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# Electromyographic Evidence of Muscle Activation During Proprioceptive Neuromuscular Facilitation Patterns in Healthy Individuals: A Scoping Review

## Sağlıklı Bireylerde Proprioseptif Nöromüsküler Fasilitasyon Paternleri Sırasında Kas Aktivasyonunun Elektromiyografik Kanıtı: Kapsamlı Bir İnceleme

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## Öz

**Amaç:** Proprioseptif Nöromüsküler Fasilitasyon (PNF) konsepti, rehabilitasyon müdahalelerini vücut fonksiyonları/yapıları ve aktivite kısıtlılıklarını hedef alacak şekilde yapılandırır. Bu kapsamlı derleme çalışmasının amacı, sağlıklı bireylerde PNF paternleri sırasında kas aktivitesine ilişkin mevcut elektromiyografik araştırmaları belirlemek ve özetlemektir.

**Yöntem:** PubMed, PEDro, SCOPUS ve Web of Science veri tabanlarında 1980 ile Ekim 2025 tarihleri arasında yayımlanan çalışmalar kapsamlı bir şekilde taranmıştır. Çalışmalar, aşağıdaki kriterleri karşılamaları durumunda dâhil edilmiştir: (i) 18–65 yaş arası sağlıklı bireylerin dâhil edilmesi, (ii) PNF diyagonal paternlerinin ve temel fasilitasyon prensiplerinin uygulanması ve (iii) kas aktivitesinin değerlendirilmesinde elektromiyografinin kullanılması. Çalışma kalitesi, Uluslararası Sağlık Enstitüleri Gözlemsel Kohort ve Kesitsel Çalışmalar için Kalite Değerlendirme Aracı kullanılarak tanımlayıcı biçimde incelenmiştir.

**Bulgular:** Toplam 250 katılımcıyı içeren 11 kesitsel çalışma dahil edildi. Bunlardan dokuz çalışmada EMG elektrot yerleşimi için önceden tanımlanmış veya standartlaştırılmış herhangi bir kriter belirtilmemişti. Genel metodolojik kalite zayıftan iyiye kadar değişiyordu; örneklem büyüklüğü hesaplamalarının olmaması, çalışma popülasyonunun yetersiz tanımlanması, uygun bireyler arasında belirtilmemiş katılım oranları ve temel potansiyel karıştırıcı değişkenlerin değerlendirilmemesi yer alıyordu. Bu sınırlamalara rağmen, bulgular orta ve alt trapez kaslarının üst ekstremite fleksiyon-abdüksiyon-eksternal rotasyon paterni sırasında önemli bir rol oynadığını gösterdi. Bununla birlikte, PNF paternlerinin serratus anterior kasının aktivasyonunu önemli ölçüde etkilemediği sonucuna varıldı. Ek olarak, gluteus medius kası alt ekstremite fleksiyon-abdüksiyon-internal rotasyon paterni sırasında önemli bir aktivasyon gösterdi.

**Sonuç:** Elektromiyografik veriler, PNF paternlerinin seçilen paternin özelliğine bağlı olarak hedef kaslarda farklı düzeylerde aktivasyon oluşturduğunu göstermektedir. Bununla birlikte, bu derlemenin bulguları, standartlaştırılmış tasarımlara sahip ileri araştırmalara duyulan ihtiyacı vurgulamaktadır.

**Anahtar Kelimeler:** Elektromiyografi, Hareket, Kas Aktivasyonu, Proprioseptif Nöromüsküler Fasilitasyon, Derleme

## Abstract

**Purpose:** The Proprioceptive Neuromuscular Facilitation (PNF) concept structures the rehabilitation intervention, addressing both body function/structures and activity limitations. This scoping review aimed to identify and summarize existing research on electromyographic muscle activity during PNF patterns in healthy individuals.

Methods: A comprehensive search was conducted in PubMed, PEDro, SCOPUS, and Web of Science databases for studies published between 1980 and October 2025. Studies were included if they: (i) involved healthy individuals aged 18–65 years, (ii) applied PNF diagonal patterns and basic facilitation principles, and (iii) used electromyography to assess muscle activity. Study quality was examined descriptively using the NIH Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.

**Results:** A total of 11 cross-sectional studies involving 250 participants were included. Of these, nine studies did not specify any predefined or standardized criteria for EMG electrode placement. Overall methodological quality ranged from poor to good; however, most studies were of low quality and exhibited bias. Common limitations included the absence of a priori sample size calculations, inadequate definition of the study population, unspecified participation rates among eligible individuals, and failure to assess key potential confounding variables. Despite these limitations, the findings indicated that the middle and lower trapezius muscles play a significant role during the upper-limb Flexion–Abduction–External Rotation pattern. However, it concluded that the PNF patterns did not significantly affect the activation of the serratus anterior muscle. Additionally, the gluteus medius muscle demonstrated significant activation during the lower-limb flexion-abduction-internal rotation pattern.

**Conclusion:** Based on electromyographic data, PNF patterns tend to induce varying degrees of muscle activity in the target muscles, depending on the choice of pattern. However, the findings of this scoping review underscore the need for further research with a standardized design.

**Key Words:** Electromyography, Movement, Muscle Activation, Proprioceptive Neuromuscular Facilitation, Review

## 1. Introduction

Proprioceptive Neuromuscular Facilitation (PNF), which is a widely used rehabilitation concept, was developed by Dr. Kabat and Mrs. Knott in the 1950s (1). It has been further developed by the International PNF Association (IPNFA) to provide practical techniques and clinical applications aligned with current findings on motor learning and task-specific training (2-4). The PNF concept structures rehabilitation interventions based on the International Classification of Functioning, Disability and Health (ICF), addressing both body functions and structures as well as activity limitations. The PNF concept aims to improve patients' participation through facilitation (5). Results from several studies support the efficiency of PNF across different fields of rehabilitation, and its efficacy in musculoskeletal or neurological rehabilitation is widely discussed (6-8). There is also evidence regarding the effects of the PNF concept on gait, facial, and respiratory functions in various conditions (9-11). When examining those studies, it becomes clear that PNF techniques are generally discussed and compared with other rehabilitation interventions. However, some basic principles and procedures for facilitation are used in the PNF concept. The main procedural stimuli are patterns that lead to producing spiral and diagonal movements, mimicking actions from sports and activities of daily living (5).

To develop an evidence-based rehabilitation program using the PNF concept, it is crucial to address questions such as which muscles are involved, the extent of

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contraction achievable with these patterns, and whether this amount differs across exercises. In this context, surface electromyography (sEMG) emerges as an objective tool that captures the electrical signal generated by the arrangement of muscles during a particular movement (12). In the literature, some studies aim to observe muscular recruitment via sEMG during different PNF patterns. However, a scoping review is needed to map the main scientific findings. Therefore, this scoping review was conducted to investigate the existing evidence on muscle activity observed during PNF patterns and to identify gaps in the current literature.

## 2. Materials and Methods

### 2.1. Protocol and Registration

This scoping review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist (13). The protocol for this review was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO) in 2020 (CRD CRD 42020184826). The original protocol submitted to PROSPERO included randomized clinical trials that had an experimental group receiving PNF treatment and a control group. However, recognizing the limited availability of such trials, we expanded the scope to include a broader range of study types. The revised criteria now encompass “published cross-sectional, randomized, and non-randomized clinical trials that have an experimental group receiving PNF application and a control group.” Additionally, the criterion of “PEDro scale score was less than 5 points” was deleted, further enhancing the inclusivity of our review.

### 2.2. Search Strategy

On August 20, 2025, we conducted a thorough search of several databases, including PubMed (NLM), PEDro, SCOPUS, and Web of Science, covering the period from 1980 to the present. The final searches were completed in October 2025. To enhance our search results, we also employed forward citation tracking and manually reviewed the reference lists of eligible studies. Additionally, we set up search alerts to keep track of new results that emerged after the initial search until the review was finalized. Two reviewers, TBO and PV, evaluated any relevant articles identified through these alerts for eligibility. We applied the following search strategy across all databases, targeting the title, abstract, and keyword fields: [(proprioceptive neuromuscular facilitation OR PNF) AND (electromyography OR EMG)]. The search terms were selected using the MeSH (Medical Subject Headings) browser. Our searches were restricted to English-language articles, but we did not impose any limits on publication dates.

### 2.3. Eligibility

The following criteria were used to include studies for the review: (1) involved healthy participants aged between 18 and 65 years, (2) published cross-sectional, randomized, and non-randomized clinical trials that have an experimental group receiving PNF application and a control group, (3) performed a PNF approach by using basic principles and its diagonal patterns, (4) reported at least one EMG data as an outcome measure, (5) published in English, and (6) were reported as a full-text peer-reviewed paper. The studies were excluded if (1) participants have any musculoskeletal, neuromuscular, neurological, or rheumatologic diseases, any injury or surgery history, (2) any machine or device was used during the treatment, (3) performing the assessment at the

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contralateral limb, and (4) studies were literature reviews, case studies or case reports, and animal studies.

**2.4.** Screening

Two independent reviewers, TBO and PV, screened all studies by first examining the titles and abstracts, and then conducting a full-text review. Any disagreements regarding study eligibility between the reviewers were resolved through discussion. If they could not reach a consensus on inclusion, a third reviewer, BEH, independently assessed the paper. Additionally, two independent reviewers carefully checked the reference lists of the articles to ensure that no relevant studies were overlooked.

**2.5.** Risk of Bias

The National Institutes of Health (NIH) Quality Assessment of Observational Cohort and Cross-Sectional Studies tool was used to assess the risk of bias in the included studies (14). Two of the authors (BEH and TBO), acting independently, reviewed the included to determine whether the research question was clearly described, the study population specified, the participation rate of eligible persons was >50%, subjects recruited were similar populations, a sample size justification, power description or variance and effect estimates were provided, valid and reliable outcome measurements were used, the outcome assessors were blinded, the overall dropout rate was <20%, and whether key potential confounding variables were measured and adjusted statistically. Any disagreements were resolved through consensus.

**2.6.** Data Extraction

Two independent authors, TBO and PV, extracted the data, and a third author, BEH, verified the accuracy of this extraction. Any disagreements were resolved through consensus. The parameters extracted from the studies included (a) study information (year and sample size), (b) participant characteristics (age and gender), (c) application-specific parameters (targeted muscle, technique, pattern, and comparative condition), and (d) sEMG variables used as outcome measures (Table 1).

**3. Results**

**3.1.** Search Strategy

The search strategy was comprehensive and identified 1257 studies for screening. After removing duplicates and conducting a title and abstract review, 36 full-text articles were selected for further evaluation. Following this review, 25 articles were excluded for the following reasons: absence of diagonal patterns of PNF techniques (n = 19), unavailability of full-text articles (n = 2), use of machines or devices (n = 1), and assessment of the contralateral limb (n = 3). Consequently, 11 studies were included in the final analysis (15–25). Figure 1 presents the number of records identified, included, and excluded, along with the reasons for exclusion. The studies included in the scoping review span from 1980 to 2025. Additionally, no further relevant studies were found by reviewing the reference lists of the systematic reviews.

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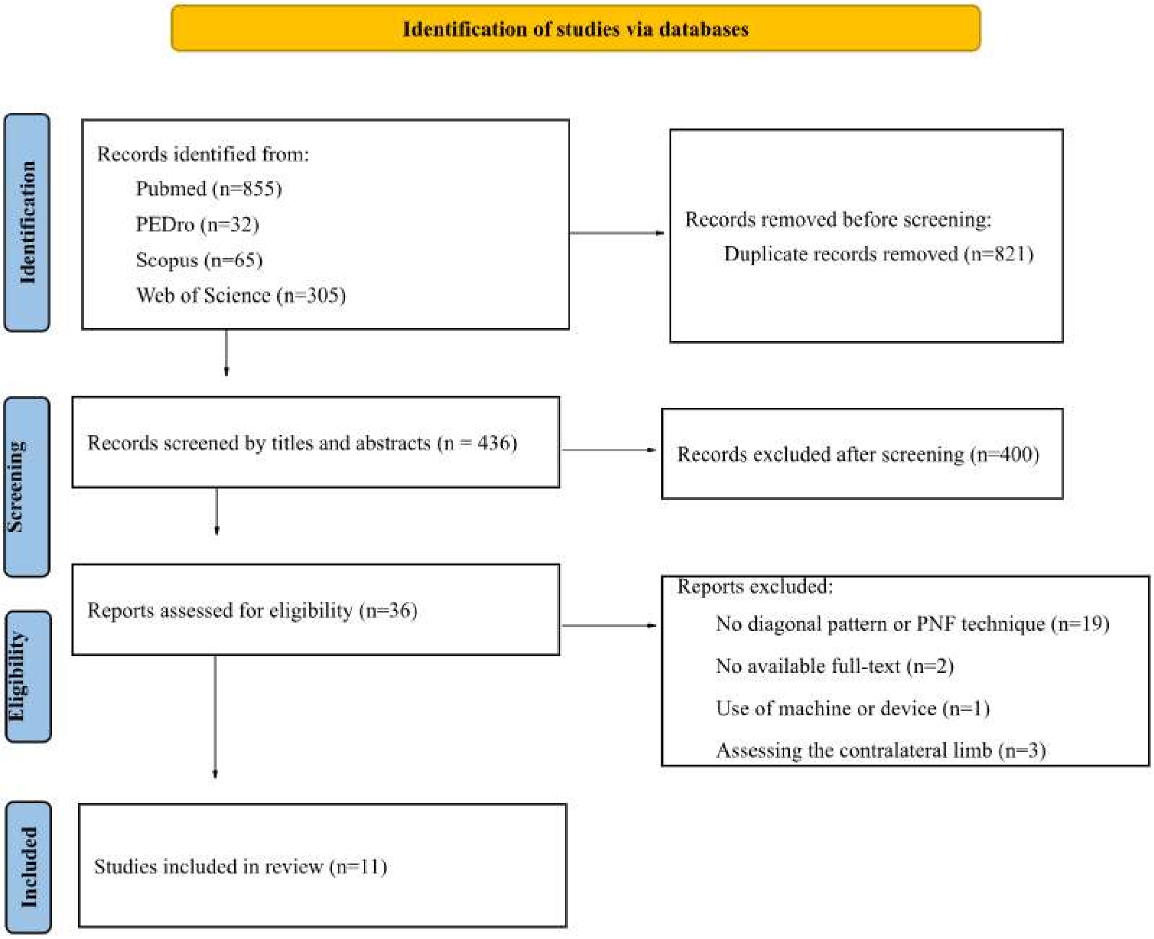


Figure I. Flow Diagram for Included Studies

**3.2.** Description of Studies in the Review

All studies were cross-sectional and lacked a control group. While all studies utilized sEMG (15,17-25), only one study used needle EMG (16). One study also examined cortisol and lactate levels in addition to EMG outcome measurements (21). Maximum voluntary isometric contraction (MVIC) was assessed in seven studies (17-22,24). Root mean square amplitude was evaluated in two studies (23,25), while mean EMG activity was analyzed in two studies (15,17). The average duration of concentric and eccentric contractions was assessed in one study (21), and muscle activation amplitude and mean coactivation were examined in another study (16).

Only one study adhered to the SENIAM recommendations for sensor placement (24); another study followed Criswell's guidelines (20). No specific criteria for EMG placement were provided in the other studies (15-19,21,23,25). Nine studies reported preparing the skin over each muscle with alcohol or another appropriate agent before sensor placement (15-21,23,25).

The muscles studied in the lower extremity included: Gluteus maximus (24), gluteus medius (20,24), vastus lateralis (24), vastus medialis (24), soleus (24), abductor hallucis (23), adductor hallucis (23), extensor hallucis longus (23), and flexor hallucis brevis (23). For the upper extremity, the examined muscles were: Upper trapezius

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(17-19,21), middle trapezius (17,18,21), lower trapezius (17-19), pectoralis major (15, 21), serratus anterior (17-19), anterior deltoid (15, 18,19), middle deltoid (15), posterior deltoid (15) infraspinatus (16, 18, 19),

(22), rectus abdominis (22), erector spinae, and external oblique (18).

One study applied the Flexion-Adduction-External Rotation, Flexion-Abduction-Internal Rotation, Extension-Adduction-External Rotation, and Extension-Abduction-Internal Rotation patterns for the lower extremity (20). On the other hand, one study applied the upper extremity Flexion-Abduction-External Rotation pattern, the lower extremity Flexion-Adduction-External Rotation, and the Flexion-Abduction-Internal Rotation pattern with the knee flexed (24). Ankle movements were evaluated in one study, which used the following patterns: Dorsiflexion-Supination-Inversion with toe extension; Plantar Flexion-Pronation-Eversion with toe flexion; Dorsiflexion-Pronation-Eversion with toe extension; and Plantar Flexion-Supination-Inversion with toe flexion (23).

Four studies applied the Flexion-Adduction-External Rotation and Flexion-Abduction-External Rotation

resistance (21), while another study applied rhythmic initiation without resistance (23). Additionally, one study used the rhythmic stabilization technique (22), another employed the replication technique (24), and one study used the combination of the isotonic technique (25).

**3.3.** Characteristics of the Participants

The studies included in this scoping review comprised 250 healthy participants, 102 males, and 148 females. The mean age of the participants ranged from 20.55±2.0 to 27.44±2.58 years. Table 1 summarizes the characteristics of these study participants.

**3.4.** Quality of the studies

subscapularis (16), teres major (16), biceps brachii (22), and triceps brachii (22). Additionally, studies assessed the pelvic floor muscles, transversus abdominis/internal oblique, external anal sphincter, gracilis (25), multifidus

patterns (15,17-19), while two studies utilized the Extension-Adduction-Internal Rotation and Extension-Abduction-Internal Rotation patterns for the upper extremity (15,17). In the other two studies, only the Flexion-Abduction-External Rotation pattern was used for the upper extremity (16,21), and only one study applied the Flexion-Adduction-External Rotation pattern together with the rhythmic stabilization technique (22). Only one study focused on pelvic patterns (anterior elevation, anterior depression, posterior elevation, and posterior depression) (25), and one additional study investigated lifting (24).

The most frequently used technique across the studies was rhythmic initiation. One study used rhythmic initiation with manual resistance (15), while five studies used rhythmic initiation with external resistance (elastic band, dumbbell, or free weight) (16-20). One study combined rhythmic initiation with both manual and external

The methodological quality assessment of the studies is presented in Table 2. The included studies varied in quality, from poor to good. However, most studies were low-quality and exhibited some bias. This was primarily due to factors such as a lack of sample size calculation, insufficient definition of the study population, unspecified participation rate of eligible individuals, and a lack of measurement of the key potential confounding variables. A meta-analysis could not be conducted because of the significant clinical and statistical heterogeneity observed among the studies.

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## 4. Disscussion

This scoping review is the first to investigate the efficiency of PNF based on electromyographic investigation results. In contrast to studies that have explored the effects of PNF on various activity or body function outcomes, this scoping review focuses on EMG activity to provide objective insights into the PNF intervention. The present findings reveal that PNF patterns induce varying degrees of muscle activity in target muscles. The magnitude of muscle activity during PNF patterns is influenced by the selection of patterns for both upper and lower extremities. However, the heterogeneity of the target pattern or technique poses a challenge, limiting the conclusiveness of the quantitative analysis of the interventions. Despite this, our rigorous review process supports the reliability of the present findings.

### 4.1. Lower Extremity

The gluteus medius was the most commonly selected muscle for sEMG assessment in healthy subjects. In young adults, the Flexion-Abduction-Internal Rotation pattern achieved 50% of the maximum voluntary isometric contraction (MVIC), indicating a high level of activation of the gluteus medius during both static standing and dynamic lower extremities against elastic band resistance (20).

In a study conducted by Marchese et al., twenty-four healthy women were recruited to participate in assessments of four PNF patterns: an upper limb (UL) pattern involving Flexion-Abduction-External Rotation, and three lower limb patterns: Flexion-Adduction-External Rotation with knee flexion (lower limb pattern 1 [LL1]), Flexion-Abduction-Internal Rotation with knee flexion (lower limb pattern 2 [LL2]), and a lifting movement to the right. sEMG activity was recorded from the gluteus medius during each PNF pattern as well as during a sit-to-stand task. It was found that LL2 and lifting to the right were more effective than the UL pattern at recruiting the gluteus medius (24). Marchese et al. also assessed the vastus lateralis using MVIC data. They found that both lifting to the right and LL1 were more effective than the UL pattern in activating the vastus lateralis (24).

Pelvic pattern effects were observed only in one study, and pelvic floor muscle activation was similar in the four pelvic patterns within the PNF framework. A combination of isotonics technique (especially during concentric contraction) was found to cause greater pelvic floor muscle activity (25). Additionally, Park and Hwang examined the activities of intrinsic foot muscle using the D1 (Dorsiflexion-Supination-Inversion with toe extension; Plantar Flexion-Pronation-Eversion with toe flexion) and D2 (Dorsiflexion-Pronation-Eversion with toe extension; Plantar Flexion-Supination-Inversion with toe flexion) diagonals of the lower extremity and compared the results with non-three-dimensional exercises, specifically the short foot and toe spread-out exercises. Their findings revealed that the extensor hallucis longus showed greater activity during the diagonal movements compared to the non-three-dimensional exercises, whereas the abductor hallucis and flexor hallucis brevis muscles exhibited similar activity levels during both types of exercise (23).

### 4.2. Upper Extremity

The trapezius muscle group, consisting of upper, middle, and lower parts, is the most commonly assessed muscle in the upper extremity using sEMG in healthy subjects (17-19,21). Witt et al. observed maximal voluntary contraction in 21 healthy subjects across four resisted upper limb patterns. They found that the activities of the lower and middle trapezius muscles were significantly greater during the Flexion-Abduction-External Rotation pattern with elastic resistance compared

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to other patterns. Moreover, upper trapezius muscle activity was significantly higher during flexion patterns than during extension patterns (17). Similarly, Youdas et al. discovered that the middle trapezius muscle showed greater activation during the Flexion-Abduction-External Rotation pattern compared to the Flexion-Adduction-External Rotation pattern. The average activation of the lower trapezius muscle was also greater for Flexion-Abduction-External Rotation, according to MVIC data (18). Kim et al. also found that the Flexion-Abduction-External Rotation pattern effectively activated the lower trapezius muscle (19). Furthermore, visual tracing conditions provided an additional advantage by activating the lower trapezius muscle (19). Comel et al. reported that the Flexion-Abduction-External Rotation pattern induced greater muscle recruitment than dumbbell exercise for upper and middle trapezius muscles (21). Based on these data, the middle and lower trapezius muscles are effectively activated by the Flexion-Abduction-External Rotation pattern, while data regarding the upper trapezius muscle remain insufficient for a conclusive statement.

The anterior deltoid muscle is the second most commonly investigated upper extremity muscle using sEMG in PNF studies (15,18,19). Sullivan and Portney found that among all upper extremity patterns, the anterior deltoid muscle showed the highest electrical activity during the Flexion-Adduction-External Rotation pattern, which requires shoulder flexion and adduction (15). Conversely, Kim et al. reported higher anterior deltoid muscle activity with the Flexion-Abduction-External Rotation than with the Flexion-Adduction-External Rotation (19). Youdas et al. noted that the anterior deltoid muscle showed greater activation for arm abduction in the plane of the scapula (scaption) compared to both the Flexion-Adduction-External Rotation and Flexion-Abduction-External Rotation patterns (18). Given these results, drawing a definitive conclusion regarding the effective activation of the anterior deltoid muscle is challenging.

The pectoralis major muscle (sternal part) was most active during the Extension-Abduction-Internal Rotation pattern, which includes shoulder adduction and extension, compared to other upper extremity patterns (15). Comel et al. compared the muscular recruitment of the pectoralis major muscle during the Flexion-Abduction-External Rotation pattern and a dumbbell exercise, observing greater activity during the PNF pattern (21). Although PNF upper extremity patterns activate the pectoralis major muscle through both direct and overflow effects, identifying the most effective pattern remains difficult.

Infraspinatus muscle activity during upper extremity PNF patterns was examined in three studies included in this review (16,18,19). Swanik et al. compared four shoulder exercises (Pitchback, Flexion-Abduction-External Rotation pattern with elastic band, push-up plus, and slide board) and found that infraspinatus muscle activation was similar across all exercise types (16). Youdas et al. reported that sEMG activation of the infraspinatus was greater during scaption than during the Flexion-Adduction-External Rotation and Flexion-Abduction-External Rotation patterns (18). The infraspinatus muscle is equally or more activated by alternatives like scaption exercise, and the overflow effect may be beneficial in situations where one upper extremity cannot be exercised. Furthermore, Kim et al. emphasized the significance of visual tracing during shoulder movement to activate the scapulothoracic muscles, including the infraspinatus (19).

Witt et al. reported that the PNF pattern did not significantly influence serratus anterior %MVIC output, with muscle activation demonstrating a relatively narrow range from 42.5% MVIC during Extension–Abduction–Internal Rotation with elastic resistance to 50.0% MVIC during Flexion–Adduction–External Rotation with elastic resistance (17). Similarly, Youdas et al. recommended the Flexion–Adduction–External Rotation pattern, combined with scaption, to elicit sufficient serratus anterior activity for strengthening purposes (18). Kim et al. also reported increased %MVIC values of the serratus anterior during flexor patterns; however, a significant visual trace effect was observed during these tasks (19). Collectively, these findings suggest that PNF pattern selection can be tailored according to specific rehabilitation goals targeting the serratus anterior. When maximal co-activation of the upper, middle, and lower trapezius muscles together with the serratus anterior is desired, the Flexion–Abduction–External Rotation pattern performed with elastic resistance or external loading may be preferred. In contrast, when the goal is to minimize upper trapezius activity while enhancing activation of the lower trapezius and serratus anterior, the Extension–Adduction–Internal Rotation pattern with elastic resistance may be considered. Moreover, relatively isolated activation of the serratus anterior, accompanied by minimal activation of all trapezius portions, was observed during the Extension–Abduction–Internal Rotation pattern with elastic resistance (17). In this context, the use of visual trace or visual feedback strategies may further augment serratus anterior activation during training, although their influence on motor control should be considered (18,19).

This scoping review has some limitations: (i) the studies included generally had poor or fair evidence quality due to the study methodology, (ii) the varied nature of these studies made it difficult to obtain precise results when comparing different PNF patterns or techniques. It was challenging to achieve precise results due to comparisons across different techniques. Further research with a standardized design is needed to collect reliable, comparable EMG data from primary muscle groups to investigate the effectiveness of PNF patterns and techniques in healthy subjects. The data obtained in this way will guide the techniques and patterns used for functional impairment and activity limitation.

## 5. Conclusion

In the studies included in this scoping review, it is observed that PNF patterns generally lead to significant EMG activity in both upper and lower extremity target muscles. While it is not yet possible to definitively determine the most effective pattern and technique for each muscle, the current findings suggest that the Flexion-Abduction-External Rotation pattern in the upper extremity elicits the highest muscle activity in the serratus anterior, middle trapezius, and lower trapezius.

Besides the serratus anterior, middle, and lower trapezius muscles, which were found to contribute to the Flexion-Abduction-External Rotation pattern with a significant level of muscle activation in the upper extremity, there is a need for further research, based on high methodological quality, to determine the PNF techniques and patterns for other muscle groups. These areas represent current gaps in our knowledge, and addressing them could lead to significant advancements in our understanding of muscle activation according to EMG data.

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**Table 1.** Summary of the included studies

| Study | Gender and Mean Age | Targeted Muscle Groups | PNF Pattern | PNF Technique* | Comparative Condition | EMG Variables | Findings |
|---|---|---|---|---|---|---|---|
| **Sullivan & Portney (15) / 1980 (N=29)** | 25F / 4M<br>26 years | Anterior Deltoid (AD)<br>Middle Deltoid (MD)<br>Posterior Deltoid (PD)<br>Pectoralis Major (PM) | Flex-Abd-ER<br>Ext-Add-IR<br>Flex-Add-ER<br>Ext-Abd-IR | Rhythmic initiation w/ manual resistance | PNF patterns w/ elbow straight, flexing, and extending | sEMG<br>Average EMG activity | All muscles are less active in antagonistic patterns than their optimal pattern (15% ↓).<br>Elbow straight: MD and AD ↑<br>Elbow flexing: PD ↓<br>PM: → |
| **Swanik et al. (16) / 2011 (N=33)** | 33M<br>20.55±2.0 years | Infraspinatus (IFS)<br>Teres Minor (TM)<br>Subscapularis (SBS) | Flex-Abd-ER | Rhythmic initiation w/ external resistance | Pitchback with Plyoball<br>Push-up plus<br>Slide board | Needle EMG<br>Mean coactivation level | SBS:<br>*Push-up-plus > Pitchback > PNF pattern*<br>IFS activation is similar among exercises.<br>TM activation is similar among exercises. |
| **Witt et al. (17) / 2011 (N=21)** | 15F / 6M<br>25.4 years | Upper Trapezius (UT)<br>Middle Trapezius (MT)<br>Lower Trapezius (LT)<br>Serratus Anterior (SA) | Flex-Add-ER<br>Ext-Abd-IR<br>Flex-Abd-ER<br>Ext-Add-IR | Rhythmic initiation w/ external resistance | PNF patterns w/ elastic band or a weight | sEMG<br>Average EMG activity | In the same diagonal patterns<br>*Elastic band = Weight*<br>UT: Flexor patterns ↑<br>MT: Flex-Abd-ER w/ elastic band or a weight ↑<br>LT: Flex-Abd-ER w/ elastic band ↑<br>SA: → |
| **Youdas et al. (18) / 2012 (N=25)** | 12M<br>26.1±4.4 years<br>13F<br>24.5±1.9 years | Upper Trapezius (UT)<br>Anterior Deltoid (AD)<br>Serratus Anterior (SA)<br>Infraspinatus (IFS)<br>Middle Trapezius (MT)<br>Lower Trapezius (LT) | Flex-Add-ER<br>Flex-Abd-ER | Rhythmic initiation w/ external resistance | Scaption w/ external resistance | sEMG<br>Relative EMG activity | MT:<br>*Flex-Abd-ER > Flex-Add-ER*<br>LT:<br>*Flex-Abd-ER > Flex-Add-ER*<br>AD:<br>*Scaption > Flex-Add-ER* |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Erector Spinae (ES)<br>External Oblique (EO) | | | | | ES: Scaption ↓<br>UT, SA, IFS, and EO: → |
| **Kim et al. (19) / 2015 (N=16)** | 16M<br>22.81±1.33 years | Upper Trapezius (UT)<br>Lower Trapezius (LT)<br>Serratus Anterior (SA)<br>Deltoid Anterior (DA)<br>Infraspinatus (IFS) | Flex-Add-ER<br>Flex-Abd-ER | Rhythmic initiation w/ external resistance | w/ and w/o visual trace | sEMG<br>Average EMG activity | LT:<br>*Flex-Abd-ER > Flex-Add-ER*<br>*Flex-Abd-ER w/ visual trace* ↑<br>AD:<br>*Flex-Abd-ER > Flex-Add-ER*<br>SA:<br>*Flex-Abd-ER w/ visual trace* ↑ |
| **Youdas et al. (20) / 2015 (N=26)** | 13F<br>23.7±1.3 years<br>13M<br>25.3±3.1 years | Gluteus Medius (GMed) | Flex-Add-ER<br>Flex-Abd-IR<br>Ext-Add-ER<br>Ext-Abd-IR | Rhythmic initiation w/ external resistance | Stance limb vs. moving limb | sEMG<br>Average EMG activity | Stance Limb = Moving Limb<br>GMed: Flex-Abd-IR ↑<br>Flex-Add-ER ↓ |
| **Comel et al. (21) / 2018 (N=21)** | 15F / 6M<br>22±2.5 years | Upper Trapezius (UT)<br>Middle Trapezius (MT)<br>Pectoralis Major (PM) | Flex-Abd-ER | Rhythmic initiation w/ resistance | Manual resistance vs. dumbbell | sEMG<br>Average EMG activity | UT, MT, and PM:<br>*PNF w/manual resistance > PNF w/Dumbbell*<br>Cortisol Levels:<br>*PNF w/manual resistance = PNF w/Dumbbell*<br>Lactic Acid Levels<br>*PNF w/manual resistance > PNF w/Dumbbell* |
| **Dionisio et al. (22) / 2018 (N=8)** | 4F / 4M<br>21.5±1.58 years | Biceps Brachii (B)<br>Triceps Brachii (TB)<br>Multifidus (MF)<br>Rectus Abdominis (RA) | Flex-Add-ER | Rhythmic stabilization | Functional Reach | sEMG<br>Average EMG activity | Ipsilateral MF: Rhythmic stabilization ↑<br>BB, TB, and RA: → |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Park & Hwank (23) / 2020 (N=16)** | 8F / 8M<br>27.44±2.58 years | Abductor Hallucis (AbH)<br>Adductor Hallucis (AdH)<br>Extensor Hallucis Longus (EHL) Flexor Hallucis Brevis (FHB) | DF-Sup-Inv w/ toe extension (D1F)<br>PF-Pron-Ev w/ toe flexion (D1E)<br>DF-Pron-Ev w/ toe extension (D2F)<br>PF-Sup-Inv w/ toe flexion (D2E) | Rhythmic initiation | Short Foot (SF) and Toe Spread Out (TSO) Exercises | sEMG<br>Average EMG activity | AbH: D2F ↓<br>AdH: →<br>EHL: D1F ↑<br>D2F ↑<br>FHB: TSO ↑<br>AbH/AdH ratio:<br>*TSO > D2F*<br>*D2E > D2F* |
| **Marchese et al. (24) / 2021 (N=24)** | 24F<br>24.29±3.34 years | Gluteus Maximus (GMax)<br>Gluteus Medius (GMed)<br>Vastus Medialis (VM)<br>Vastus Lateralis (VL)<br>Soleus (SL) | Flex-Abd-ER (UL)<br>Flex-Add-ER w/ knee flexion<br>Flex-Abd-IR w/ knee flexion<br>Lifting to right | Replication | Sit to stand | sEMG<br>Average EMG activity | Sit to stand: VL, VM, and SL ↑<br>Lifting to the right: Gmax ↑<br>GMed:<br>*Lifting to the right and Flex-Abd-IR w/ knee flexion > Flex-Abd-ER (UL)*<br>VM and VL:<br>*Lifting to the right and Flex-Add-ER w/ knee flexion > Flex-Abd-ER (UL)*<br>SL:<br>*Lower limb pattern > Upper Limb pattern* |
| **Ferro et al. (25) / 2022 (N=31)** | 31F<br>23.3±3.2 years | Pelvic Floor Muscles (PFM)<br>Transversus Abdominis/Internal Obliques (TrA/IO)<br>Gracilis (GRc) | Pelvic Patterns | Combination of isotonics | Pelvic Patterns | sEMG<br>Average EMG activity | Four pelvic patterns have similar effects.<br>Combination of isotonics: PFM ↑<br>Muscles synergistic to the PFM:<br>*Anterior elevation pattern ↑*<br>*Posterior patterns ↓* |

Abbreviation: Add, Adduction; Abd, Abduction; ER, External Rotation; Ext, Extension; F, Female; Flex, Flexion; IR, Internal Rotation; M, Male; PNF, Proprioceptive Neuromuscular Facilitation; sEMG, Surface Electromyography; w/, with; w/o, without.

↑: Increase, ↓: Decrease, →: Similar or unchanged, >: Higher, and <: Lower.

*The Proprioceptive Neuromuscular Facilitation technique applied in the studies was determined according to explanations in the methods section.

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**Table 2.** Methodological quality assessment of studies

| Study | Items | | | | | | | | | | | Summary Quality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 11 | 12 | 13 | 14 | |
| Sullivan & Portney (15) | Yes | No | NR | No | No | No | No | Yes | NA | NR | No | Poor |
| Swanik et al. (16) | Yes | No | No | Yes | No | No | No | Yes | NA | NR | No | Poor |
| Witt et al. (17) | Yes | No | NR | Yes | No | No | No | Yes | NA | NR | No | Poor |
| Youdas et al. (18) | Yes | No | Yes | Yes | Yes | No | No | Yes | NA | NR | No | Fair |
| Kim et al. (19) | Yes | No | NR | Yes | Yes | No | No | Yes | NA | NR | No | Poor |
| Youdas et al. (20) | Yes | No | Yes | Yes | Yes | No | No | Yes | NA | Yes | No | Good |
| Comel et al. (21) | Yes | Yes | NR | Yes | No | No | No | Yes | NA | Yes | No | Fair |
| Dionisio et al. (22) | Yes | Yes | NR | Yes | No | No | No | Yes | NA | NR | No | Poor |
| Park & Hwank (23) | Yes | No | Yes | Yes | Yes | No | No | Yes | NA | Yes | No | Good |
| Marchese et al. (24) | Yes | Yes | Yes | Yes | Yes | No | No | Yes | NA | Yes | No | Good |
| Ferro et al. (25) | Yes | Yes | NR | Yes | Yes | No | No | Yes | NA | Yes | No | Good |

Abbreviations: NA, not applicable; NR, not reported.