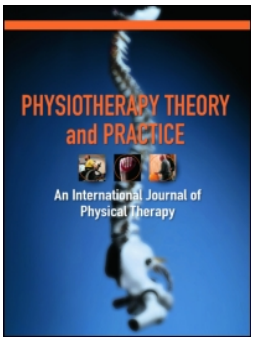

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RESEARCH REPORT

An electromyographic investigation of the pattern of overflow facilitated by manual resistive proprioceptive neuromuscular facilitation in young healthy individuals: a preliminary study

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Abstract

Aim: To investigate the pattern of overflow facilitated by the use of resistive proprioceptive neuromuscular facilitation (PNF). *Method*: In a group of 12 young, healthy individuals, recruitment of electrical activity into the tibialis anterior (TA) muscle of the right lower limb (RLL) was assessed using surface electromyography (sEMG) during a random-sequence application of manually-resistive PNF to the other three limbs. *Results*: Resistance exercise applied to the left lower limb (LLL) was associated with a considerable increase in sEMG activity in the RLL TA muscle compared to its baseline level ($p = 0.001$). Resistance exercise applied to the right or left upper limbs (RUL or LUL) respectively showed similar sEMG activity in RLL TA muscle to its baseline level. *Conclusion*: A resistance exercise would appear to be effective in producing electrical activity in the contralateral homologous muscles of non-exercised limb.

Keywords

Electromyography, irradiation, muscle stretching exercises, overflow, proprioception

History

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Introduction

Proprioceptive neuromuscular facilitation (PNF) has been one of the most recognized treatment concepts in physiotherapy since the 1940s. This dynamic manual approach for the evaluation and treatment of patients with lesions in the neuromusculoskeletal system was originally described by Herman Kabat and Margaret Knott in 1947, as a treatment regime for encouraging maximum recruitment of the patients' reserves and was designed as an intensive functional training program (Kabat, 1950). Voss (1967) suggested that PNF may promote neuromuscular function through the stimulation of proprioceptive mechanisms using various combinations of movement patterns. The PNF patterns combine motion in the sagittal, coronal and transverse planes producing a movement that is ''spiral and diagonal'' (Knott and Voss, 1968). Resistance, one of the basic procedures used in PNF, is defined as ''the amount of resistance provided during an activity in order to produce a smooth coordinated movement'' (Adler, Beckers, and Buck, 2008). If specifically applied, the resistance can result in irradiation (overflow) to other muscle groups and their reinforcement (Adler, Beckers, and Buck, 2008). Kabat, McLeod, and Holt (1959) wrote that it is resistance to motion that produces irradiation, and the spread of muscular activity will occur in specific patterns. In the original PNF concept, resistance was always applied manually allowing the therapist to alter the resistance according to the response of the patient. Today, patients may also be instructed to self-resist using weight and pulley systems or specialized rubber tubing. The increased muscular activity in the exercised limb and other parts of the body produces an impulse which is measurable by surface electromyography (sEMG) (Sullivan and Portney, 1980). Axial rotation is the key component to effective resistance and correct resistance will strengthen the entire pattern of movement (Adler, Beckers, and Buck, 2008). Adler, Beckers, and Buck (2008) described the current principles of PNF, as being a combined approach, with each treatment being directed towards the functional rehabilitation of the patient and not towards a specific body segment. The treatment is directed towards attaining the highest level of function for the patient (Adler, Beckers, and Buck, 2008; Knott and Voss, 1968).

The mechanisms underlying the dynamic effects of PNF as a rehabilitation technique remain unclear. Verification exists for the recruitment of contralateral homologous muscles (Carroll et al, 2006; Fog, 1949; Hortobágyi, 2005); however, there is limited evidence to substantiate the occurrence of overflow or the facilitation of a wider spread effect from the stronger to weaker muscle groups using specific PNF procedures.

In this article, we aim to provide objective evidence that the use of resistive PNF patterns of movement to one limb facilitates the recruitment of muscle activity into the homologous muscles of the non-exercised limb.

Methods

Subjects

A convenience sample of 12 young, healthy volunteers, 10 of whom were female, was recruited for this study from the staff of the physical therapy department of the hospital. In Israel, there are more female than male therapists who choose to work in a hospital setting rendering a relatively high female-to-male ratio in the participants of this study. Eleven of the 12 participants recruited to this study were qualified physical therapists; the remaining subject was an alternative therapist specializing in Chinese Medicine. Details of subjects included in this study are

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shown in Table 1. Ethics approval was granted by the Helsinki Committee of the Reuth Medical Centre, Tel Aviv, Israel. All participants signed an informed consent form.

Procedure

An intervention study was undertaken to assess the level of recruitment and pattern of overflow of electric activity into the tibialis anterior (TA) muscle of the non-exercised right lower limb (RLL), using sEMG when applying a specific PNF pattern (D2 Flexion) and the hold-relax-active-movement (HRAM) technique (Sullivan, Markos, and Minor, 1982) in random order to the other three limbs: (i) left lower limb (LLL); (ii) left upper limb (LUL) and (iii) right upper limb (RUL). The D2 (Flexion) pattern was specifically chosen because in the lower limb we particularly wanted to facilitate eversion in the ankle together with dorsiflexion. For conformity, we also used the D2 (Flexion) in the upper limb. The HRAM technique was applied because it has a particular effect on strengthening muscles and producing overflow (Markos, 1979).

The D2 (Flexion) pattern as described by Sullivan, Markos, and Minor (1982) and as applied in this study, is operationally defined as flexion, abduction with external rotation in the upper limb and flexion, abduction and internal rotation in the lower limb with dorsiflexion and eversion at the foot. The technique HRAM is operationally defined as the patient first being asked to hold a graded, manually resisted isometric contraction in the mid-to-shortened ranges of a pattern into which he/she has been placed. When the therapist resisting the movement in mid-range decides that the contraction is optimal the subject is then given a command to relax. The therapist quickly moves the limb into the lengthened range of the pattern of weakness and applies a quick stretch or repeated stretches to the same pattern. Using the dynamic verbal commands ‘‘fingers and wrist up and turn your hand, bend your arm and bring your hand towards your mouth’’ for the upper limb or ‘‘toes and foot up, turn your heel out and bend your knee’’ for the lower limb, the patient is instructed to return to the more shortened range (Sullivan, Markos, and Minor, 1982).

The treating therapist is a qualified physical therapist with over 40 years of experience in treating neurological patients. She was trained in the PNF approach at the Kaiser Rehabilitation Center, Vallejo, CA. She is extremely skilled in the PNF concept and practice of these techniques having developed post-graduate workshops and undergraduate courses in PNF both nationally and internationally for more than three decades.

All subjects were lying supine on the treatment bed and the PNF pattern and technique described were applied in random order to the RUL, LUL and LLL. The manual contacts and positioning of the therapist are as shown in Figures 1 and 2. The HRAM as described was repeated three times to each of the exercised limbs.

RLL was chosen as the control limb throughout the study and therefore not actively exercised. The electromyographic sensors were positioned on the belly of the RLL TA muscle on a line between the head of the fibula and the medial malleolus according to the European recommendations for sensors and sensor placement procedures and signal processing methods for sEMG at 2 cm inter-electrode interval (Cram, Kasman, and Holtz, 1998; Hermens et al, 1999). Three repetitions were performed on each limb using the technique described (as shown in Figures 1 and 2) and sEMG activity was recorded for 8 s during the hold stage of

Table 1. Characteristics of individuals included in this study.

Characteristics	Value
Number	12
Females	10 (83%)
Dominance (right)	10 (83%)
Age (years)	23.8 ± 5.8
Height females (cm)	168.0 ± 4.6
Weight females (kg)	61.4 ± 5.9
BMI females (kg/m^2)	21.8 ± 2.3
Height males (cm)	181.0 ± 2.8
Weight males (kg)	82.0 ± 2.8
BMI males (kg/m^2)	25.1 ± 0.1

Nominal variables are presented as numbers, while continuous variables are presented as mean ± standard deviation.

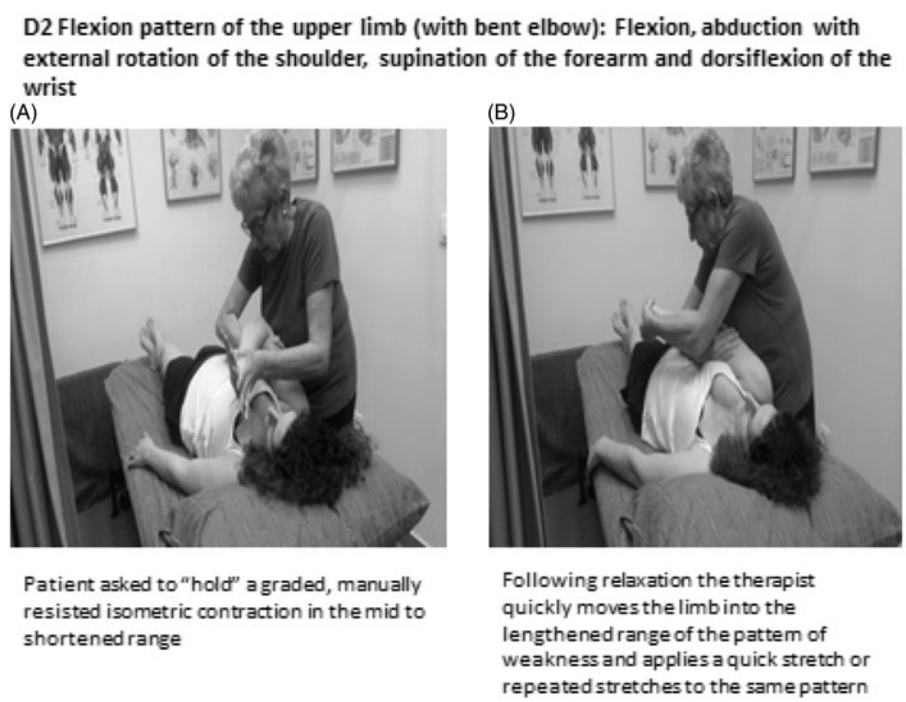

Figure 1. Upper extremity patterns of movement.

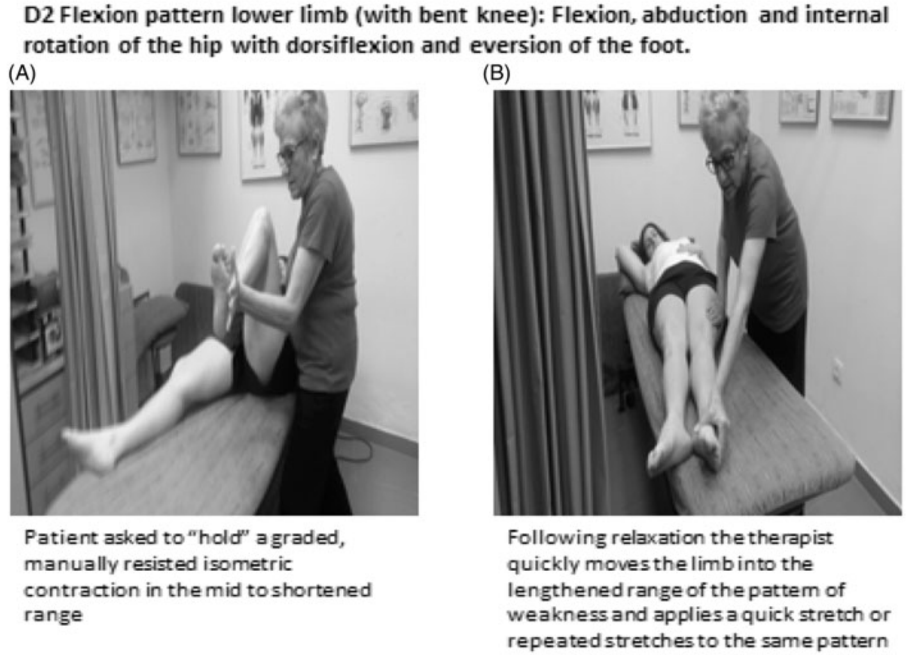

Figure 2. Lower extremity patterns of movement.

the exercise. The mean sEMG activity of the passive RLL (overflow) was calculated during the middle 6 s of hold. In order to compare the results between subjects, we normalized the sEMG values using the submaximal isometric contraction method (Cram, Kasman, and Holtz, 1998). Before beginning the PNF patterns all subjects were asked to stand on their heels for 3 s, in-order to acquire a sub-maximal isometric contraction measure to be used for normalization (the participants hands were lightly held so that they could retain balance). The average sEMG activity during the 2nd second was used as the reference value. The normalized values were computed as a percentage of the mean sEMG obtained during the application of the PNF patterns divided by the values obtained while standing on heels.

Equipment

sEMG was used to determine the presence of electrical activity in the non-exercised muscle. The muscular activity was monitored with the ProComp/BioGraph device (Thought Technology Ltd., Quebec, Canada) with specifications as follows: input impedance, 1 000 000 mega-ohm (MΩ); bandwidth, 20–500 hertz (Hz); input range, 0–400 microvolts (μV) root mean square (RMS); accuracy, ±0.3 μV RMS and sampling frequency of the EMG was 32 Hz. The sEMG sensor with an integrated pre-amplifier and the silver chloride (AgCl) electrodes were placed at 2 cm inter-electrode interval on the TA muscle as previously described (Cram, Kasman, and Holtz, 1998; Hermens et al, 1999).

Statistical analysis

Data were tested for normality using the Kolmogorov–Smirnov test. Due to normal distribution of the data, the one-way analysis of variance (ANOVA) was used to assess differences of normalized sEMG activity in RLL TA during activation of LLL, LUL or RUL-to-RLL baseline. Additionally, *post-hoc* testing was performed using the Student–Newman–Keuls test for pairwise comparisons. Statistical significance was defined at the conventional 5% level. All computations were performed using the SPSS statistical package v.17.0.2 (SPSS Inc., Chicago, IL). The *post-hoc* power calculation was performed using the PS (Power and Sample Size Calculation version 3.1.2 software, WD Dupont and WD Plummer, Nashville, TN) (Dupont and Plummer, 1990).

Table 2. Kolmogorov–Smirnov test.

Normalized sEMG	*N*	Mean (%)	SD	*p* value
Baseline	12	0.54	0.36	0.960
LLL	12	19.17	16.00	0.754
LUL	12	0.74	0.61	0.289
RUL	12	0.57	0.46	0.671

N, number of individuals; SD, standard deviation.

Results

The sEMG activity was measured in 12 young subjects (mean age = 23.83 ± 5.75 years) of whom 10 (83%) were females and 10 (83%) had right hand/foot dominance. All individuals had BMI ≤ 25 kg/m^2 (Table 1). The sEMG data were normalized using the mean sEMG activity in RLL TA when standing on heels and were presented as a percentage. Mean normalized baseline sEMG activity in RLL TA muscle was 0.54 ± 0.36% (Table 2). Mean normalized sEMG activity in RLL TA muscle during the activation of LLL, LUL and RUL was 19.17 ± 16.00, 0.74 ± 0.61 and 0.57 ± 0.46%, respectively (Table 2). Kolmogorov–Smirnov test indicates that data in all categories assessed were normally distributed ($p > 0.05$; Table 2). The one-way ANOVA indicates that there were significant differences between the stimulation of LLL, LUL, RLL and baseline in the RLL TA sEMG (F-ratio = 16.09, $p < 0.001$). In order to investigate which particular stimulation was significantly different from the baseline, *post-hoc* test was performed using Student–Newman–Keuls test. The *post-hoc* test results are shown in Figure 3. The stimulation of LLL was associated with marked increase in sEMG activity in RLL TA compared to the RLL TA sEMG baseline ($p = 0.001$; *post-hoc* power = 98.1%). No other significant differences were observed (Figure 3).

Discussion

The main finding of this study is that when a resistance exercise is applied in random order to three of the four limbs, overflow of the sEMG activity is observed predominantly in the contralateral homologous muscles in young, healthy individuals. Earlier studies have suggested that it is resistance to motion that produces

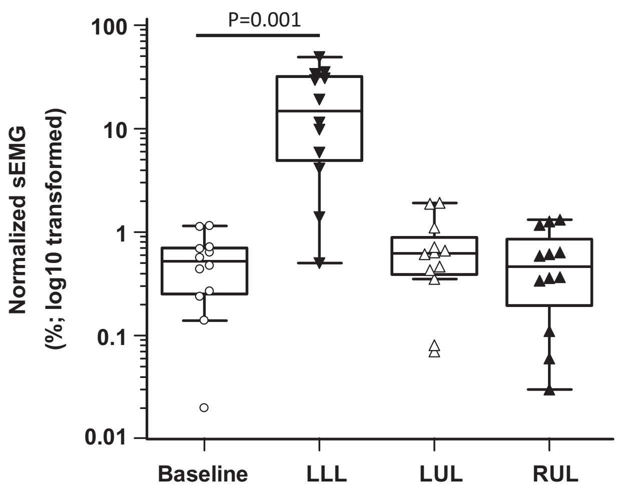

Figure 3. Comparison of the sEMG activity in RLL TA muscle during activation of the remaining three limbs to its baseline. Normalized sEMG values are plotted. Data are expressed as median and interquartile range with maximum and minimum data points (whiskers). *p* value by Student–Newman–Keuls test for pairwise comparison.

overflow, and the spread of the muscular activity will occur in specific patterns (Kabat, McLeod, and Holt, 1959). It has been demonstrated that the proprioceptive reflexes from contracting muscles increase the response of synergistic muscles at the same joint, and depending upon the amount of resistance may also increase the response of associated synergists around neighboring joints (Loofbourrow and Gellhorn, 1949). Our observations of PNF-mediated contralateral overflow are in accord with previous findings supporting the theory that the non-exercised contralateral limb becomes active during the exercise (Carroll et al, 2006; Markos, 1979; Pink, 1981). It has been suggested that this phenomenon could be associated with the cross education and homologue connectivity both centrally and peripherally (Birbaumer, 2007; Carroll et al, 2006; Hortobágyi, 2005). Accordingly, Chan (1984) and Shimura and Kasai (2002) suggested that the adoption of PNF patterning and resisted activity would appear to enhance this response. In addition, diagonal resistance has been shown to be more efficient than straight line resistance, possibly due to the biomechanical readjustments that are required to stabilize the body (Pink, 1981; Shimura and Kasai, 2002).

The current study has a number of limitations. The available sample size was relatively small, and the majority of participants were women limiting the relevance of our findings to men. Since the majority (11 out of 12) of the participants were physical therapists, they were familiar with the concept of PNF and the spiral and diagonal patterns of movement, but they were not aware of the pattern of overflow. In view of the fact that this study was a preliminary investigation prior to the possible use of these techniques with stroke patients it was decided to concentrate on the pattern which would directly oppose the plantar flexion–inversion pattern usually seen in the lower limb of stroke patients. We therefore used the D2 (Flexion) pattern as described by Sullivan, Markos, and Minor (1982) in both upper and lower limbs, a pattern which would produce dorsiflexion at the ankle together with eversion of the foot. Although we were interested in both dorsiflexion and eversion at the ankle we assessed only the sEMG of the TA. As fibularis longus (FL) is the primary evertor of the foot, it would have been useful to have sampled the sEMG of this muscle also. It is important to note that our findings are founded on healthy individuals, thus the potential therapeutic implications of our findings warrant further investigations in other contexts (e.g. patients with compromised mobility). The use of alternative control to RLL such as RUL or LUL also would be useful to ensure the generalizability of the findings. Furthermore, we observed a relatively high amount of variation from the mean overflow in our group of individuals suggesting a variability of muscle recruitment between subjects when the resistance exercise was applied. Finally, although the maximum sampling rate provided was relatively low (32 Hz), it has been shown that the average sEMG amplitude and total sEMG area are not significantly affected when down sampled (Ives and Wigglesworth, 2003). Since we aimed to investigate the average recruited amount of overflow recorded during the stable part of an isometric contraction (the mid-section), the low temporal resolution was adequate to evaluate which of the exercised limb/s was most likely to initiate overflow to the RLL TA muscle during the D2 (Flexion) pattern performed on the RUL, LUL and LLL.

Practical application

Outcomes from this study suggest that the contralateral strengthening effect described in the literature can be enhanced using PNF procedures. Although the overflow phenomenon is present throughout the whole body, stimulation of one lower limb will predominantly enhance muscle activity in the contralateral lower limb. These techniques may be of use in the rehabilitation of a wide range of patients with diverse pathologies, such as stroke, incomplete paraplegia or tetraplegia or those patients with complex regional pain syndrome (CRPS).

The results of this study can also be effective in preventing possible complications that may arise following long-term immobilization of limbs due to fracture or burns. It can be seen that by exercising the homologues muscle groups in patterns of functional movement disuse atrophy of the affected muscle groups may be minimized.

Declaration of interest

The authors report no declarations of interest.

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