Electromyographic activation during motor irradiation of proprioceptive neuromuscular facilitation: a scoping review

Ativação eletromiográfica durante a irradiação motora da facilitação neuromuscular proprioceptiva: uma revisão de escopo

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ABSTRACT

Background: This scoping review examined the effectiveness of motor irradiation in activating specific muscles in adults, using surface electromyography (EMG). The literature suggests motor irradiation, a basic procedure of Proprioceptive Neuromuscular Facilitation (PNF), can stimulate contractions in weak muscles by applying resistance to stronger ones. This could potentially reduce complications in neurological and orthopedic conditions. However, despite its widespread use in physiotherapy, there's a lack of research on the exact impact of motor irradiation on target muscle activity. Methods: Online databases (PubMed, Scielo, Lilacs, and Google Scholar) were used to identify papers published between 1981-2025, that utilized EMG analysis as a primary or secondary outcome variable in individual of both sexes with and without any disorders. Results: The search yielded 30 potentially relevant articles after removing duplicates. Of these, only nine articles met the inclusion criteria (articles in English, Spanish, or Portuguese that analyzed EMG during PNF motor irradiation). The studies analyzed EMG activity of the upper limb, trunk, and lower limb muscles during motor irradiation (flexor and extensor patterns of both upper and lower limbs). Significant differences were observed between flexor and extensor movement patterns, with specific muscles showing distinct activation profiles. The lower limb patterns evoked higher activation in homologous and contralateral muscles, while upper limb patterns seem to evoke less activation. The limited number of studies, small sample sizes, methodological issues, and the fact that a few studies have investigated upper limb muscle activity highlight the need for further research to achieve a comprehensive understanding of PNF dynamics.

Keywords: Motor activity. Isometric contraction. Rehabilitation exercise. Proprioceptive neuromuscular facilitation. Physical therapy. Electromyography. Scoping review.

RESUMO

Introdução: Esta revisão de escopo examinou, em adultos, a eficácia da irradiação motora na ativação de músculos específicos usando eletromiografia de superfície (EMG). A literatura sugere que a irradiação motora, um procedimento básico de Facilitação Neuromuscular Proprioceptiva (FNP), pode estimular contrações em músculos fracos aplicando resistência aos mais fortes. Isso poderia reduzir potencialmente complicações em condições neurológicas e ortopédicas. No entanto, apesar do uso generalizado em fisioterapia, há uma falta de pesquisa sobre o impacto exato da irradiação motora na atividade do músculo alvo. Métodos: Bancos de dados online (PubMed, Scielo, Lilacs e Google Scholar) foram usados para identificar artigos publicados entre 1981-2025, que utilizaram análise de EMG como uma variável de resultado primária ou secundária em indivíduos de ambos os sexos com e sem quaisquer distúrbios. Resultados: A busca gerou 30 artigos potencialmente relevantes após a remoção de duplicatas. Destes, apenas nove artigos atenderam aos critérios de inclusão (artigos em inglês, espanhol ou português que analisaram a EMG durante a irradiação motora da FNP). Os estudos analisaram a atividade EMG dos músculos dos membros superiores, tronco e membros inferiores durante a irradiação motora (padrões flexores e extensores dos membros superiores e inferiores). Diferenças significativas foram observadas entre os padrões de movimento flexor e extensor, com músculos específicos mostrando perfis de ativação distintos. Os padrões dos membros inferiores evocaram maior ativação em músculos homólogos e contralaterais, enquanto os padrões dos membros superiores parecem evocar menos ativação. O número limitado de estudos, amostras pequenas, questões metodológicas e o fato de que poucos estudos investigaram a atividade muscular dos membros superiores destacam a necessidade de mais pesquisas para atingir uma compreensão abrangente da dinâmica do PNF.

Palavras-chave: Atividade motora. Contração isométrica. Exercício de reabilitação. Facilitação neuromuscular proprioceptiva. Fisioterapia. Eletromiografia. Revisão de escopo.

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INTRODUCTION

Proprioceptive Neuromuscular Facilitation (PNF) emerged in the 1940s through the pioneering work of Herman Kabat, Margaret Knott, and Dorothy Voss[1–3]. Initially devised as a rehabilitation method for patients with neuromuscular injuries, motor disorders, and debilitating conditions, PNF has since evolved into a widely adopted concept by physiotherapists for treating diverse disorders[4–7]. By employing specific techniques and principles, PNF aims to enhance motor coordination, facilitate tasks that are limited by various impairments, and ultimately unlock an individual's maximal physical and motor potential[8,9].

Motor irradiation is one of the fundamental procedures of PNF. In this procedure, activation of a target muscle is evoked through sequential actions commonly referred to as movement patterns. Specifically, these movement patterns involve the patient actively resisting forces applied by a physiotherapist. Often, these movements are performed in diagonal directions in relation to the main body axis[9]. The rationale behind motor irradiation is that imposing resistance during the movement of the stronger parts of the body would produce activation of the weaker ones[10,11]. To achieve this, specific movement patterns associated with some PNF basic principles (resistance, approximation, visual, tactile and auditive stimulation, for example) can be employed. In neuromechanical terms, the weaker segment must be forced to maintain stability while the therapist applies destabilizing forces in the stronger parts[9].

Motor irradiation proves valuable in scenarios where an indirect approach to the affected limb becomes necessary due to muscle weakness, as observed in peripheral[12,13] and central injuries[14], as well as in conditions such as limb immobilization, burns, pain, and fractures[7,10,15–17]. Most of the benefits of motor irradiation can be attributed to increases in muscle activity and strength[4–7].

Although widely utilized in physiotherapeutic practice, there is a gap in the literature regarding the extent to which motor irradiation affects the activity of target muscles. This issue holds significant as it precedes questions about the therapeutic effects of the method, which have been sparsely investigated in previous studies[12,18–20]. Furthermore, the nomenclature is unclear and confusing. To address this gap, a scoping review was undertaken to comprehensively map the research conducted in this area. The review specifically aimed to identify findings from observational and experimental studies regarding the activity of target muscle during motor irradiation. The focus was primarily on studies utilizing surface electromyography (sEMG), a non-invasive technique recording the electrical signals of muscles fibers adjacent to electrodes placed on the skin. Throughout the process, a system of nomenclature was proposed to facilitate general comprehension of the movement patterns used in the studies.

METHODS

A scoping review, a method to map the current state of research in a specific field[21], was conducted to identify research gaps within the proposed theme. The PICO strategy was established as follows: adult individuals of both genders (population); motor irradiation (intervention); without a comparison group or measure (comparison); muscle activation measured through sEMG (outcomes).

Experimental or observational studies spanning 44 years were selected from available literature. To identify studies relevant to the topic, a bibliographic search encompassed PubMed, Scielo, Lilacs, and Google Scholar databases were undertaken. This search was carried out from January 1981 to May 2025, by two researchers (CHRH, LASO) utilizing the terms "motor irradiation", "overflow", "proprioceptive neuromuscular facilitation", "PNF", "electromyography", "EMG", "electromyography" and "muscle activity" (Table 1). The inclusion criteria comprised articles written in English, Spanish or Portuguese, focusing on investigating the effects of PNF motor irradiation on muscle activation measured through sEMG. Articles discussing different PNF techniques or those using motor irradiation exclusively in treatment sessions were excluded.

Table 1 – Database search strategy.

Database	Strategy	Search strings
PUBMED	1	(PNF) AND (EMG)
	2	(Proprioceptive Neuromuscular Facilitation) AND (electromyography)
	3	("electromyography" OR EMG) AND ("proprioceptive neuromuscular facilitation") AND (overflow OR irradiation) AND NOT ("contract-relax" OR "hold-relax" OR "rhythmic initiation" OR "combination of isotonic") AND PUBYEAR > 1981 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "cr"))
Google SCHOLAR	1	allintitle: (Proprioceptive Neuromuscular Facilitation) AND (electromyography) -stretching
	2	"Surface electromyography" AND "proprioceptive neuromuscular facilitation" AND (irradiation OR overflow) -contract-relax -hold-relax -"rhythmic initiation" -"combination of isotonic"
SCIELO	1	(Proprioceptive Neuromuscular Facilitation) AND (electromyography)
	2	ti: PNF or FNP or irradiação AND eletromiografia or EMG or electromyography
	3	(PNF) OR (irradiação) OR (irradiation) OR (overflow) OR (FNP) AND (EMG) OR (eletromiografia) OR (electromyography)
	4	("eletromiografia de superfície" OR "electromiografia de superficie" OR "surface electromyography" OR EMG) AND ("facilitação neuromuscular proprioceptiva" OR "facilitación neuromuscular propioceptiva" OR "proprioceptive neuromuscular facilitation" OR PNF) AND ("irradiação" OR "overflow") NOT ("contrair-relaxar" OR "manter-relaxar" OR "combinação de isotônicas" OR "iniciação rítmica")
BVL/LILACS	1	((((("PNF") or "FNP") or "OVERFLOW") or "FACILITACAO NEUROMUSCULAR PROPRIOCEPTIVA") or "PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION") or "DIAGONAIS-CONTRALATERAIS" [Palavras] and ((("EMG") or "ELETROMIOGRAFIA") or "ELETROMIOGRAPHY") or "RMS" or "ELETROMIOGRAFIA/METODOS" [Palavras] and not (("ALONGAMENTO") or "STRETCH") or "STRETCHING EXERCISE, PNF" [Palavras]
	2	(("eletromiografia de superfície" OR EMG OR "electromyography") AND ("facilitação neuromuscular proprioceptiva" OR PNF) AND ("irradiação" OR "overflow")) NOT ("contrair-relaxar" OR "manter-relaxar" OR "combinação de isotônicas" OR "iniciação rítmica")

The search process was divided into several phases: identification (conducting textual search in databases); preliminary selection (reviewing titles and abstracts according to the eligibility criteria for inclusion); eligibility checking (reading the full texts and applying the criteria of eligibility to include or exclude the study); and finally, the selection of studies for analysis. The attributes extracted from the articles were: authors, journal, study design, objectives, sample characteristics and main results. The extracted data was reported in specific subsections referring to "Movement patterns", "Target muscles" and "Electromyographic evidence of muscle activity". The flowchart for article selection is shown in Figure 1.

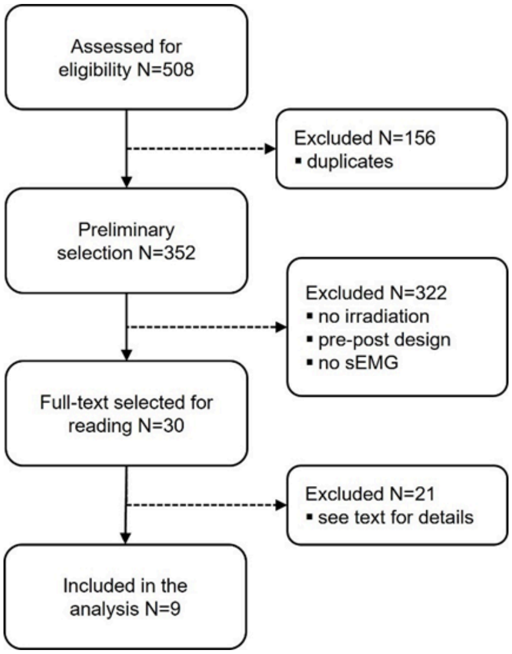

Figure 1- Flowchart article selection

RESULTS

In the identification phase, the database search retrieved 508 studies: 407 from Pubmed; 73 from Scielo; 8 from Lilacs; 17 from Google Scholar; and 3 from articles' references. After removing duplicates (N=156), 352 studies remained for further screening. Of these, 322 studies were excluded because they were not relevant to the topic (N=33), focused on a PNF technique other than motor irradiation (N=217), or did not use sEMG as muscle activity measurement (N=72). During the eligibility checking phase, 30 studies were fully reviewed, and 21 articles were excluded after further screening.

Among the excluded articles, some: used the PNF as an intervention (N=6); referenced to the use of weights or elastic bands instead of manual resistance applied by a physiotherapist (N=4); analyzed only the limb receiving resistance (N=4); did not include electromyography (N=2); used other PNF techniques such as stretching (hold and relax), rhythmic initiation and combination of isotonic (N=4) and were published as conference proceedings rather than peer-reviewed articles (N=1).

Finally, 9 articles were included for analysis. The respective authors, study locations, designs, and sample characteristics are shown in Table 2. All studies were written in English, except for Queiroz et al. (2016), which was written in Brazilian Portuguese[22]. The studies took place in different countries: Brazil[18,22–24]; Portugal[25]; Iran[26]; Israel[27]; Japan[15]; and USA[102]. Most of the studies were observational, assessing healthy young people (with samples mostly around 20 to 30 years old). A few preliminary investigations were found, along with a single randomized trial. Elderly individuals as well as people with stroke, hemiparesis, or musculoskeletal disorders were sparsely investigated.

Table 2. General descriptions of the selected studies and their samples.

no	Reference	Origin	Study design	Sample features	Sample size	Age*
25	Abreu et al. (2015)	Portugal	Observational	Healthy people	30 (19 females)	21
23	de Oliveira et al. (2018)	Brazil	Preliminary cross-sectional and explanatory study	Healthy people People with acute stroke (av. 46 days after diagnostic) People with chronic poststroke (av. 24 months after diagnosis)	08 (03 females) 06 (03 females) 08 (03 females)	57 57 54
15	Hazaki et al. (1996)	Japan	Observational	Healthy people	10 (05 females)	22
26	Lotfi et al. (2021)	Iran	Observational	Healthy people People with patellofemoral syndrome	26 (18 females) 26 (18 females)	23 23
18	Marchese et al. (2021)	Brazil	Randomized crossover trial	Healthy people	24 (all females)	24
10	Pink (1981)	USA	Observational	Healthy people	10 (all females)	22-34
22	Queiroz et al. (2016)	Brazil	Quasi-experimental	Healthy people Hemiparetic people (6-72 months post-stroke)	05 (non-related) 05 (non-related)	61 62
27	Reznik et al, (2015)	Israel	Preliminary investigation	Healthy people	12 (10 females)	38
24	Oliveira et al. (2025)	Brazil	Observational	Healthy people	30 (23 females)	NA

*In years, showed as min.-max. or mean. av., average. NA, not available.

Movement patterns

The motor irradiation's movement patterns used in the selected studies, along with their main body parts engaged, are shown in Table 3. Six studies used movement patterns for upper limbs[10,18,22,24,25,27] and six for lower limbs[15,18,23,24,26,27]. Movement patterns focused on the trunk were used in one study[18].

For upper limbs, the movement patterns used were shoulder extension, adduction, and internal rotation[10,24,25] and flexion, abduction, and external rotation[10,18,22,24,25,27].The movement patterns for lower limb were hip extension, abduction and internal rotation[15]; flexion, adduction, and external rotation[15,23,26]; flexion, abduction, and internal rotation[15,18] and extension, adduction, and external rotation[15,24,26]. Three authors used movement patterns with the knee flexed: one using flexion, adduction, and external rotation, flexion, abduction, and internal rotation[24] and the other flexion, abduction, and internal rotation[18,23].

Abreu et al. (2015) were the only authors who did not engage a PNF practitioner to apply motor irradiation, using instead an isokinetic device during the movement pattern[25]. In turn, Lotfi, Moghadam, and Mohsen (2021) compared the effect of performing different lower limb diagonal movement patterns either with the application of manual resistance or a load applied according to age (weight of 1 kg <20 years; 1.4 kg 20-24 years; 2 kg >24 years)[26]. Other movement patterns used were single leg raising[26] and lifting pattern[18].

Table 3. Movement patterns applied in the selected studies.

Body segment	Patterns	References
UPPER LIMBS	Extension, adduction, and internal rotation	10,24,25
	Flexion, abduction and external rotation	10,18,22,24,25,27
LOWER LIMBS	Extension, abduction, and internal rotation	15
	Extension, adduction, and external rotation	15,24,26
	Flexion, adduction, and external rotation	15,26
	Flexion, adduction, and external rotation with knee flexed	18,23
	Flexion, abduction and internal rotation	15,27
	Flexion, adduction, and external rotation with knee flexed	18
	Flexion, abduction, and internal rotation with knee flexion	24
TRUNK	Lifting	18

References: [25]Abreu et al. (2015); [23]de Oliveira et al. (2018); [15]Hazaki, Ichihashi and Morinaga (1996); [26]Lotfi, Moghadam, and Shati (2021); [18]Marchese et al. (2021); [10]Pink (1981); [22]Queiroz et al. (2016); [27]Reznik, Biros and Bartur (2015) [24]Oliveira et al. (2025).

Target muscles

The main target muscle investigated in the selected studies are shown in Table 4. Five articles evaluated the muscles of the lower limbs[15,18,24,26,27], three evaluated the muscles of the upper limbs[18,22,25] and three analyzed the effect of motor irradiation on the muscles of the trunk[10,23,25].

The muscles studied in the lower limbs were biceps femoris[15], gluteus maximus and gluteus medius[18], rectus femoris[15,24], medial and lateral gastrocnemius[24], soleus[18], tibialis anterior[27], vastus lateralis[15,18,24,26] and vastus medialis oblique[15,18,24,26].

For the upper limbs, the following muscles were analyzed: anterior and posterior deltoid[23], middle deltoid[25] and extensor carpi radialis longus and brevis[22].

In the trunk, the following muscles were assessed: pectoralis major[10,23,25], latissimus dorsi and infraspinatus[10], upper trapezius[25] and external oblique[23] (Table 4).

When evaluating the articles, the vastus lateralis, vastus medialis and pectoralis major were the muscles most analyzed during motor irradiation, appearing in three articles each. All the other muscles cited were analyzed only in one study.

Table 4. Targe-muscles for PNF maneuvers analyzed in the selected studies.

Body segment	Target-muscles	References
Forearm	Extensor carpi radialis longus	22
	Extensor carpi radialis brevis	22
Shoulder complex and trunk	Anterior deltoid	23
	Middle deltoid	25
	Posterior deltoid	23
	Pectoralis major	15,23,25
	Infraspinatus	10
	Upper trapezius	25
	Latissimus dorsi	10
	Obliquus externus	23
Lower limbs	Tibialis anterior	27
	Soleus	18
	Lateral gastrocnemius	24
	Medial gastrocnemius	24
	Vastus medialis	15,18,24,26
	Vastus lateralis	15,18,24,26
	Rectus femoris	15,24
	Biceps femoris	15
	Gluteus medius	18
	Gluteus maximus	18,25

References: [25]Abreu et al. (2015); [23]de Oliveira et al. (2018); [15]Hazaki, Ichihashi and Morinaga (1996); [26]Lotfi, Moghadam, and Shati (2021); [18]Marchese et al. (2021); [10]Pink (1981); [22]Queiroz et al. (2016); [27]Reznik, Biros and Bartur (2015) [24]Oliveira et al. (2025).

Electromyographic evidence of muscle activity

The main findings obtained by the selected studies are shown in Table 5.

Table 5. Main findings.

Reference	Methodological concerns	Main findings
25	Patterns applied in an isokinetic dynamometer set for isometric contraction, in the non-preferred arms	Increases in EMG levels from upper trapezius (28% during FLX, and 14% during EXT) and pectoralis major (23% during FLX, and 15% during EXT) was observed in all patterns; males showed higher activation than females during maximal (16 vs. 14%), but not submaximal contractions
23	Four different contexts with varying positions of the upper and lower limb, with or without manual resistance	Increases in EMG activity of pectoralis major in healthy persons and those with stroke, depending on the positioning of the upper and lower limbs; The external obliquus showed higher activation solely in those with stroke; posterior and medial deltoid was also activated in specific contexts
15	FLX and EXT patterns with knee extension applied in isometric conditions and manual resistance during flexor and extensor lower limb	Increased activity of rectus femoris, vastus and biceps femoris during FLX patterns and biceps, vastus and rectus femoris during EXT pattern
26	PNF maneuvers (FLX and EXT patterns) with and without overload (1-2 kg, depending on the participants' age)	Differences in EMG activity of vastus muscles in those with vs. without PFS, with higher activity of the vastus lateralis; addition of overload promotes increases in EMG in both groups. Less activation in individuals with PFS
18	Intervention with exercise training plus irradiation; isometric contraction regimen with manual resistance	PNF maneuvers in the lower limb promote higher EMG levels than those focused on upper limbs
10	Slow, reverse patterns applied in the right side, with the elbow in straight position; maximal resistance applied, full range of motion	Increased EMG for the infraspinatus during FLX-ABD-EXR pattern, and for latissimus dorsi during EXT-ADD-INR
22	Patterns applied in the right side of healthy people and in the contralateral side of those with stroke; four repetitions to practice followed by 8 applications; four repetitions more applied as intervention	Non-significant increases in EMG levels from the first to the second round of irradiation (19% in healthy people and 7% in those with stroke)
27	Both upper limbs and left lower limb tested through submaximal isometric contraction with manual resistance	Overall increases in EMG levels in the FLX-ABD-INR applied to the lower limbs
24	Patterns applied in the non-dominant side of healthy people to irradiate to the contralateral side	EMG activity was observed in all PNF patterns and linear movements. There was a significant difference in the pattern of flexion-abduction and internal rotation of the hip with knee flexion when compared to the other diagonals of the upper limb and the rectilinear movement. The greater the strength of the rectus femoralis muscle on the dominant side, the greater the EMG activity during flexion lower limb pattern, and that the higher the strength of the medial gastrocnemius, to the diagonals and rectilinear motion

FLX, flexion. EXT, extension. ABD, abduction. ADD, adduction. EXR, external rotation. INR, internal rotation. PFS, patellofemoral syndrome. References: [25]Abreu et al. (2015); [23]de Oliveira et al. (2018); [15]Hazaki, Ichihashi and Morinaga (1996); [26]Lotfi, Moghadam, and Shati (2021); [18]Marchese et al. (2021); [10]Pink (1981); [22]Queiroz et al. (2016); [27]Reznik, Biros and Bartur (2015) [24]Oliveira et al. (2025).

Comparing the flexor movement pattern (flexion, abduction, and external rotation of the upper limb) with the extensor pattern (extension, adduction, and internal rotation of the upper limb), Pink (1981) reported greater EMG activation in the contralateral infraspinatus muscle during the flexor movement pattern. In contrast, the latissimus dorsi muscle showed greater EMG activation during the extensor pattern. For the pectoralis major, similar levels of activation were observed during both movement patterns (flexor and extensor)[10].

Abreu et al. (2015) compared the same movements (flexors and extensors) mentioned by Pink (1981) [10,25]. However, they analyzed the EMG activation of the medial deltoid, pectoralis major and upper trapezius muscles during the maximum and submaximal (25% of maximal) torques measured using isokinetic equipment[25]. In this study, the contralateral muscles were more activated when the maximum torque was applied compared to the submaximal torque. When the maximum torque was applied, the upper trapezius muscle showed greater activation in the upper limb flexor pattern (flexion, abduction, and external rotation) when compared to the upper limb extensor pattern (extension, adduction, and internal rotation ($p<0.001$). The pectoralis major was more activated during flexion, abduction, and external rotation in both torques ($p<0.001$). Interactions were found between gender and the intensity of the contraction, with similar values being observed during the submaximal torque for men and women and in the maximum torque higher values for men when compared to women[25].

The flexion pattern of the upper limb (flexion, abduction and external rotation) was also applied by Queiroz et al. (2016) to analyze the activation of the extensor carpi radialis longus and brevis in 5 post-stroke and 5 healthy individuals during isometric contraction (manual resistance applied 3 times on each side with the individual seated to determine if the participants were able to contract the wrist actively) and 2 phases of the movement pattern (teaching and learning). In the first phase, the idea was to teach the movement pattern (4 times) with EMG signal collected bilaterally. Next, the movement was performed 8 times without EMG data collection. Finally, the second phase was conducted (4 times) with electromyographic signal acquisition[22]. Queiroz et al. (2016) found activation of the extensor carpi longus and brevis with an increase of 7.3% in the hemiparetic group and 18.6% in the control group (healthy individuals) when comparing the two phases; nevertheless, this difference was not statistically significant, probably because the sample size was small. However, muscle activation was detected when applying motor irradiation patterns[22].

Hazaki, Ichihashi, and Morinaga (1996) analyzed the EMG activity of the vastus lateralis, vastus medialis, rectus femoris and biceps femoris muscles during flexor and extensor movement patterns of the lower limb. The percentage of EMG activation was highest for the rectus femoris, followed by the vastus lateralis, vastus medialis and biceps femoris (in decreasing order of activation) when the flexor patterns (flexion, abduction, and internal rotation and flexion, adduction, and external rotation) were applied. In the extensor patterns (extension, abduction and internal rotation and extension, adduction, and external rotation) the percentage of electromyographic activation was highest in reverse order (biceps femoris, vastus medialis, vastus lateralis and rectus femoris). The rectus femoris showed significantly higher activation in the flexor patterns when compared to the extensors, while the biceps femoris showed significantly higher activation in the extensor patterns when compared to the flexors[15].

Reznik, Biros, and Bartur (2015) used movement patterns of flexion, abduction, and external rotation of the upper limbs (right and left), and flexion, abduction, and internal rotation of the left lower limb to examine motor irradiation of the right tibialis anterior muscle. All the 12 individuals analyzed exhibited activation of the tibialis anterior muscle while executing both the upper and lower limb patterns in comparison to baseline[27].

de Oliveira et al. (2018) used the movement pattern of flexion, adduction and external rotation of the lower limb and evaluated the EMG activity of the anterior deltoid, posterior deltoid, pectoralis major and external oblique muscles in 3 groups (healthy individuals and patients with stroke in the acute phase and in the chronic phase). Each group was analyzed in 4 different positions for 5 seconds: (P1) supine position, with upper limbs at rest, lower limb contralateral to the impairment, positioned with hip and knee flexion (90 degrees), hip external rotation (10 degrees) and adduction; (P2) supine position, upper limbs at rest, with manual resistance on the contralateral lower limb maintaining isometry in the movement pattern; (P3) supine position, affected upper limb positioned in flexion, abduction and external rotation of the shoulder and elbow extension, with manual resistance in the contralateral lower limb maintaining isometry in the movement pattern; and (P4) supine position, affected upper limb positioned in flexion, abduction and external rotation of the shoulder with a fixed strap (non-elastic velcro) to maintain the positioning of the upper limb during the isometric contraction in the movement pattern for the contralateral lower limb. Which upper limb was tested in the control group was not clearly stated[23].

The authors found specific differences between positions, but not among the groups. For example, the pectoralis major and external oblique were more active in the control group during P1 than in P4, while the chronic group showed more activation of the pectoralis major during P1 compared with P2. Additional findings came from the examination of effect sizes measures (Cohen's d): for individuals with acute stroke, the posterior deltoid seemed more active at P2, while the pectoralis major was more active at P3 and P4; for individuals with chronic stroke, there was a clinically relevant difference for anterior deltoid activity at P2 and for the pectoralis major and external oblique at P4[23].

Lotfi, Moghadam, and Shati (2021) analyzed the flexor (flexion, adduction, and external rotation) and extensor (extension, adduction. and external rotation) movement patterns of the lower limb with or without load application[26]. The load was administered according to age (1kg <20 years; 1.4kg 20-22 years; 1.7kg 22-24; 2kg >24 years). In this study, a significant reduction in the activation of the vastus medialis oblique of individuals with patellofemoral pain syndrome was observed during the flexor pattern, with and without load[26].

There was also a reduction in the activation of the vastus lateralis for the flexor and extensor components (extension, adduction and external rotation) with and without load. Adding weight to the flexor and extensor components resulted in a significant increase in the activity of both the vastus medialis oblique and the vastus lateralis muscles in both healthy individuals and in those with patellofemoral pain syndrome. Additionally, the ratio between the vastus medialis oblique and the vastus lateralis activity was higher during movement patterns than during the straight leg raising[26].

To produce activation of the vastus medialis oblique, vastus lateralis, gluteus medius, gluteus maximus and soleus muscles in healthy individuals, Marchese et al. (2021) applied the following movement patterns: flexion, abduction, and external rotation of the upper limb; flexion, abduction, and internal rotation with knee flexion; and flexion, adduction, and external rotation with knee flexion and lifting[18].

In the study by Oliveira et al. (2025), the electromyographic profile of the lower limb muscles of healthy individuals was analyzed in response to four motor irradiation patterns applied to the contralateral side. Greater activation was observed during the flexor pattern of the lower limb (hip flexion, abduction and internal rotation with knee flexion). The authors highlighted that muscle strength influences irradiation - the greater the strength of the rectus femoris muscle on the dominant side, the greater the electromyographic activity in the flexion pattern; in addition, greater strength of the medial gastrocnemius was associated with greater activation in diagonal and rectilinear movements[24].

Each muscle produced more activation in a particular pattern: for the soleus, the flexor pattern of the lower limb (flexion, adduction, and external rotation with knee flexion) provoked more activation when compared to the flexor patterns of the upper limb (flexion, abduction, and external rotation); for the gluteus maximus, the activation was increased by lifting to the right when compared with others movement patterns (lower and upper limb); lifting and flexion, adduction, and external rotation with knee flexion pattern of flexion produced greater activation in the gluteus medius, when compared flexor pattern of the upper limb; for the extensors knee (vastus medialis and lateralis), lifting and flexion, adduction and external rotation with keen flexion produced more activation when compared to the flexor pattern of the upper limb; finally, the vastus lateralis showed greater activation when compared in the lifting and lower limb flexor pattern (flexion, adduction and external rotation with knee flexion) when compared to the upper limb flexor pattern.

DISCUSSION

The aim of this study was to present, by means of a scoping review, studies that have evaluated muscle recruitment using EMG during motor irradiation to determine whether it can produce activation of the target muscles. Over a period of 44 years (1981–2025), only nine eligible articles were published on the subject.

The nine studies presented above provide important information on muscle activation during the application of movement patterns for motor irradiation in PNF, allowing for the analysis of muscle function during different motor tasks[10,15,18,22–27]. However, the studies provided limited information on EMG acquisition as well as on the main muscles targeted by each pattern. Overall, it remains unclear which movement patterns are best for activating specific muscles.

A general analysis of the literature reveals a greater capacity of lower limb patterns (extensors or flexors) to irradiate to homologous and contralateral target muscles, while upper limb patterns seem to evoke less activation in the target muscles. This difference may be related to the volume and size of the lower limb muscles: being larger and stronger, they tend to generate more activation in the target muscles to maintain body position during the application of movement patterns. Upper limb patterns, however, seem to generate more proximal muscle irradiation than distal muscle activation, especially when the target muscle is homologous to the movement. This activation tends to be reduced when compared to other patterns (trunk or lower limb). It is possible that upper limb muscles are recruited less because they are smaller in size and volume, and experience less muscle tension than lower limb muscles.

One of the limitations found in the studies is the small sample size: of the eight articles reviewed, five used samples of fewer than 30 participants. Moreover, few studies have investigated upper limb muscle activity, which is fundamental to rehabilitation in various clinical conditions. For use in clinical practice, several points need to be addressed in future studies, such as: the ideal amount of manual resistance to be applied; how movement patterns affect different muscles; the optimal position for applying manual resistance—whether at the beginning, middle, or end of the pattern; the ideal limb position for analyzing the target muscle during irradiation; and a better understanding of muscle activation patterns, particularly regarding the effects of movement patterns on proximal and distal muscles. The assessment of patients with different clinical conditions is also an issue, as only two studies included stroke patients, and another evaluated patient with patellofemoral syndrome. Further experimental studies addressing these questions should provide more information on the effects of motor irradiation on neuromuscular activity.

Another important point overlooked in these previous studies was the nomenclature used to refer to motor irradiation. Various terms are associated with motor irradiation, which is itself a general term used to describe involuntary muscle activation that accompanies voluntary muscle activation[28]. Another expression widely associated with motor irradiation is 'overflow,' a phenomenon where the activation of a muscle group spreads beyond the targeted muscle due to neural connections or synergistic muscle activation patterns. Such muscle activation spread can be observed in healthy adults under conditions of exertion and fatigue[29] and could also be related to involuntary movements found in individuals with neurological conditions[30]. Given this ambiguous interpretation, 'overflow' may not be an appropriate term to refer to motor irradiation.

Another term often used in research related to motor irradiation is cross-education or cross-training. In this case, the untrained muscles on the side opposite to the trained ones (stronger parts) are activated, leading to an increase in muscle strength[31]. Although similar in promoting muscle activity on the weaker side, cross-training differs from motor irradiation in that it involves the use of weights, lacks specific movement patterns, and does not pre-establish the position of the target limb[4,31]. It is essential to consider the context in which these terms are used to avoid confusion, as there are several terms with similar meanings, such as motor irradiation.

Although the included studies provide insights into muscle activation during motor irradiation, few described whether these patterns were applied in the context of functional activities. Most interventions were analyzed in isolated movement patterns, without linking them to tasks such as walking, transfers, or postural control. Furthermore, key methodological details—such as position, repetition, frequency, and integration with daily activities—were rarely standardized or clearly reported. This heterogeneity makes it difficult to reproduce findings and apply them clinically. Future studies should prioritize ecological validity by incorporating functional outcomes and standardized reporting of PNF irradiation protocols.

CONCLUSION

This scoping review highlighted the overall neuromuscular activation of target and associated muscles during PNF movement patterns. A variety of EMG activation levels in different muscles were found for each movement pattern reviewed, with marked differences between flexor and extensor patterns. Irradiation procedures involving the lower limbs seem to evoke higher activity in target and non-target muscles compared to irradiation using the upper limbs. Considering the limitations in these studies, highlighted above, further investigation is needed for a comprehensive understanding of the neuromuscular dynamics of this PNF technique.

Additionally, despite evidence suggesting that motor irradiation can activate target muscles beyond the site of resistance, the studies included in this review lack consistent methodological detail regarding this issue. Critical aspects such as the number of repetitions, duration of resistance application, and progression criteria were rarely described. This lack of standardization impairs reproducibility and limits the translation of research findings into clinical protocols. Future studies should aim to establish and report clear methodological parameters to enhance the consistency and clinical applicability of motor irradiation.

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