Proprioceptive Neuromuscular Facilitation in Combination with Electrical Stimulation: Combined Treatment in Comparison to Each Treatment Alone

Marko Munih, PhD*, ▪ Pavla Obreza, PT†, ▪ Janez Šega, Dipl. Ing*, ▪ Tadej Bajd, PhD*, ▪ Rajmond Šavrin, MSc, MD†

*Faculty of Electrical Engineering, University of Ljubljana and †Institute for Rehablitation, Republic of Slovenia, Ljubljana, Slovenia

▪ Abstract

The objective of the study was a quantitative examination of Proprioceptive Neuromuscular Facilitation (PNF) exercise in simultaneous combination with FES of lower extremity muscles in comparison to voluntary movement, training with PNF alone, or training with FES alone. Two subjects were monitored during a one-month rehabilitation period. The PNF pattern included flexion, adduction, and external rotation of the hip, knee flexion, and dorsiflexion with inversion of the ankle, a pattern similar to the swing phase of walking. Quantitative measurements were conducted by using goniometers on the hip, knee, and ankle joints. Major changes were found in the hip angle. Improvements in goniograms were greatest during the first week, smaller during the second week, and showed only a slight positive trend in the last two weeks. The measurements made two months after the start of training showed somewhat lower values in comparison to previous sessions. ▪

Key Words: electric stimulation, isotonic contraction, proprioceptive neuromuscular facilitation (PNF), range of motion, rehabilitation.

INTRODUCTION

The concept of proprioceptive neuromuscular facilitation (PNF) is widely used in therapeutic exercise programs. It was developed as a treatment modality for patients with movement deficits in the late 1940s and early 1950s by Herman Kabat, with the strong involvement of two physiotherapists, Margaret Knott and Dorothy Voss (1,2). The work of Charles Sherrington was also important in PNF procedures (3).

As a treatment philosophy, PNF is derived from the idea that all human beings, including those with disabilities, have untapped existing potentials (1,2,4). A variety of methods fall under the rubric of PNF, including the exploitation of postural reflexes, the

Address correspondence and reprint requests to: Marko Munih, Faculty of Electrical Engineering, University of Ljubljana, Ljubljana, 1000, Slovenia. Email: marko@robo.fe.uni-lj.si.

Neuromodulation, Volume 7, Number 1, 2004 48–55

use of gravity to facilitate movement in weak muscles, the use of eccentric contractions to facilitate agonist muscle activity, and the use of diagonal movement patterns to support the activation of biarticular muscles (4,5). The mechanisms that influence muscle activity: pressure, promotion of function, movement, facilitation, inhibition, strengthening, and relaxation of muscle, result in actions such as rhythmic initiation, combination of isotonic movement, reversal of antagonists, repeated stretch, contract-relax, and hold-relax (1,4,6). These coordinated and synergistic muscle activations form the patterns of PNF (4). The patterns combine motion in all three planes, sagittal, frontal and transverse, with the result that the motion is spiral and diagonal. Two antagonistic patterns represent a diagonal one (all patterns receive their names from the final position of the movement). Physiotherapists combine and modify procedures and techniques to suit the needs of each patient (2,4).

Researchers first began studying the effectiveness of PNF exercise as compared to other forms of stretching. There were concerns about the possible risk involved in the method, and determination of the underlying neurologic mechanisms was also important (7). There was significant interest in the initiation of a voluntary movement influenced by limb position changes prior to the start of such movement (5,8). Change in muscle length was found to produce sensory inputs from peripheral organs, such as muscle spindles, that could influence motor output mechanisms of the central nervous system (CNS) (9–12). During normal limb position changes, the ensemble of spindles within a muscle dynamically signals a slight distortion of muscle length (13). Furthermore, limb position changes prior to voluntary movement affect the combination of agonist/antagonist muscles involved in the activity and the order in which they are activated (14,15).

The majority of comparative studies found PNF to be significantly more effective for increasing the range of motion and flexibility of the joints than other static, ballistic, or passive stretching (7,12). Some studies focused on electromyographic (EMG) recordings (16), while other system variables, such as heart rate and systolic blood pressure, were also verified. Among the isotonic studies, range of motion was the variable most commonly followed on a day-to-day basis (7).

At our rehabilitation center, PNF exercise represents a frequently used modality for selected candidates. Similarly, the FES (functional electrical stimulation) technique is used with a suitable population (17). As a natural combination, in the present study FES has been added to the PNF pattern (18,19). The coupling of both activities is synchronized by a physiotherapist responsible for PNF therapeutic intervention. The PNF stimulator is triggered by a special foot switch and electrical stimulation is applied via surface electrodes (20,21). The motivation for the present study is the quantitative examination of the PNF-FES combination in comparison to leg activation achieved voluntarily, with FES alone, or with PNF alone. The results indicate that the combination of PNF and FES may be of importance for activation of paralyzed muscles. Two subjects were monitored during a one-month period, with measurements being taken from the right leg. The range of joint motion was assessed by the use of ankle, knee, and hip goniometers.

MATERIALS AND METHODS

Protocol

A Manumed model 225 (ENRAF NONIUS, Netherlands), adjustable tilt table was used as a work area. In resting position, the subjects lay supine with their legs and arms stretched out. The physiotherapist first placed the stimulation electrodes above the peroneal nerve in order to trigger the flexion withdrawal reflex of the right leg. Three Biometrics Ltd. goniometers (Penny & Giles Biometrics, Ltd., Blackwood, UK) were strapped to the hip, knee, and ankle joints and were always zeroed before each activity.

The measurement was divided into two major parts. During free movement in all three joints four types of activity were induced:

1 Voluntary movements of the right leg (five consecutive trials and five minutes of rest). After a verbal command to begin, the patient produced active movement in all three joints (hip and knee flexion, ankle dorsiflexion). The physiotherapist verbally stimulated the subject in order to achieve as good a range of motion as possible. The experimental conditions were similar to those shown in

Fig. 1. Movement guidance at final position.

Fig. 1, except that there was no assistance from the physiotherapist. The heel slid on the tilt table during movement initiation and was raised as the hip joint angle increased. There was no manual guidance of limb movement.

2 Movement caused only by electrical stimulation (five consecutive trials and five minutes of rest). On each day of the experiment, a pair of electrodes was placed over the peroneal nerve to elicit the flexion withdrawal reflex of the leg. Because of partially preserved sensation in both subjects, the stimulation amplitude was set by the physiotherapist before the session based on visual observation of the stimulation response, as well as with regard to the pain sensations reported by the subject. This is normal practice and was not tailored specifically for the needs of our measurements. During the trial, the stimulation amplitude was controlled by the physiotherapist with a typical time course of the stimulation current, as shown in Fig. 1. The electrode positions and stimulation parameters remained constant for all experiments conducted that day.

3 PNF treatment (five consecutive trials and five minutes of rest). For daily training and measurement trials, the following PNF pattern was used: flexion, adduction, and external rotation of the hip, knee flexion, and dorsiflexion with inversion of the ankle. The movement represented an isotonic and concentric contraction. The extent of manual guidance of the limb was small, but sufficient in regard to PNF practice. The starting position was extension, abduction, and internal rotation of the hip, knee extension, plantarflexion and eversion of the ankle. The final position of the lower leg is shown in Fig. 1.

4 PNF combined with FES (PNF-FES, five consecutive trials and five minutes of rest). The subject contributed voluntarily and the physiotherapist activated the electrical stimulator with a pedal control. The physiotherapist also applied a PNF sequence as described in the previous paragraph. The efforts of the patient and the physiotherapist were well synchronized.

Measurement Setup and Stimulator

The following parameters were acquired for each of the above measurements through the use of goniometers and a PC computer with Matlab/Simulink (Natick, MA): ankle, knee, and hip angles, stimulation current amplitude (using a Textronix (Beaverton, OR current probe model AM503A and sample and hold circuit) and the presence of stimulation pulses. The data acquisition for the full range included 12 bits using a Burr-Brown PCI 20098C data-acquisition board (Texas Instruments, Inc., Dallas, TX).

The stimulator used in conjunction with PNF has been described previously (20,21). The microprocessor-based one channel unit is placed into an amplifier volume adjustment box, which is normally placed on the floor. The top of the housing (the pedal) flexes and is linked directly to an amplitude potentiometer (Fig. 2). Another

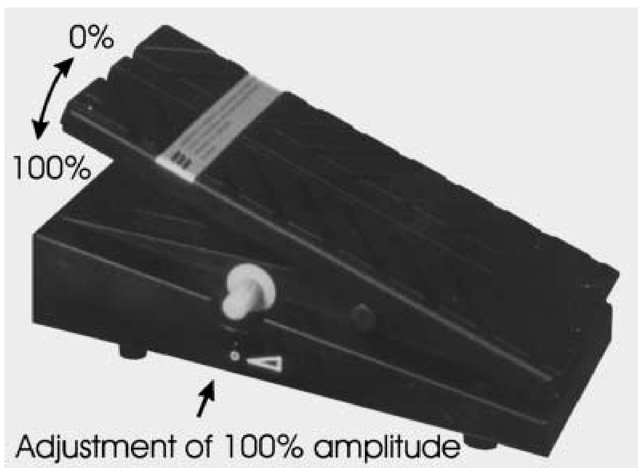

Fig. 2. The PNF stimulator.

potentiometer, mounted beside the housing, is used to set the overall maximum stimulation amplitude when the pedal is fully pressed down. This was usually set by the physiotherapist before the session. The potentiometer mounted on the pedal plate is meant for the modulation of the stimulus amplitude during the session, from zero up to the maximum level set in advance. The physiotherapist controls the pedal plate with her foot during the PNF sequence, and the amplitude is low when the pedal is in its uppermost position. The unit usually remains on the floor and during sessions is operated by foot only.

To enhance the versatility of the stimulator and accommodate the device to individual needs, the clinician can set the following stimulation parameters by the use of a simple external module in advance or during exercise if necessary: pulse width, stimulation frequency, and amplitude. The external module enables communication with the user via two pushbuttons and an LED bar display. The frequency can be preset to 15, 20, 25, 30, 40, 50, 70, or 100 Hz; the pulse width can be set to 150, 200, 250, 300, 350, 400, 500, 600, or 700 µs; and amplitude can be selected from 0 to 135 V (voltage output). The most frequently used combination of stimulation parameters during the study was a frequency of 20 Hz and a pulse duration of 300 µs, while the amplitude was adjusted and modulated by the therapist as explained above.

Subjects

Two patients were selected for the evaluation of the effectiveness of PNF use in combination with FES. The first patient was a female (Subject A), 54 years old, with L2/L3 incomplete spinal cord injury after hernia disci (June 6, 2001). One month after she entered the rehabilitation program, she was trained every morning with the established bilateral protocol for maintaining the range of motion in joints, with FES of the quadriceps muscles and with general mobility training. At beginning of the study, the patient had voluntary activity in the left m. iliopsoas. Muscular status improved considerably during the rehabilitation period, with voluntary activity being present in all muscle groups of the lower extremity. The grade in general did not exceed 3 – except both m. quadriceps, which were graded as 4. The patient was altogether classified as an ASIA C on acceptance and discharge as well. Finally, this enabled her to walk short distances by using a walker. Sensation was initially present at level L1 and improved to a partially present state in the entire body by the end. Reflex activity was preserved.

The second subject was a male (Subject B), 62 years old, an incomplete spinal cord injury C5-T2 as a result of a vascular stroke (July 5, 2001). His entrance into the rehabilitation program commenced one month later with exercises for maintaining range of motion, increasing muscle strength with FES, standing exercise, and general mobility training. Similar to the case above, at the beginning of the study he started training with PNF and FES. After the final day of our experiment, he received training in treadmill walking and continued later with walking using parallel bars and suspension. Muscular response was initially better in several muscle groups in the left leg than in the right leg. Both sides improved considerably and the muscular strength increased. However, the grades in all major muscle groups of the right leg were lower than 3, the left side being better with a grade of 4. He was classified as ASIA C at entrance into the program, at the end of our study, and also at discharge. Voluntary activity and sensation were present all over the body, and reflex activity was partially preserved at the beginning and at discharge. The initial and final range of motion for both subjects is evident from the data in the *Results* section.

During the period of this study, both left and right legs were trained in the morning sessions every day with established rehabilitation protocol, including the PNF-FES combination. In addition, measurements were scheduled twice a week, Monday and Thursday, only in the right leg. The measurement protocol was the same throughout the one-month testing period. One assessment session was concluded approximately one month after the end of the exercise following the same protocol as during all the other measurements. The rehabilitative training during this last month remained the same as used during the initial one-month testing period.

RESULTS

Based on the measurement protocol described in the *Materials and Methods* section, each activity was

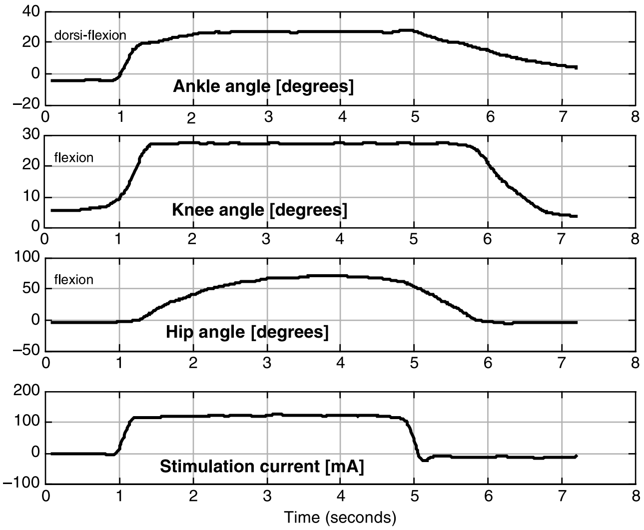

Fig. 3. Goniograms for ankle, knee, and hip joints, and the envelope of stimulation pulses (Subject A, activity 4).

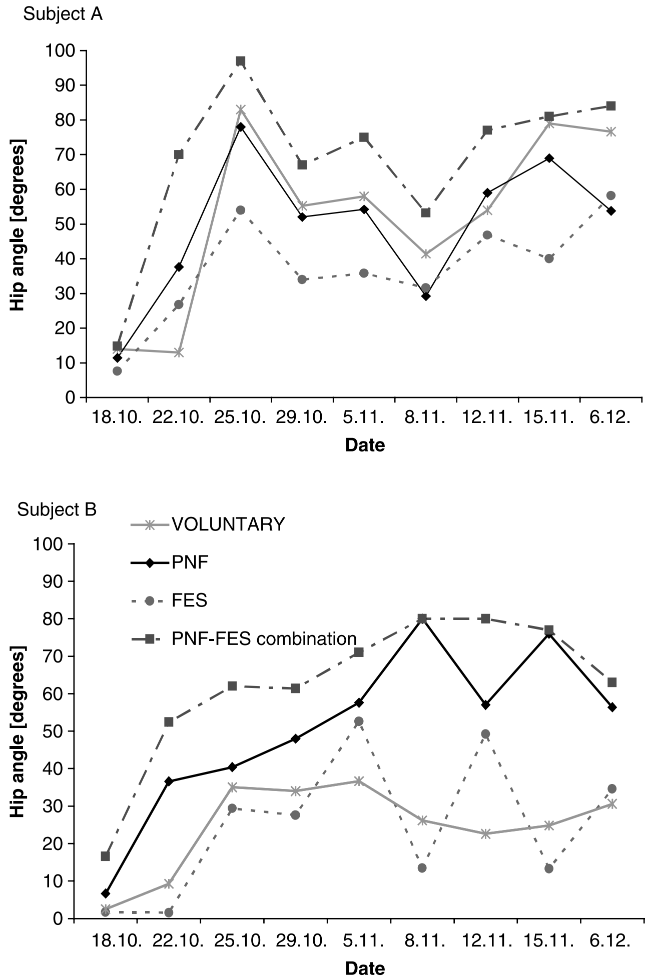

Fig. 4. Maximum values of angle in the hip at various dates and for all four types of activity.

repeated five times, resulting in 5 + 5 + 5 + 5 = 20 movements per single day of the experiment. In nine sessions, 180 assessments were made for each subject.

Figure 3 represents the ankle, knee, and hip angle time courses for a typical free movement experiment (Subject A, November 12, 2001, activity 4). The fourth curve shows the degree of modulation of the stimulation current. The electrical stimulation was ramped up at the beginning and decreased at the end, in both cases controlled by the physiotherapist and synchronized with the voluntary activity and verbal cue.

From each angle time course, such as the one presented in Fig. 3, only the maximum value of a particular parameter was read. For the five equal consecutive trials done for every activity, the values were averaged to produce one reading for each experimental day in Figure 4. Here are also given the values for the hip angles for all four free (isotonic) activities for both subjects, A and B. The four separate curves represent four experimental activities. For both subjects and all activities, very low values were found on the first trial day, with the range of motion significantly increased on the second day and in later experiments. For Subject B, responses improved over time in both PNF and PNF-FES combined activity. For subject A, the responses toward the end of the treatment showed some fluctuation.

The PNF-FES combination provided the largest range of motion in most cases. This activity is shown more in detail in Figure 5. Each point represents a single trial (rather than an average of five, as above). The order of the experimental sequence is evident, as well as minimum and maximum values.

In Figs. 4 and 5, the ninth session occurred three weeks after the eighth session as a verification measurement. Here, very little difference for Subject A could be observed, and Subject B had somewhat lower values in comparison to previous sessions. This signifies that the range of motion had not decreased back to the initial starting level.

The range of motion in the knee and ankle joint is very similar for all four activities and changes little over time. After the very limited range of motion during the first session, the response improved and remained at a plateau for all the remaining experiments. In observing the highest values, we can claim that the PNF-FES combination

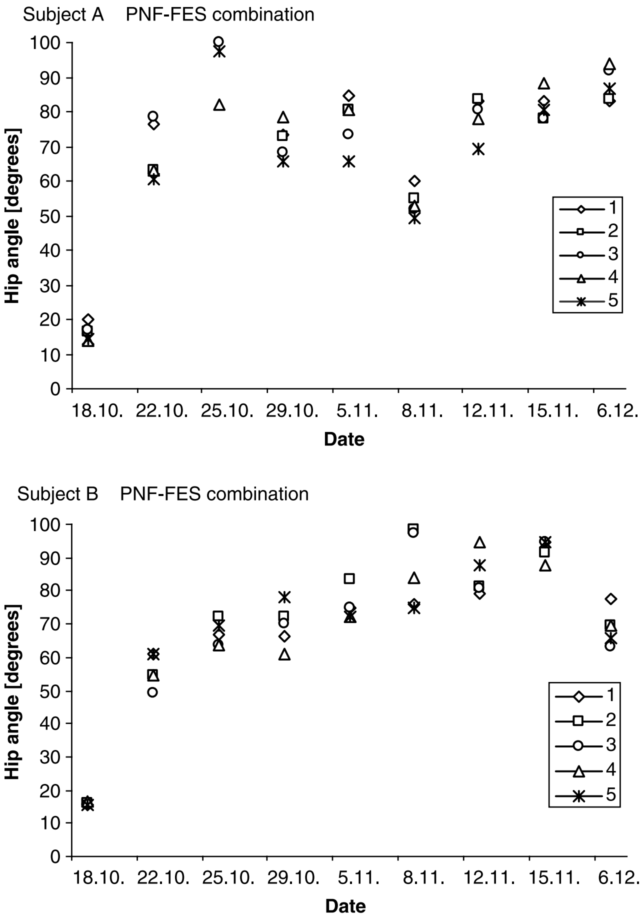

Fig. 5. Single values of maximum angles for the hip at various dates for PNF-FES combined activity. The numbers in the legend represent the order of sequence in the experiment.

proved to be equal or somewhat better than the best of the other three activities.

DISCUSSION AND CONCLUSIONS

From Fig. 3 one can observe a steady increase in all three angles up to the maximum value, which is then followed by a steady decrease. The first part of the movement, when angles increase appears to be finished at the time of ~4 s, when movement towards the initial state begins. The fourth graph in Fig. 3 shows the amplitude modulation of the electrical stimulation, which was mainly utilized for ramping up at the start and at the end of the movement and for synchronization with voluntary movement. All trials show similar trends, and this particular trial was randomly selected from the data library.

For the calculated average values (Fig. 4), hip angle represents the most significant parameter, demonstrating noticeable improvement for all types of activities during the first week and minor increase or variability in range of motion in the second week of training and after. Towards the end of treatment one can observe fluctuations in Subject B and moderate improvement in Subject A. No further improvement was noticed in the last verification measurement in comparison to the status after the second week. In general, considerable variability can be noticed between the dates. Because the measurement equipment and procedures were uniform throughout the study period, the variations could be attributed to the subjects.

When comparing various types of activity, voluntary activity seems to be nearly equal to PNF exercise (Subject A). For Subject B, voluntary activity was inferior to PNF and comparable to the results of FES only. During our study, FES activity produced lower values for the hip with two exceptions for Subject B. Here it should be noted that the adjustment of the FES amplitude was based on visual observation of muscle response and in accordance with the sensations reported by the subject.

As observed, the PNF technique leads to a comparable (Subject A) or greater range of motion than the voluntary technique (Subject B). Following the data in Fig. 4 for both subjects, we can state that the greatest angular response for the hip was obtained with the PNF-FES combination at most dates. Except for one date for Subject A and two dates for Subject B the combined exercise yielded at least 10 degrees greater response than any other type of activity. The benefit of combined activity is even as much as 20 degrees for Subject B (dates October 22, October 25, first and second measurement in the second week) and 30 degrees for Subject A (date October 22). The improvement measured in hip angle during the first week was 80 degrees (Subject A) and 40 degrees (Subject B). The hip angle in our study seems to be the best indicator that the PNF-FES combination is the activity that shows the most significant improvement.

This improvement demands closer examination of the PNF-FES combination data in Fig. 5. Due to value overlapping, it is difficult to distinguish all five bullet types for all five trials for some dates. The most extreme example is the first date for

Subject B, where all trials produced the same response. The next observation is associated with experimental sequence with the annotated numbers and bullet symbols in the legend. If there were a noticeable influence of fatigue in one day and again in some other experimental day, then the bullets for these days would form vertically the same repeatable pattern of circles, triangles and other shapes. Figure 5 could not confirm this, meaning that the acquired values were likely not influenced by fatigue. Next, the spread of the data points should be checked. For Subject A, for five out of nine dates the difference between minimum and maximum value is approximately 10 degrees, and for the four trials it is in the range of 20 degrees. For Subject B, seven out of nine dates show a difference lower than 10 degrees, and the other two measurements show a difference up to 20 and 30 degrees.

For the measured values of the knee and ankle data at various dates (not shown here) and for all four types of activity, none of the activities showed themselves to be superior. This could be explained by recalling that the PNF pattern used flexion, adduction, and external rotation in the hip, knee flexion, and dorsiflexion with inversion in the ankle. Considerably larger responses were obtained in the hip than in the knee and ankle joints. When observing the PNF-FES combination, the nature of the flexion withdrawal reflex must be considered (17). On one hand a nonconstant amplitude and reflex habituation both introduce variability into responses (22). On the other hand, this reflex is predominantly used to accomplish the swing phase of walking, where strong hip flexion works against gravity and the inertial components of the entire leg.

In the final analysis, it is fair to say that the experimental data on the two subjects in this study demonstrate that the PNF-FES combination is equal or better when compared to pure voluntary movement, or PNF or FES activation only when regarding the range of movement in the hip joint at the beginning of the training period. This improvement was very rapid in the first week of training, and later on fluctuated for Subject A and showed moderate improvement for Subject B. The results for the final assessments after approximately two months of training (Fig. 4) show that the PNF-FES combination in comparison to other activity showed somewhat lower values in comparison to previous sessions, but still produced the greatest range of motion in the hip among all activities for that date. Because of the encouraging results, the therapeutic combination was well received by patients and therapists.

ACKNOWLEDGMENT

We appreciate kind support from Prof. Dr Martin Štefančič, MD and Tatjana Škorjanc, MD on the clinical side and Imre Cikajlo, Univ. Dipl. Ing. at the computer desk.

REFERENCES

1. Kabat H. Studies on neuromuscular dysfunction, XV; The role of central facilitation in restoration of motor function in paralysis. *Arch Phys Med* 1952;33: 521–533.

2. Knott M. Introduction to and philosophy of neuromuscular facilitation. *Physiother* 1967;53:2–5.

3. Sherrington C. *The Integrative Action of the Nervous System*. New Haven: Yale University Press, 1947.

4. Adler S, Beckers D, Buck M. *PNF in Practice an Illustrated Guide*. Berlin: Springer Verlag, 1993.

5. Shimura K, Kasai T. Effects of proprioceptive neuromuscular facilitation on the initiation of voluntary movement and motor evoked potentials in upper limb muscles. *Hum Mov Sci* 2002;21:101–113.

6. Griffin WJ. Use of proprioceptive stimuli in therapeutic exercise. *Phys Ther* 1974;54:1072–1078.

7. Sady PS, Wortman M, Blanke D. Flexibility training: ballistic, static or proprioceptive neuromuscular facilitation. *Arch Phys Med Rehabil* 1982;63:261–263.

8. Kasai T, Kawanishi M, Yahagi S. Evidence of facilitation of motor evoked potentials (MEPs) induced by motor images. *Brain Res* 1996;744:147–150.

9. Entyre BR, Abraham LD. H-reflex changes during static stretching and two variations of proprioceptive neuromuscular facilitation techniques. *Electroencephal Clin Neurophysiol* 1986;63:174–179.

10. Romano C, Schieppati M. Reflex excitability of human soleus motoneorons during voluntary shortening or lengthening contraction. *J Physiol (London)* 1987;390:271–284.

11. Smith JL, Hutton RS, Eldred E. Postcontraction changes in sensitivity of muscle afferents to static and dynamic stretch. *Brain Res* 1974;78:193–202.

12. Weiss PL, Kearney RE, Hunter IW. Position dependence of stretch reflex dynamics at the human ankle. *Exp Brain Res* 1986;63:49–59.

13. Prochazka A, Gorassini M, Taylor J. Adaptive control of proprioreception. In: Jami L, Pierrot-Deseilligny E, Zytnicki O, eds. *Muscle Afferents and Spinal Control of Movement*. New York: Pergamon Press, 1992: 129–136.

14. Furubayashi T, Kasai T. Influence of initial forearm position on premotor times (PMTs) of the biceps brachii during an elbow flexion task. *Hum Mov Sci* 1990;9:583–598.

15. Pink M. Contralateral effects of upper extremity proprioceptive neuromuscular facilitation patterns. *Phys Ther* 1981;61:1158–1162.

16. Moore AM, Hutton RS. Electromyographic investigation of muscle stretching techniques. *Med Sci Sports Exer* 1980;12:322–329.

17. Kralj A, Bajd T. *Functional Electrical Stimulation: Standing and Walking After Spinal Cord Injury*. Boca Raton. FL: CRC Press, 1989.

18. Obreza P, Munih M, Benko H. Proprioceptive neuromuscular facilitation with electrical stimulation. In: *Proceedings of the 3rd International Conference on Bioelectromagnetism*. Bled, Slovenia. 2000: 209–210.

19. Obreza P, Šega J, Munih M, Bajd T, šavrin R. PNF with electrical stimulation. In: *Proceedings of the 6th International Functional Electrical Stimulation Society Conference*. Ljubljana, Slovenia. 2002: 335–337.

20. Munih M, Obreza P, Ott E, Benko H. PNF electrical stimulator. In: *Proceedings of the 4th International Functional Electrical Stimulation Society Conference*. Sendai, Japan. 1999: 167–168.

21. Ott E, Munih M, Kralj A. Voluntary controlled peroneal stimulator. In: *Proceedings of the International Conference of the IEEE Engineering in Medicine and Biology*. Atlanta, GA. 1999: 661.

22. Granat MH, Heller BW, Nicol DJ, Baxendale RH, Andrews BJ. Improving limb flexion in FES gait using the flexion withdrawal response for the spinal cord injured person. *J Biomed Eng* 1993;15:51–56.