Muscle Spindles and the Regulation of Movement
John P Scholz and Suzann K Campbell

PHYS THER. 1980; 60:1416-1424.

The online version of this article, along with updated information and services, can be found online at:
http://ptjournal.apta.org/content/60/11/1416

Collections
This article, along with others on similar topics, appears in the following collection(s):
- Anatomy and Physiology: Musculoskeletal System
- Anatomy: Central Nervous System and Neuromuscular System
- Motor Control and Motor Learning

E-Letters
To submit an e-Letter on this article, click here or click on "Submit a response" in the right-hand menu under "Responses" in the online version of this article.

E-mail alerts
Sign up here to receive free e-mail alerts
Muscle Spindles and the Regulation of Movement

JOHN P. SCHOLZ, MACT, and SUZANN K. CAMPBELL, PhD

This paper presents the complexities of muscle spindle structure and function. Experimental evidence indicates that the contribution of muscle spindles to motor control depends upon the cooperation of two distinct systems, one dynamic and one static. The traditional idea that load compensation depends on the segmental stretch reflex action of muscle spindle afferents on alpha motor neurons is questioned and evidence is provided to support the direct dependence of load compensation upon supraspinal centers. Information from muscle spindle afferents allows the nervous system 1) to compare the actual muscle length and velocity of contraction to the desired length and velocity for a particular movement and 2) to compensate for any discrepancies that develop. Segmental pathways from muscle spindle afferents appear to function with Golgi tendon organs to regulate the stiffness or compliance of a muscle.

Key Words: Motor activity, Muscle contraction, Neural transmission.

In nearly a century of intensive research, aided by technological advances in neuroanatomical and neurophysiological study, our understanding of the structure and function of the muscle spindle has been enhanced. Particular interest and controversy has centered on the role of the muscle spindle in motor control. That muscle spindles participate in the regulation of muscle action is generally accepted, although knowledge of muscle spindle physiology is far from complete.

Because a primary concern of physical therapists is to restore motor capacities altered by trauma or disease, clinicians must understand the basic mechanisms contributing to normal motor performance. Muscle spindle function is one important mechanism to remember. Many therapeutic approaches used to treat patients with neurological impairment are based in part upon current concepts of muscle spindle function. In light of new scientific information, these methods of patient care must continually be modified and evaluated to determine if a correlation exists with responses obtained in relatively nonphysiological experimental conditions and, more importantly, to what extent such modifications improve patient performance.

The purposes of this paper are 1) to review briefly recent evidence for the modification of classical concepts of the structure and physiology of the muscle spindle and 2) to discuss the implications of the evidence for muscle spindle function. Some clinical applications of this information will then be presented. For a detailed account of the classically accepted structure and physiology of the muscle spindle, see Eldred, Shambes, and Figure 1.

STRUCTURAL CONSIDERATIONS

Muscle spindles of both the cat and man are now known to contain three distinct types of intrafusal muscle fiber: nuclear chain (NC) fibers and two types of nuclear bag fiber. Nuclear bag fibers are distinguished by their differences in length, diameter, histochemical profile, ultrastructure, and contractile properties. Nuclear bag fibers are classified by their functional properties as dynamic nuclear bag (DNB) and static nuclear bag (SNB) fibers. Most spindles contain nuclear bag fibers of both types along with several NC fibers, although spindles containing only one type of nuclear bag fiber or without NC fibers have been found. A diagram of the present concept of muscle spindle innervation is shown in Figure 2. Branches of a large Ia afferent nerve fiber terminate as sensory spirals or primary endings on all intrafusal muscle fiber types.
at their equatorial region. Only one la afferent supplies any one spindle. The smaller group II afferents are more numerous, and each terminates in a separate secondary ending on the spindle’s polar region. Group II afferents are typically found only on NC fibers, but occasionally innervate an SNB fiber.

Two types of efferent innervation, the dynamic gamma fusimotor fiber and the static gamma fusimotor fiber, have been identified. The fibers are classified by the effect that their activation has on the response of muscle spindle afferents during muscle stretch and release and during active contraction. Both anatomical and physiological evidence indicate that dynamic gamma efferent fibers selectively innervate DNB fibers. The SNB and NC fibers are innervated by static gamma fusimotor fibers, and these intrafusal fibers often share the same motor innervation. Static gamma fusimotor fibers are apparently less selective than their dynamic counterparts, inasmuch as they have been observed to innervate DNB fibers as well, although this is not the rule. The functional significance of this finding is not clear.

Intrafusal fibers are also innervated by collaterals of alpha motoneurons called beta fibers. These axons are intermediate in size between alpha and gamma motoneurons and, upon repetitive stimulation, produce acceleration of spindle primary afferent discharge in addition to contraction of extrafusal muscle fibers.

**PHYSIOLOGY OF THE MUSCLE SPINDLE**

**Indexes Reflecting Stretch Sensitivity**

The discharge patterns of muscle spindle primary and secondary endings can be distinguished by the static and dynamic sensitivities to ramp-and-hold and sinusoidal stretches. A ramp-and-hold stretch refers to a large-amplitude stretch of the spindle, occurring at a constant velocity, which is then held at the end point of the range. Sinusoidal stretching involves a rhythmic alternation of the spindle’s length between two points in the range of movement and occurs at a predetermined frequency (Hz). The sensitivity of an afferent ending to stretch is defined as the amount of modulation of its frequency of discharge with each millimeter of stretch (impulses/sec/mm). The dynamic index of an afferent ending is defined as the decrease in the frequency of its firing in the first 0.5 second after completion of a ramp-and-hold stretch. It reflects the velocity responsiveness of the ending, because those endings that are most sensitive to the velocity of a stretch will display a larger initial fre-

---

*Fig. 1. Schematic drawing of the classical concept of muscle spindle structure and innervation. (With permission of the author and Cambridge University Press.)*

*Fig. 2. Schematic diagram of the typical pattern of innervation of a muscle spindle. P = primary endings of group la afferents. DNB = dynamic nuclear bag intrafusal fiber. SNB = static nuclear bag intrafusal fiber. NC = nuclear chain intrafusal fibers. S = secondary endings from group II spindle afferents. $\gamma_s$ = gamma dynamic motoneuron. $\gamma_s$ = gamma static motoneuron. (Adapted from Boyd, with permission of the author and Cambridge University Press.)*
Afferent Response Characteristics

Primary endings exhibit greater absolute sensitivity to stretch than do secondary endings, and they are sensitive to both the change in muscle spindle length and the velocity of length change. Secondary endings are more sensitive to the absolute length than to the velocity of length change (Fig. 3). The higher threshold to stretch exhibited by secondary endings may be attributed to their selective innervation of NC intrafusal fibers. The NC fibers have "kinks" in their juxtaequatorial region, near the site of innervation by group II afferents (Fig. 4). A larger amplitude stretch is thus required to cause these endings to discharge, especially in the absence of fusimotor activity.

The greater velocity sensitivity of primary endings is illustrated in Figure 5, which depicts the effect on the dynamic index of increasing the velocity of stretch. This response characteristic of primary endings, recorded from the Ia afferent to the spindle, appears to be related to the mechanical properties of the DNB intrafusal fiber rather than of the SNB or NC fibers.

Fusimotor Influence on Afferent Response

Gamma motoneurons, by causing contraction of regions of the spindle poles, exert a powerful influence on the frequency of discharge of muscle spindle afferents both during stretch and during extrafusal contraction. In the presence of static gamma motoneuron activity alone, both the primary and secondary endings become increasingly sensitive to increments in the length of the spindle. However, the velocity sensitivity of the primary ending, as measured by the dynamic index, is reduced by static gamma activity. Dynamic gamma stimulation, on the other hand, improves both the length and velocity responsiveness of the primary ending, provided that the velocity of stretch is sufficient. These results, however, were

---

Fig. 3. The contrasting responses of spindle primary and secondary endings to a rapidly applied stretch (about 14mm at 70mm/sec) shown both in the presence (ventral spinal roots intact) and absence (ventral spinal roots cut) of fusimotor activity. VR = ventral spinal roots. (With permission of the author and Edward Arnold [Publishers] Ltd.)

Fig. 4. The displacement (arrows) of various regions of a nuclear chain (NC) intrafusal fiber of an isolated spindle, and the stretch of the sensory region produced by maximal contraction of the contractile elements. A = resting length, B = displaced length. (Adapted from Boyd, with permission of the author and Longman Group Ltd.)
obtained during stimulation of single gamma fibers, which might activate only a small number of intrafusal fibers or perhaps only one pole of a single intrafusal fiber.

In one study, both types of fusimotor fiber were simultaneously stimulated during a 1-Hz sinusoidal stretch.\textsuperscript{17} The effectiveness of each fiber type in modulating primary afferent response was found to vary with the phase and amplitude of stretch. For example, during stretches of amplitude greater than 50 µ, an increase in the discharge of the primary endings during the stretching phase of the cycle could be attributed to both dynamic and static gamma action, with the greatest contribution coming from dynamic gamma motoneurons (Fig. 6). However, discharge of the primary endings during the falling phase of the cycle was attributed solely to static gamma motoneuron effects. This latter result is in accord with the finding that only static gamma motoneurons produce an intrafusal contraction rapidly enough to allow primary ending discharge to continue during extrafusal shortening.\textsuperscript{12, 18}

The described differences in combined effects should certainly have functional significance. However, interpretation and application of the results of these experiments require caution, inasmuch as experimental preparations of muscle fall short of the physiologically normal condition. The results do indicate the complexities of muscle spindle organization.

The responsiveness of the sensory endings of each intrafusal fiber type might be controlled independently by the CNS through individual gamma motoneurons for the motor task at hand.\textsuperscript{12} Differences in the mechanical properties and the efferent innervation among the DNB, SNB, and NC fibers allow for variations in the response characteristics of the primary endings and, therefore, variations in the signal transmitted to the Ia afferent, depending on which intrafusal fibers are being activated by gamma motoneurons. Also, because electrical discharges of several primary endings interact at the Ia afferent, the CNS may receive a resultant signal when several intrafusal fibers are influenced at once, which is probably the common situation. The resultant signal may be the summation of two or more independent inputs from primary endings, the instantaneous value of the input signal having the highest instantaneous frequency, or the result of some intermediate operation.\textsuperscript{12}

Static gamma motoneuron activation, by increasing the length sensitivity of the primary ending of the

Fig. 5. The dynamic responsiveness of primary and secondary muscle spindle afferents to large stretches in the presence of fusimotor influence. (With permission of the author\textsuperscript{12} and Edward Arnold [Publishers] Ltd.)
SNB and NC fibers and perhaps the secondary endings of NC fibers, might be responsible for allowing the provision of constant length feedback to the CNS as well as maintaining the overall sensitivity of the spindle afferent endings during extrafusal shortening. The activation of dynamic gamma motoneurons, by increasing the velocity and length sensitivity of the primary ending of DNB fibers, would appear to allow the nervous system to respond more rapidly to undesired changes in muscle length. The high-frequency impulses generated in the primary ending in response to the velocity of stretch may provide more rapid facilitation of alpha motoneurons and subsequent reflex compensation.

The velocity and length sensitivity provided by the nervous system through dynamic and static gamma motoneurons may be operative in muscle spindles of a contracting muscle, in those of its antagonist during agonist action, or both. Sensitivity of antagonistic stretch reflexes may help limit the depth and extent of excitation of the agonist motoneuron pool during certain movements. In any case, the variety of responses obtained during controlled gamma stimulation may reflect the repertoire of control options available to the CNS.

**SPINAL CIRCUITS**

The group Ia afferents from primary endings that transmit sensory impulses to the spinal cord have been shown to have both monosynaptic and polysynaptic excitatory connections to homonymous motoneurons. Through interneurons, such as Ia-inhibitory interneurons, Ia fibers disynaptically inhibit motoneurons to antagonistic muscles. The disynaptic connections of group II spindle afferents have previously been thought to be inhibitory to extensor motoneurons and excitatory to flexor motoneurons regardless of their muscle of origin. Recent data, however, have provided evidence for both monosynaptic and disynaptic excitatory effects of these afferents on extensor motoneurons in both animals and man. Inasmuch as the exact nature of the reflex effects of group II muscle spindle afferent activation is controversial and the contribution of these afferents to motor control is unclear, they will not be further discussed. A recent review of the controversy over their function may be found elsewhere.

**FUNCTIONAL CONSIDERATIONS**

**Follow-up Length Servo Hypothesis**

How does the nervous system use information from muscle spindle afferents? Historically, several hypotheses have been considered. An early hypothesis proposed that the stretch reflex was used by the nervous system to hold the muscle at a particular length commanded by gamma discharge. Such a system was referred to, in engineering terminology, as a follow-up length servo mechanism. According to this model, muscle contraction by way of a direct alpha motoneuron pathway could result in a powerful depression of feedback information from muscle spindles, because the spindles lie in parallel with the main muscle. By increasing the firing of muscle spindle primary afferents, however, the gamma system would produce an increase in alpha motoneuron discharge until the muscle had shortened to a desired length, while at the same time providing for continued feedback from the muscle spindle to the CNS. The continued sensitivity to stretch of muscle spindle afferents would provide a mechanism for maintaining the muscle at a constant length in the face of external forces. Allum has hypothesized that for this indirect gamma action to occur, the gain of the segmental loop would need to be quite high.

Experiments on lower-order primates and humans, however, indicate that extrafusal muscle activity precedes, rather than follows, spindle afferent activity at the onset of a contraction. Contrary to the follow-up length servo model, this implies that skeletomotor contraction is not dependent upon an increased spindle afferent discharge, although the contraction may be supported by the increased discharge once the contraction is initiated.

**Servo Assist Hypothesis**

The discovery of the temporal relationship between muscle spindle afferent discharge and skeletomotor contraction led to the postulation of an alternate hypothesis, the servo assist hypothesis. Studies have confirmed that instead of gamma motoneurons indirectly driving extrafusal contraction as a part of a length servo system, there is a coactivation of both alpha and gamma motoneurons during muscle activation. As previously mentioned, fusimotor activation of the muscle spindle, probably by way of static gamma motoneurons, allows for the maintained sensitivity of spindle primary endings during muscle shortening. Because of the delay in the muscle spindle loop, compensation for the unloading effects of extrafusal shortening lags slightly behind the muscle contraction. This delay is greater with isotonic than with isometric conditions.

According to the servo assist model, any slight disturbance in the programmed contraction would then be compensated for by modified spindle input. For example, an unexpected increase in external resist-
ance would result in further extension of the primary endings above the amount provided by the fusimotor control. (Changes in external resistance to the muscle might be due to the inertial properties of the limb itself—for example, during rapid movement of the limb to a sudden stop—as well as to a load applied externally to the limb.) The resulting increase in Ia afferent facilitation of alpha motoneurons could then provide immediate compensation through greater motor outflow, without engaging higher centers of the CNS. Marsden has provided evidence from experiments on humans that the latency of the compensatory reflex response is at least 60 msec, greater than the 22-msec response to a tendon tap of the flexor pollicis longus. This finding has been confirmed by others, indicating that a polysynaptic pathway is involved.

Although static gamma motoneurons improve the length sensitivity of the muscle spindle primary afferents, their singular activation actually decreases the velocity responsiveness. During static gamma action alone, full correction would be significantly delayed by a phase lag because of transmission time in the circuit. The delay would cause the limb to oscillate. Dynamic gamma motoneurons, by increasing the velocity sensitivity of the primary ending of DNB fibers, provide for a more vigorous reaction to the change in length as the stretch progresses. As a result, the reflex response actually exhibits a phase lead ahead of muscle stretch. Evidence from recent studies on humans indicates that the CNS is also sensitive to the acceleration component of muscle stretch and that this sensitivity further improves the phase lead of the response. Thus, there is a more effective damping of the limb oscillations that tend to occur when the actual length and velocity of the muscle contraction deviate from that desired for the particular movement.

Use of Spindle Afferent Feedback by Higher Centers

In addition to providing servo assistance to spinal circuits, muscle spindle afferents project to higher levels of the CNS. First-order spindle afferents from hindlimb muscles project to Clarke's column in the spinal cord, from which second-order afferents ascend to the cerebellar vermis by way of the dorsal spinocerebellar tract. Campbell and associates have shown that afferents responding to stretch of forelimb, head, and neck muscles activate cells in the external cuneate nucleus of the rat medulla. These cells project to the cerebellum through the cuneocerebellar tract. In addition, information from spindle afferents is projected to area 3a of the sensorimotor cortex. It would be expected that higher nervous centers put this information to some functional use. One practical use would be to assess the current state of affairs at the periphery in order to select and dispatch appropriate motor commands to the spinal cord. Another important function might be to provide signals for learning so that a particular motor act could be improved by allowing higher centers to "see" how far the actual course of movement differed from that which had been intended. If this is so, and if sufficient plasticity in neural circuitry existed, then the controlled use of the stretch reflex loop to facilitate motor patterns in therapy could provide useful information for influencing the reorganization of damaged nervous centers or the centers involved in compensating for the effects of injury. Although Taub and associates have provided evidence that afferent input from limbs is not essential for motor learning, they found such input to be helpful in speeding up the learning process, especially for complex performance requirements. Sensory feedback may be even more important to the damaged CNS.

Transcortical Servo

Recent correlations of experimental evidence from humans and lower primates suggest the need for further modification of the servo assist hypothesis. In the experiments previously mentioned, the latency of the EMG response to stretch of the flexor pollicis longus was found to be at least 60 msec, indicating that the response was not monosynaptic, yet was too early to be voluntary. Moreover, the same latency response occurred when the muscle was not lengthened by a stretch but was slowed in its contraction by an unexpected increase in resistance. Based upon these findings, a transcortical servo assist loop was postulated, that is, that reflex compensation for an unanticipated change in muscle loading was completely effective only through involvement of suprasegmental pathways. A monosynaptic reflex involving only spinal circuits was not sufficient to produce successful load compensation.

It was once believed that such a short latency response could not involve supraspinal centers. Experiments on primates have provided evidence, however, that responses with latencies as short as 30 to 40 msec may involve a transcortical loop. Therefore, a 60-msec transcortical response in humans is not inconceivable. In addition, the latency of a transcerebellar reflex loop would be consistent with the experimental findings. The efferent limb of the response from the cerebellum could occur indirectly through the vestibular nuclei and vestibulospinal tracts or the pontine reticular nuclei and reticulospinal tract.
Servo Information Theory

Recently, force disturbances of the human shoulder were studied by applying displacement forces to rotate the shoulder while subjects tried to maintain a constant position against a preexisting force bias. Both EMG and rotational forces were recorded. The earliest force response to a disturbance recorded by the investigator was not associated with an EMG response and was attributed to the viscoelastic properties of the muscle. Thus the earliest force response to stretch is not reflex (that is, neural) at all, but rather is due to the intrinsic properties of the muscle itself.

In this study of the shoulder, the earliest force response associated with an increase in electrical activity of the muscle occurred 70 to 90 msec after the disturbance and was found to contribute only 10 percent of the final steady-state correction force. This response was seen as an immediate response of the CNS to assist the earlier viscoelastic force component in stabilizing the movement. Only the third segment of the force response was functionally effective in correcting the disturbance. The latency of this EMG response was about 200 msec and clearly involved more than the time required for a monosynaptic, segmental reflex.

Results from these experiments indicate that, rather than functioning as a true servomechanism, muscle spindle afferents might send a test signal designed to inform the CNS of the current loading on a muscle. This information would then allow the CNS to select an appropriate response to the changing situation. It was suggested that this representation would provide considerable advantages for memory storage and, consequently, for learning. These results also support an earlier contention that load compensation occurs as triggered reactions through long-latency pathways rather than through a transcortical or segmental stretch-reflex loop.

More recent experiments on humans, using a different paradigm to separate voluntary triggered reactions from reflex responses, provide evidence that compensation for undesired length and velocity changes during movement is indeed reflex in nature. These responses are hypothesized to involve multiple long-loop pathways from muscle spindle afferents to the cerebellum, which then influences spinal centers. The transmission characteristics of the reflex pathways are thought to be controlled by supraspinal influences on gamma motoneurons.

Role of Segmental Pathways

If supraspinal circuits are essential to load compensation, what is the function of the segmental stretch reflex? Allum found no early EMG response consistent with a monosynaptic stretch reflex, suggesting that this segmental loop has no direct effect on compensation for load changes, although it would presumably heighten the excitability of the motoneuron pool. But Crago and associates, in studies using a similar paradigm, recorded EMG responses with latencies ranging between 25 and 60 msec. These responses were thought to represent the onset of reflex action, inasmuch as they were not dependent upon prior instruction to the subject nor upon the randomness of the applied disturbance. The authors contend that the function of the segmental stretch reflex is to regulate muscle stiffness (the ratio between force change and length change). The stiffness or compliance of the muscle would determine how resistant it is to displacement of the limb by an external disturbance. Regulation of muscle stiffness requires information about muscle tension as well as muscle length. This is provided by the Golgi tendon organs (GTOs), which are most responsive to the tension or force developed in the muscle. Increased feedback to homonymous motoneurons from GTOs results in inhibition of these motoneurons and thus reduces muscle stiffness. Muscle spindle afferent feedback may have the opposite effect. The degree of stiffness depends upon the relative dominance of the two feedback systems, controlled by influences on gamma motoneurons and on interneurons in the disynaptic GTO pathway to alpha motoneurons.

In summary, current evidence indicates that segmental pathways from muscle spindle afferents to alpha motoneurons are inadequate to provide for load compensation. Rather, research supports the contention that compensation for disturbances in muscle loading depends upon mediation through supraspinal centers, which use information on length and velocity from muscle spindle afferents to produce compensatory responses. In this way, the CNS acts as a comparator, comparing the actual muscle length and velocity of contraction to the desired length and velocity, and compensating for any discrepancies that develop. The sensitivity of the transmission circuits can be modified by supraspinal centers to match the demands of the particular movement. Whether the compensatory responses produced are triggered reactions or reflex in nature remains controversial.

The segmental pathways to alpha motoneurons from spindle afferents and GTOs may act to regulate the initial compliance of the muscle or its resistance to stretch.

**THERAPEUTIC IMPLICATIONS**

Several widely used therapeutic techniques incorporate stretch and resistance to muscle groups as a
means of reinforcing appropriate patterns of posture and movement. Resistance to a contracting muscle is thought to enhance the feedback from muscle spindle afferents and to provide added facilitation of the motoneuron pool innervating that muscle. It may also improve kinesthetic awareness of the evolving movement. Vibration is used therapeutically to enhance excitation of the motoneuron pool through polysynaptic pathways from spindle Ia afferents and is thought to be especially effective in enhancing the contraction of a muscle with a spastic antagonist.26

As was previously mentioned, compensation for the unloading effects of extrafusal contraction and concomitant maintenance of spindle afferent sensitivity to stretch does lag further behind isotonic muscle contraction than isometric contraction.18 Therefore, resistance to a contracting muscle may provide more effective facilitation during an isometric contraction than an isotonic contraction, particularly when the muscle is being inhibited by a spastic antagonist.

The effectiveness of this technique is, of course, dependent upon the normal activation of the appropriate dynamic and static gamma motoneurons by the CNS. In addition, inasmuch as any substantive effect on alpha motoneuron discharge must be mediated by supraspinal centers, their integrity is also required for the elicitation of an appropriate response. The possibility of the response's being altered by damaged neural components is therefore greater than if the response involved the segmental stretch reflex apparatus alone.

The response characteristics of the muscle spindle afferents may be controlled or modified by the cerebellum, the cortex, and other areas of the cerebrum.12 Independent control of static and dynamic gamma motoneurons in the same spindle may be operated by different areas of the brain.12 Therefore, various sites of brain damage may have different effects on the control options available to the CNS during various movements and on the responsiveness of the muscle spindle to facilitation techniques.

Recent data from normal humans and patients with CNS dysfunction support this contention.4 For patients in that study with spasticity, athetosis, and cerebellar damage, the response characteristics of the stretch reflex during movement differed both quantitatively and qualitatively from normal persons and from each other. More importantly, there were variations between subjects who had a clinically comparable degree and extent of involvement. The point is further emphasized by the fact that some patients with cerebral spasticity exhibit an exaggerated tonic vibration reflex, while other patients with exaggerated muscle tone and brisk tendon reflexes display a weak or absent tonic vibration reflex.4 The complexity of the control options available to the CNS causes variations in control dysfunction, even in those patients who seem to be similar.

Whether a particular technique is effective will depend upon the specific area of the lesion and the effect of the technique on the response characteristics of the stretch reflex as well as on other control systems. A therapist cannot assume that a particular technique will be effective by virtue of the fact that it has worked with similar patients. The therapist must carefully evaluate the type of muscle tone and reflex response that each patient exhibits before selecting a particular technique, and then he must critically and continually evaluate its effects.

SUMMARY

This paper has discussed some of the complexities and current ideas about muscle spindle structure and function. Concepts of patient management must be continually modified in the light of new information. Although it seems logical to expect that therapeutic techniques involving stretch, resistance, and vibration will enhance the force of a muscular contraction, the various effects of different lesions are likely to produce variations in response effectiveness. Clinical research under controlled therapeutic conditions, in concert with modern neurodiagnostic techniques for lesion characterization, is needed to document 1) effectiveness of specific techniques, 2) variations in response under different parametric conditions, and 3) variations in response in different pathological conditions.
REFERENCES

2. Allum JHJ: Responses to load disturbances in human shoulder muscles: The hypothesis that one component is a pulse test information signal. Exp Brain Res 22:307–326, 1975