eliminate the active contraction of the muscle. The interaction forces between the robot and the subject's forearm were measured with a 6-axis force/torque transducer and displayed on a computer screen. The magnitude and direction of the forces in 2 planes were represented by the length and orientation, respectively, of a series of lines drawn in real time. Subjects were encouraged to remain relaxed during movements. Increased effort on the part of the robot, reflecting either volitional or involuntary muscle contraction, was visually detected and used to modify instructions to the subject.

Unlike previous studies, the exercise modality used included slow passive ROM. Stretching of a particular joint or muscle group was not included in the exercise protocol.

#### Electrodiagnostic Studies

All subjects underwent a baseline H-reflex study of the involved upper extremity before starting the exercise intervention and again within 10 minutes after the exercise intervention. All electrodiagnostic tests were performed with subjects in the supine position as described by Zehr<sup>9</sup> by using an electrodiagnostic system.<sup>a</sup> Subjects were studied in a climate-controlled environment (32°–34°C). The upper limb was placed on the examination table in a supine position. An active

electrode was placed over the muscle belly of the flexor carpi radialis muscle at a fixed and standardized distance approximately one third of the distance from the medial epicondyle to the radial styloid. The reference electrode was placed 4cm distal to the active electrode, and the ground electrode was placed between the active electrode and the stimulation site of the median nerve at the cubital fossa, medial to the brachial artery. The active, ground, and reference self-adhesive electrodes were of equivalent size in all subjects. The median nerve was stimulated at the elbow at a rate of 0.5Hz. A rectangular pulse of 0.5 to 1 millisecond duration was used.<sup>20</sup> The intensity of the stimulus was increased incrementally to obtain the H-reflex, and the waveform with the maximum onset-to-peak amplitude (Hmax) was recorded. The stimulus intensity required to obtain the Hmax ranged from 8 to 49mA. Then, the intensity was increased until the H-reflex completely attenuated, and the maximum motor response (Mmax) was obtained. The intensity required to obtain the Mmax ranged from 30 to 100mA. From this, an Hmax/Mmax ratio was calculated.

#### RESULTS

Of the 23 subjects, a total of 19 completed the study. Two were unable to tolerate the electrodiagnostic portion, and H-reflexes were not reliably obtained in 2 other subjects. All 19

subjects were men. The average age was  $61.8 \pm 10.7$  years. The time from the onset of the stroke to the H-reflex study ranged from 1 month to 72 months (median, 5mo). Thirteen subjects had 3/5 or less strength for both shoulder abduction and elbow flexion, and 6 had 4/5 strength for both (collective mean shoulder and elbow scores,  $2.73 \pm 1.2$ ). Testing the strength of more distal muscle groups responsible for wrist extension and finger flexion revealed 16 subjects with 3/5 or less muscle strength, and 3 subjects had 4/5 strength for each muscle group (collective mean wrist and fingers scores,  $1.94 \pm 1.4$ ). The MAS score obtained during elbow extension and shoulder flexion averaged  $1.6 \pm 1.3$  collectively (range, 0–4; scale range, 0–5).

Findings of the pre- and postexercise H-reflex average values, and standard deviations were  $1.74 \pm 1.28$ mV and  $1.73 \pm 1.33$ mV, respectively. The pre- and postexercise M-response average values were  $4.25 \pm 1.70$ mV and  $4.11 \pm 1.69$ mV, respectively. The average pre-exercise Hmax/Mmax ratio was  $.39 \pm .24$ , and the postexercise Hmax/Mmax ratio was  $.42 \pm .28$ . Because most of the variability observed was because of between-subject variation, to enhance the power of the tests, values before and after the intervention were paired for every subject and the differences compared by paired *t* test and Wilcoxon rank-sum test.

The data analyses did not show a statistically significant difference in the average amplitude of the H-reflex when measured before and after exercise testing (paired *t* test,  $P = .94$ ; Wilcoxon test,  $P = .77$ ). The mean baseline amplitude of the H-reflex was within the normative range reported by DeLisa.<sup>20</sup> There was no statistical difference in the M response (paired *t* test,  $P = .49$ ; Wilcoxon test,  $P = .60$ ) or Hmax/Mmax ratio (paired *t* test,  $P = .40$ ; Wilcoxon test,  $P = .53$ ) before and after exercising with the robotic arm. Because of the small sample size, it was difficult to evaluate subsets of subjects. Nevertheless, we conducted an analysis of data by using analysis of covariance, controlling for age and sex. There was no change in the finding. Because of the small sample size, we used a nonparametric procedure (Wilcoxon signed-rank test), which does not require the assumption of normality. Furthermore, with a small sample size, there is potentially little loss of power if the underlying distribution of data were normal.

## DISCUSSION

Increase in muscle tone is common sequelae of CVAs. In addition to medications, passive movement is commonly used to maintain ROM of an extremity. There have been no previous studies available to determine changes in motoneuron excitability after passive movement exercise that do not include sustained stretching, despite the common use of passive exercise in stroke rehabilitation. Passive exercise, after stroke, is commonly done to the entire extremity rather than to any particular joint. The goal of these exercises has been 2-fold in most cases: first, to decrease muscle tone that would otherwise limit functional use of the extremity and, second, to maintain full joint range, thereby preventing the common complication of contractures.

The objective of this study was to determine the changes, if any, in motoneuron excitability with passive exercise of the upper extremity in patients with history of stroke. Despite the common use of passive exercise in stroke rehabilitation, there have been a limited number of previous studies describing the effect on motoneuron excitability of passive ROM in hemiplegic patients.

In the relative absence of a cortical inhibitory influence in stroke patients, there is increase in tone. One of the clinical manifestations is hyperactive tendon reflexes. Pisano et al<sup>21</sup> studied 53 stroke patients to examine the correlation between H/M ratio, muscle tone via the MAS, and total stiffness index as measured with a torque meter. The results indicated that

there was linear distribution of these values, suggesting these measures may correlate well with motoneuron excitability as documented by Hmax/Mmax ratio.

There are several studies in the literature regarding influences of active exercise on H-reflex in healthy subjects. Active exercise in the lower extremities of healthy subjects causes an immediate attenuation followed by potentiation of the H-reflex. Trimble and Harp<sup>13</sup> studied 10 college students who underwent a vigorous set of concentric-eccentric triceps surae exercises. Immediately after exercise, they noted an initial depression in the H-reflex, followed by statistically significant potentiation in half of the subjects.

A previous study by Suzuki et al<sup>16</sup> involved 10 stroke subjects who had their affected arms continuously stretched for 1 minute. They found a decrease in H-reflex and H/M ratio only during stretching in those subjects with moderately increased tone. No changes persisted after stretch was discontinued. Unlike our study, Suzuki's group used continuous stretching of 1 particular joint in the upper extremity.

Nuyens et al<sup>6</sup> studied 10 stroke and healthy subjects and concluded that torque measurements, electromyographic activity, and H-reflexes changed after passive repetitive isokinetic knee movements. These studies reflect differences in the effect on motoneuron excitability of various exercises in subjects with increased tone because of stroke and in normal controls. This can be measured quantitatively with an electrically elicited monosynaptic stretch reflex via the H-reflex.

In our study, the passive exercise involved the shoulder and elbow joints of the upper extremity. We tried to simulate common passive exercises that were performed in a clinical setting. Our study differs from these studies in that we used a set of standardized passive exercises involving the upper extremity to determine possible changes in motoneuron excitability with exercise.

We found that there is no significant difference in the amplitude of H-reflex and Hmax/Mmax ratio before and after passive exercise, which suggests that the passive ROM does not change motoneuron excitability. This may suggest that peripheral input via passive exercise may not be sufficient to change the altered central input to muscle tone.

During the robotic arm exercise, the wrist joint was immobilized within the splint. One may question whether the absence of changes in the H-reflex from the flexor carpi radialis muscle was because of this immobilization. Many previous studies have shown changes in H-reflexes in muscles not directly involved in exercise. For instance, Motl et al<sup>22</sup> studied 12 healthy subjects and found that changes in soleus H-reflex were documented after cycle ergometry during which the ankle was immobilized in a cast. This is thought to be because of central inhibition.<sup>14</sup>

Throughout the study, the variability caused by environmental factors was minimized to the best of our abilities. In addition, the computer-controlled arm movements, ROM, and angular joint velocities were kept constant to minimize the exercise variability between subjects. However, it should be noted that the timeframe from completion of the passive exercises to obtaining the postexercise nerve conduction study was within 10 minutes. The variability in timing may have affected the Hmax/Mmax ratio outcome measure.

One possible reason for a lack of appreciable change in H/M ratio after exercise may be because of the fact that the velocity of the robotic arm's passive movement was purposefully slow to minimize tone and enhance safety. There are several possibilities for the lack of statistical significance of our results. Perhaps, the low statistical power of the nonparametric Wilcoxon rank-sum test was because of a low sample size, low effective size, and/or variable responses to exercise. It should also be noted that our robotic arm exercise protocol was not designed to include end ranges of joint motion, only passive exercise

within the functional ROM. Inclusion of end ranges of joint motion may have been more comparable to stretching that is also included in most physical and occupational therapy prescriptions for stroke patients.

A longstanding debate in upper-limb stroke therapy is whether the goal is to increase voluntary muscle contraction (strength)<sup>23</sup> or to reduce abnormal tone in antagonistic muscles.<sup>24</sup> In either case, avoidance of velocity-dependent, stretch-induced activity improves the desired joint torques. It is common, during passive motion performed by a therapist, to use resistance that is sensed to modify the applied force. The MIME robot only changes its velocity (stops) if a safety threshold is exceeded.<sup>17</sup> Therefore, passive movements in this study were performed at velocities used successfully in previous studies conducted with the MIME system. It was programmed to execute the movements over 10-second intervals to minimize the effects of velocity-dependent increases in muscle tone. Although it is difficult for a therapist to perform such movements smoothly, accurately, and with multiple repetitions, robots excel at such tasks. The results support such a role.

In the absence of spinal changes, 1 possible mechanism for improvement in motor control previously reported by using MIME and other robotic systems could be cortical plasticity. Additional studies focusing on cortical activity changes appear to be warranted. In our study, peripheral input via passive exercise may not have been sufficient to change the altered central input to muscle tone.

Future studies may gain further insight by comparing specific subsets of the stroke population by age, size, location, or type and duration of stroke.

### CONCLUSIONS

Passive ROM, when standardized on a robotic arm, does not appear to affect the motoneuron excitability, as measured by the Hmax/Mmax ratio, in the affected upper extremities of our population of hemiparetic stroke subjects. The type of exercise delivered by MIME does not appear to alter the excitability of the motoneuron pool in the spinal cord.

**Acknowledgment:** We thank Martin Lee, PhD, at University of California Geffen School of Medicine, Los Angeles, CA, for his assistance with statistical analysis.

### References

1. Little JW, Halar EM. H-reflex changes following spinal cord injury. *Arch Phys Med Rehabil* 1985;66:19-22.
2. Enola RM. *Neuromechanical basis of kinesiology*. 2nd ed. Champaign: Human Kinetics; 1994. p 151-91.
3. Braddom RL. *Physical medicine and rehabilitation*. 2nd ed. Philadelphia: WB Saunders; 2000. p 593.
4. DeLisa JA. Therapeutic exercise. In: DeLisa JA, Gans BM, Currie DM, editors. *Rehabilitation medicine: principles and practice*. 2nd ed. Philadelphia: JB Lippincott; 1993. p 346.
5. Scremin AM, Kunkel CF, Scremin OU. Functional electrical stimulation induced cycling decreases the amplitude of the tibial H-reflex. *J Am Paraplegia Soc* 1990;13:98-9.

6. Nuyens G, De Weerd W, Spaepen A Jr, Kiekens C, Feys HM. Reduction of spastic hypertonia during repeated passive knee movements in stroke patients. *Arch Phys Med Rehabil* 2002;83:930-5.
7. Renshaw B. Influence of discharge of motoneurons upon excitation of neighboring motoneurons. *J Neurophysiol* 1941;167-83.
8. Kato T, Takeda Y, Tsuji T, Kasai T. Further insights into post exercise effects on H-reflexes and motor evoked potentials of the flexor carpi radialis muscles. *Motor Control* 2003;7:82-99.
9. Zehr PE. Considerations for use of the Hoffmann reflex in exercise studies. *Eur J Appl Physiol* 2002;86:455-68.
10. Funase K, Imanaka K, Nishihira Y. Excitability of the soleus motoneuron pool revealed by the developmental slope of the H-reflex as reflex gain. *Electroencephalogr Clin Neurophysiol* 1994;34:477-89.
11. Higashi T, Funase K, Kusano K, et al. Motoneuron pool excitability of hemiplegic patients: assessing recovery stages by using H-reflex and M response. *Arch Phys Med Rehabil* 2001;82:1604-10.
12. Panizza M, Balbi P, Russo G, Nilsson J. H-reflex recovery curve and reciprocal inhibition of H-reflex of the upper limbs in patients with spasticity secondary to stroke. *Am J Phys Med Rehabil* 1995;74:357-63.
13. Trimble MH, Harp SS. Postexercise potentiation of the H-reflex in humans. *Med Sci Sports Exerc* 1998;30:933-41.
14. Bulbulian R, Darabos B. Motor neuron excitability: the Hoffmann reflex following exercise of low and high intensity. *Med Sci Sports Exerc* 1986;18:697-702.
15. Sugawara K, Kasai T. Facilitation of motor evoked potentials and H-reflexes of flexor carpi radialis muscle induced by voluntary teeth clenching. *Hum Mov Sci* 2002;21:203-12.
16. Suzuki T, Saitoh E, Tani M, et al. Effect of continued stretching of the affected arm in patients with cerebrovascular diseases by examining H-reflex characteristics. *Electromyogr Clin Neurophysiol* 2003;43:51-6.
17. Burgar CG, Lum PS, Shor PC, Machiel Van der Loos HF. Development of robots for rehabilitation therapy: the Palo Alto/Stanford experience. *J Rehabil Res Dev* 2000;37:663-73.
18. Kendall MP. *Muscles: testing and function*. 3rd ed. Baltimore: Williams & Wilkins; 1983.
19. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state." A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res* 1975;12:189-98.
20. DeLisa JA. *Manual of nerve conduction velocity and clinical neurophysiology*. 3rd ed. New York: Raven Pr; 1994. p 168-9.
21. Pisano F, Miscio G, Del Conte C, Pianca D, Candeloro E, Colombo R. Quantitative measures of spasticity in post-stroke patients. *Clin Neurophysiol* 2000;111:1015-22.
22. Motl RW, Knowles BD, Dishman RK. Acute bouts of active and passive leg cycling attenuate the amplitude of the soleus H-reflex in humans. *Neurosci Lett* 2003;347:69-72.
23. Brunnstrom S. *Movement therapy in hemiplegia*. London: Harper & Row; 1970.
24. Bobath B. *Adult hemiplegia evaluation and treatment*. 2nd ed. London: Heinemann; 1975.

### Supplier

- a. Sierra LT; Cadwell Laboratories Inc, 909 N Kellogg St, Kennewick, WA 99336.