ORIGINAL ARTICLE

Surface electromyography analysis of contralateral muscle irradiation in proprioceptive neuromuscular facilitation

Análise através da eletromiografia de superfície da irradiação muscular contralateral na facilitação neuromuscular proprioceptiva

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Abstract

Introduction: Proprioceptive neuromuscular facilitation (PNF) is a concept that promotes functional movement through facilitation, inhibition, strengthening, and relaxation of muscle groups. Among its principles, irradiation is defined as the propagation of the response to the stimulus, which can be evidenced as increased contraction or relaxation in synergistic muscles and movement patterns. **Objective:** To evaluate PNF patterns in muscle irradiation to the contralateral lower limb through surface electromyography in physical therapy students. **Methods:** This is a cross-sectional study with a quantitative and analytical approach. Thirty healthy volunteers participated in the study and were evaluated with surface electromyography as they performed PNF and rectilinear movement patterns. **Results**: It was found that PNF patterns radiate to the contralateral limb, with the flexion-abduction-internal rotation pattern with knee flexion being statistically significant ($p < 0.05$). It was observed that the upper patterns do not significantly irradiate to the contralateral limb when compared with lower limb movements (LL). In the correlation between strength and electromyographic activation, the medial gastrocnemius obtained the greatest strength and the lowest muscle activation in movements involving hip or shoulder flexion. **Conclusion:** PNF diagonals irradiate to the LL contralateral to that tested in the electromyography. New studies with a larger sample size are needed to investigate contralateral muscle irradiation in healthy individuals through surface electromyography in order to obtain a more robust correlation.

Keywords: Health research evaluation. Muscle strength. Stretching exercises. Electromyography.

Resumo

Introdução: *A facilitação neuromuscular proprioceptiva (PNF) é um conceito que promove o movimento funcional por meio da facilitação, inibição, fortalecimento e relaxamento dos grupos musculares. Entre seus princípios, a irradiação é definida como a propagação da resposta ao estímulo, podendo ser evidenciada como o aumento da contração ou relaxamento nos músculos sinérgicos e padrões de movimento.* ***Objetivo:*** *Avaliar os padrões de PNF na irradiação muscular para o membro inferior contralateral através da eletromiografia de superfície em estudantes de fisioterapia.* ***Métodos:*** *Trata-se de um estudo transversal com abordagem quantitativa e analítica. Participaram do estudo 30 voluntários saudáveis avaliados com eletromiografia de superfície à medida que realizaram os padrões de PNF e movimento retilíneo.* ***Resultados:*** *Verificou-se que os padrões de PNF irradiam para o membro contralateral, sendo estatisticamente significativo ($p < 0,05$) o padrão de flexão-abdução-rotação interna com flexão do joelho. Observou-se que os padrões superiores não irradiam significativamente para o membro contralateral quando comparados com movimentos de membro inferiores (MMII). Na correlação entre força e ativação eletromiográfica, o gastrocnêmio medial obteve a maior força e a menor ativação muscular nos movimentos que envolvem flexão de quadril ou de ombro.* ***Conclusão:*** *Diagonais de PNF irradiam para o MMII contralateral ao testado na eletromiografia. É necessário que novos estudos com um maior "n" amostral investiguem através da eletromiografia de superfície a irradiação muscular contralateral em indivíduos sadios para que se obtenha uma correlação mais robusta.*

Palavras-Chave: *Avaliação da pesquisa em saúde. Força muscular. Exercícios de alongamento. Eletromiografia.*

Introduction

Proprioceptive neuromuscular facilitation (PNF) is a treatment concept widely adopted by physiotherapy, which seeks to promote functional movement through the facilitation, inhibition, strengthening and relaxation of muscle groups.[1-3] In addition, it aims to improve the performance of the neuromusculoskeletal system through the stimulation of muscular and joint proprioceptors, using movement patterns that make up mass movements and muscle synergism. Such patterns are used as tools in the search for improvements in muscle strength, range of motion and pain relief.[4]

Among the principles of PNF, irradiation is defined as the spread of the response to the stimulus and can be evidenced as increased contraction or relaxation in synergistic muscles and movement patterns. The response is amplified as the stimulus grows in intensity or duration. The effects of irradiation are clinically relevant for patients with limitations due to neurological pathologies, representing a treatment option to maintain or improve the muscular activity of the injured limb, decreasing the complications caused by muscle weakness and disuse.[5]

Studies highlight the use of PNF patterns to benefit extension movements, grip strength, spasticity, dexterity in functional tasks and satisfaction of patients who have suffered cerebrovascular accident.[6-8] These patterns are executed in a diagonal and spiral direction, promoting harmony with the characteristics of the musculoskeletal system and alignment with the topographic arrangement of the muscles.[9,10]

Abreu et al.[11] carried out one of the remarkable studies in the evaluation of irradiation in PNF through electromyographic analysis, in which they investigated the effect of irradiation on the hemiplegic upper limb. The results indicated progress in muscle activations after a single training session in hemiplegic patients, both in the acute and chronic phase, especially in a certain positioning of the affected limb.

Surface electromyography is an important evaluation method used in research to validate quantitative studies aimed at investigating muscle activation during functional movements and therapeutic exercises, using electrodes positioned on the skin surface corresponding to the muscle region to be analyzed.[12]

However, there are still few studies that investigate the best pattern for activation of the muscle group of the quadriceps and triceps sural, which are responsible for maintaining the functionality of the lower limb.[13] In this context, the study of the principle of irradiation in PNF standards is necessary to understand the best way to use this principle. If it is effective, this resource can influence the functional progress of some pathologies, besides reducing muscle weakness, preventing atrophy and contributing to the gain in range of motion as well as improving the pain.

The objective of this study was to evaluate, by means of surface electromyography and muscle strength of a maximal isometric voluntary contraction (MIVC), the PNF patterns in muscular irradiation to the contralateral limb and correlate with rectilinear movement in physiotherapy students.

Methods

This study adopts a cross-sectional quantitative analytical approach. The non-probabilistic sample by convenience consists of healthy students from a physiotherapy course at a public university in Teresina-Piauí, aged between 18 and 35 years.

Individuals with orthopedic, cardiovascular, psychiatric or neurological impairment that prevented the execution of the study procedures were not included. Participants who, during the period of data collection, faced complications that made it impossible to move or perform surface electromyography were excluded, as well as those who decided to abandon the study. Thus, the study was conducted with 30 participants.

The project received approval from the Research Ethics Committee of the State University of Piauí (CAAE: 55804622.2.0000.5209). All participants were duly informed about the research procedures and signed a consent form, which was also signed by the researchers.

Data collection

Data were collected between September and December 2022. Each participant was approached individually and submitted to the procedures in the following order: analysis of body composition; familiarization of the movements to be evaluated; preparation for the placement of electrodes; MIVC through the load cell of the surface electromyography of the muscles rectus femoris (RF), medial vastus (MV), lateral vastus (LV) quadriceps and lateral gastrocnemius (LG) and medial gastrocnemius (MG) on the dominant side of each participant; and, finally, realization of the straightened hip flexion movement and PNF patterns. The anthropometric variables initially collected included body mass, height and body mass index (BMI).

After the collection of anthropometric variables, an electromyographic analysis of the quadriceps and medial and lateral gastrocnemius was performed using the previously calibrated electromiograph (EMG System of Brazil®). The recording of electromyographic signals strictly followed the guidelines of the SENIAM project.[13]

Prior to the fixation of surface electrodes (pre-amplified active bipolar, Ag-AgCl, with diameter of 1 cm and adhesive), the area was treated with a disposable shaving device (Gillette®) and the skin was cleaned with 70% alcohol, in order to remove fatty residues. The electrodes were then fixed with adhesive to prevent slip artifacts during muscle contraction.

A reference electrode was fixed in the olecranon of the dominant upper limb to eliminate external noise, acting as ground wire. The collection of the electromyographic signal was made first at rest and then during the execution of active movements and PNF patterns. After the allocation of electrodes, the signals of electromyography were normalized according to the MIVC of the muscles analyzed.

For the evaluation of MIVC and electrical activity of muscles, the volunteers were first seated in a chair with backrest, knees and ankles bent at 90°. For the analysis of medial and lateral gastrocnemius muscles, participants were placed in supine position with their ankles extended beyond the edge of the table and positioned at 20° dorsiflexion.

Two disposable and surface electrodes were placed on the skin in the RF, MV, LV, LG and MG muscle regions, according to SENIAM standards.[13] For each signal capture, the patient was asked to perform two maximal voluntary isometric quadriceps contractions (extension of the knee) and gastrocnemius (planflexion) for 10 seconds with verbal stimulus, followed by a rest period of 2 to 3 minutes between each contraction.[14] Thus, the participant lying in supine position, performed the rectilinear movement of hip flexion from the contralateral side, maintaining an isometric position for 10 seconds. The interval between the first and second electromyographic examination was 3 to 5 minutes, according to literature recommendations.[15]

PNF patterns are mass synergistic movements, executed diagonally and are components of normal functional movement. For the recording of electromyography, the participants were positioned in the final position of the PNF pattern and an isometric contraction was requested with the command "do not let me move you". The applied patterns were selected based on their recurrence in the literature (Table 1).[16] As in the execution of the rectilinear movement, the intervals recommended by the literature between the repetitions of the electromyographic examinations during the performance of the PNF patterns were respected.[17]

Data analysis

Data were tabulated and categorized into anthropometric measures and electromyographic variables of the highest value between the two repetitions performed for each movement, with average and standard deviation calculations performed in Microsoft Office Excel, version 2016.

The subsequent statistical analysis was conducted using BioEstat 5.0 software for Windows systems. The normality of the data was initially verified by the Shapiro-Wilk test. As the muscle strength data and electromyographic records did not follow a normal distribution, the Spearman correlation test was used to evaluate correlations between these measures. The correlation values were interpreted as follows: above 0.7 = strong correlation; between 0.4 and 0.6 = moderate correlation; and be-tween 0.1 and 0.3 = weak correlation.[18]

For the comparison of muscle activation between different diagonals and rectilinear movement, the Friedman test was applied to related samples. In all analyses, a significance level of $p < 0.05$ was considered.

Table 1 - Proprioceptive neuromuscular facilitation patterns evaluated

Diagonal	Segment	Movement pattern
1	Lower limb	Hip flexion, abduction and internal rotation with knee flexion on the contralateral limb
2	Lower limb	Hip extension, adduction and external rotation with knee extension
3	Upper limb	Shoulder flexion, abduction and external rotation
4	Upper limb	Extension, adduction and internal rotation on the side contralateral to the electrode application

Results and discussion

The data of 30 volunteers were recorded, of which 23 were female and 7 male, with average age of approximately 21 years and mean BMI of about 22.

Table 2 shows the correlation between specific muscle strength (MIVC) and electromyographic activity during exercises of the patterns performed in the study.

It was observed that the greater the strength of the RF muscle on the dominant side, the greater the electromyographic activity during the exercise of the diagonal 1. On the other hand, it was found that the higher the strength of the GM, the lower the that is, diagonals 1, 3 and rectilinear motion. Thus, it is suggested that individuals with lower strength in the gastrocnemius may increase electromyographic activity during contralateral training, which induces more irradiation.

This observation may be related to the anatomical and physiological properties of the muscle, which influence its adaptive response to different training protocols. As discussed by Schoenfeld et al.,[19] muscles with different fiber compositions and structural characteristics may present variations in hypertrophy and functional adaptation under different mechanical stimuli. Factors such as fascicular length, penation angle and distribution of fast and slow contraction fibers play a key role in training response, which may explain differences in adaptation between specific muscles.

Table 2 - Correlation between muscle strength of a maximal voluntary isometric contraction and muscle activation obtained during diagonals of proprioceptive neuromuscular facilitation and rectilinear movement

Muscle	Proprioceptive neuromuscular facilitation				Rectilinear movement
	Diagonal 1	Diagonal 2	Diagonal 3	Diagonal 4	
Rectus femoris	0.5907*	0.2552	0.3295	0.1177	0.2752
Vastus medialis	0.0732	-0.0900	-0.0650	-0.2120	-0.1180
Vastus lateralis	0.2925	0.2908	0.2276	-0.0630	0.3019
Gastrocnemius medialis	-0.3878*	-0.3580	-0.4189*	-0.2130	-0.4096*
Gastrocnemius lateralis	-0.0740	0.0816	-0.0840	-0.0350	-0.0030

Note: $^*p < 0.05$.

It is assumed that, similar to gastrocnemius, the electromyographic activity of the postural muscles decreases as the strength of these muscles increases. This indicates that the postural muscles may become more efficient as they strengthen, which could be relevant in preventing posture-related injuries.[20,21]

In the present study, electromyographic activity was observed in all PNF patterns and linear movement ($p < 0.05$), indicating that both diagonal and rectilinear movements induce muscular activation in the contralateral limb, as shown in Table 3.

According to Folland and Williams,[22] neurological and morphological mechanisms contribute to the increase of muscle strength resulting from strength training, in addition to neural activation, which can be improved through unilateral training, and present transverse effects to improve muscular activation of the contralateral limb.

Table 3 - Mean (standard deviation) of muscle electrical activation during the execution of proprioceptive neuromuscular facilitation diagonals and rectilinear movement

Muscle	Proprioceptive neuromuscular facilitation				Rectilinear movement
	Diagonal 1	Diagonal 2	Diagonal 3	Diagonal 4	
Rectus femoris	51.9 (72.8)	26.9 (33.5)	16.8 (34.0)[1,2]	18.6 (22.3)[1]	29.8 (64.5)[1]
Vastus medialis	32.1 (38.4)	24.0 (26.5)	14.4 (27.5)[1,2]	9.8 (12.4)[1,2]	22.4 (26.6)[3]
Vastus lateralis	38.7 (40.3)	29.2 (34.6)	18.8 (34.2)[1,2]	11.0 (17.7)[1,2]	27.0 (33.2)[3]
Gastrocnemius medialis	29.9 (21.2)	28.1 (27.5)	25.9 (26.7)[1,2]	23.0 (20.2)[1]	17.0 (10.2)[1,2]
Gastrocnemius lateralis	15.0 (13.4)	13.4 (15.2)	10.5 (13.5)[1]	11.3 (14.1)[1]	8.9 (11.4)[1,2]

Note: [1]$p < 0.05$ in relation to diagonal 1; [2]$p < 0.05$ in relation to diagonal 2; [3]$p < 0.05$ in relation to diagonals 3 and 4.

Lynch et al.[23] investigated the effects of unilateral versus bilateral strength training on maximum isometric strength and bilateral force deficit. The results suggest that both types of training are effective to increase strength, but bilateral training may be more effective in reducing bilateral force deficit.

According to Lee and Carroll,[24] the effects of cross-learning can be explained by neural mechanisms, including activation of crossed motor control pathways and neural plasticity. In addition, unilateral training not only significantly increases the strength of the trained limb, but also enhances muscular activation of the contralateral limb. This effect is related to the functional and structural connectivity between the supplementary motor areas right and left, suggesting that the integrity of white substance pathways connecting these regions plays a key role in inter-hemispheric of performance gains.[25]

In this study, there was a significant difference in the pattern of flexion-abduction and internal rotation of the hip with knee flexion ($p < 0.05$) when compared to the other diagonals of the upper limb and the rectilinear movement. This indicates that this diagonal radiates more than the others and activates more than the rectilinear movement. However, there was no significant difference between the standards 1 and 2, as shown in Table 3.

In the study by Marchese et al.,[26] it was observed that the best PNF patterns to induce muscle irradiation in muscles recruited during the act of standing up are the flexion-adduction-external rotation with knee flexion and the lower limb abduction and internal rotation with knee flexion. The upper limb pattern did not significantly induce irradiation to the contralateral lower limb. Several studies with healthy individuals and even athletes have demonstrated, through electromyography analysis, a significant increase in muscle activity in the contralateral limb after the PNF protocol, as well as improvement in athlete performance.[27-30]

Monga et al.,[31] conducted a study to evaluate the irradiation of PNF patterns of the scapula in forearm muscles in healthy women. The study involved 100 participants, ran-domly divided into four groups of 25, each submitted to a specific pattern of scapular PNF: anterior elevation, posterior depression, posterior elevation and anterior depression. The electromyographic activity of flexor and extensor muscles of the forearm was recorded to measure the resulting irradiation. The results showed a signi-ficant increase in muscle activity of forearm muscles after the application of scapular PNF patterns, indicating that these patterns may influence distal muscular activation.

In another study, Park et al.,[32] analyzed the effects of applying PNF to the lower limbs on muscular activation of the contralateral limb. The study included a group of participants who went through a specific PNF protocol, while muscle activity was recorded before and after the intervention. The results indicated a significant increase in muscular activation of the contralateral limb compared to the control group, which did not receive the intervention. The authors concluded that PNF may be an effective strategy to facilitate muscle activation in the opposite limb, suggesting its potential for rehabilitation programs.

The above-mentioned studies corroborate the findings of this study, demonstrating that the application of PNF in the contralateral limb may promote an increase in muscle activity of this limb. This finding may have significant implications for muscle performance and treatment of certain clinical conditions.

From a neurophysiological point of view, PNF involves the stimulation of proprioceptive receptors in a specific muscle or muscle group.[33] These receptors transmit sensory information to the central nervous system, that interprets and processes this information to coordinate muscle activity.[34,35] This is possible because the human body is interconnected and has a vast network of neural pathways that allow communication between different members of the body. When a limb is activated through PNF, this can trigger a neuromuscular response throughout the body, including in the contralateral limb. Additionally, PNF can also amplify overall muscle activation and coordination, which can consequently enhance strength in both limbs. These effects are a combination of spatial adding effects and irradiation effect, proposed by the PNF method.[36]

During the application of the PNF technique, the physiotherapist may request the contraction of the hip and thigh muscles of a specific limb. This muscular contraction can stimulate the neural pathways through cross-segmental innervation, which extend to the contralateral limb, intensifying muscle activation and coordination in both limbs. This can contribute to the improvement of strength and neuromuscular performance in both limbs, not only in the limb in which PNF was applied.[37] Additionally, PNF can also activate the sympathetic nervous system, which can increase blood flow to the muscle, providing more oxygen and nutrients to muscle tissues. This process can help improve muscle endurance and reduce fatigue.[38]

Regarding the potentialization of muscular activation of the contralateral limb, it is assumed that the stimulation of proprioceptive receptors in the target muscle can trigger a reflex response that influences the contralateral muscle. This reflex response is known as cross-reflex or contralateral facilitation reflex.[25] Recent research has highlighted the potential of cross-reflex response to improve muscle performance in contralateral limbs and how this response can be employed in rehabilitation of muscle and joint lesions.[39,40] However, it is essential to highlight that the cross-reflex response is only one of several mechanisms involved in strength training and rehabilitation, requiring further investigation to fully understand its role and clinical application.

Conclusion

The PNF patterns induced muscular irradiation to the contralateral limb, and the difference in electromyographic values was more significant in lower limb patterns when compared with those of upper limbs and rectilinear movement. Greater electromyographic activity was found in the pattern of flexion-abduction-internal rotation with knee flexion for the contralateral limb tested.

Concerning the analysis of force with the electromyographic activation of the medial gastrocnemius muscle, greater strength and less muscular activation were obtained in movements involving hip or shoulder flexion. The femoral rectus stood out in the correlation of strength and muscular activation, because its variables were directly proportional to the diagonal 1. It is necessary that other studies are performed using electromyography with a larger n sample, to obtain a correlation with greater statistical significance, since there are few studies that evaluate the muscle irradiation in PNF patterns in various muscle groups.

Authors' contributions

MEIMC and LSP were responsible for the design of the work; DAS, for the analysis and interpretation of data; MCIO, RSAL and SSM, for the writing of the manuscript; and LSAM, for the revision and approval of the final version.

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