

# Effectiveness of Static, Dynamic, and Proprioceptive Neuromuscular Facilitation Stretching on Hamstring Flexibility in Athletics: A Scoping Review

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## Abstract

**Background:** Hamstring flexibility is a key determinant of efficient lower-limb mechanics, optimal sports performance, and reduced injury risk. Techniques such as static stretching, dynamic stretching, and proprioceptive neuromuscular facilitation (PNF) are widely applied to increase joint range of motion, yet their physiological mechanisms and influence on performance are still a matter of discussion. A clear understanding of both the immediate and long-term effects of these methods is therefore important for designing evidence-based training and rehabilitation programs.

**Objective:** To map and synthesize the existing evidence on the effects of stretching interventions on hamstring flexibility, underlying Motor control mechanisms, and performance-related outcomes.

**Methodology:** A scoping review was conducted following established methodological frameworks and PRISMA-ScR guidelines. Electronic databases were searched to identify peer-reviewed studies examining hamstring flexibility and stretching interventions. Relevant experimental studies, mechanistic investigations, and systematic reviews were included and synthesized narratively.

**Results:** The evidence indicates that static stretching, dynamic stretching, and PNF effectively increase hamstring range of motion. Acute flexibility gains are primarily mediated by neural and perceptual adaptations rather than structural tissue changes. Prolonged static stretching performed immediately before activity may transiently impair strength and power, whereas dynamic stretching generally preserves performance. Chronic improvements in flexibility depend largely on stretching volume, frequency, and program design.

**Conclusion:** Hamstring flexibility is highly modifiable through targeted stretching interventions; however, modality selection, timing, and training variables are critical to optimize both flexibility and performance outcomes.

**Keywords:** Hamstring flexibility, Stretching interventions, Range of motion and Athletic performance

## Introduction

Flexibility is a fundamental physical attribute that contributes to efficient movement, optimal performance, and a reduced risk of musculoskeletal injury.<sup>1,2</sup> Adequate joint range of motion (ROM) is essential for maintaining normal biomechanics during functional activities and athletic tasks, while reduced flexibility may predispose individuals to compensatory movement patterns and increased tissue loading.<sup>2,3</sup> As a result, stretching has become one of the most widely prescribed interventions to improve flexibility and is routinely incorporated into warm-up routines, conditioning programs, and physiotherapy rehabilitation protocols.<sup>1,4</sup> Several stretching techniques are commonly used in clinical and athletic settings, including static stretching, dynamic stretching, and proprioceptive neuromuscular facilitation (PNF), each differing in application, intensity, and physiological effects.<sup>1,5</sup> Static stretching has traditionally been regarded as an effective method for increasing ROM and is widely used in rehabilitation and flexibility training programs.<sup>1,4</sup> Evidence suggests that prolonged static stretching performed immediately before activity can temporarily reduce strength, power, and overall performance, whereas dynamic stretching is generally preferred in warm-up routines because it improves neuromuscular readiness while maintaining or enhancing muscular performance.<sup>1,6</sup> The mechanisms underlying stretching-induced improvements in ROM have been extensively investigated, with increasing evidence suggesting that structural changes in muscle-tendon units may not be the primary contributing factor.<sup>3,7</sup> Konrad and Tilp demonstrated that increases in ROM following static stretching are largely attributed to enhanced stretch tolerance and neural adaptations rather than changes in muscle or tendon stiffness.<sup>7</sup> These findings challenge traditional assumptions regarding flexibility training and highlight the importance of neuromuscular and sensory factors in ROM enhancement.<sup>3,7</sup> The chronic effects of stretching interventions have been examined through systematic reviews and experimental studies across various joints and populations.<sup>8,9</sup> Medeiros and Martini reported significant improvements in ankle dorsiflexion ROM following long-term stretching programs, irrespective of the stretching technique employed.<sup>8</sup> Similarly, Bandy and colleagues demonstrated that both stretching duration and frequency are critical determinants of flexibility gains, particularly in the hamstring musculature.<sup>4</sup> Comparative studies further indicate that PNF stretching may produce greater immediate improvements in flexibility compared to static stretching, especially when combined with prior muscle activation.<sup>5,10</sup> Despite substantial evidence supporting the effectiveness of stretching, uncertainty remains regarding the optimal stretching modality, dosage, and timing for maximizing flexibility while minimizing adverse performance effects.<sup>9,10</sup> Therefore, a comprehensive understanding of the acute and chronic Motor control responses to different stretching techniques is essential for evidence-based clinical practice and performance optimization.<sup>1,2</sup>

## Objective

To summarize existing evidence on the effects of static, dynamic, and proprioceptive neuromuscular facilitation stretching on hamstring flexibility, and identify gaps to guide clinical practice and future research.

## Methodology

This scoping review was conducted in accordance with the methodological framework proposed by Arksey and O'Malley (2005) and further refined by Levac et al. (2010). The review process was planned

a priori; however, the protocol was not formally registered. The scoping review followed five sequential stages: (1) identification of the research question, (2) identification of relevant studies, (3) study selection, (4) data charting, and (5) collating, summarizing, and reporting the results.

The primary research question guiding this review was: What is the effect of different stretching techniques on hamstring flexibility? Secondary questions included: What are the acute and chronic effects of stretching on hamstring range of motion? What stretching parameters (type, duration, and frequency) are commonly used? What outcome measures are employed to assess hamstring flexibility?

Studies were considered eligible if they met the following inclusion criteria: (1) involved human participants, (2) examined hamstring flexibility or range of motion, (3) included stretching interventions such as static stretching, dynamic stretching, or proprioceptive neuromuscular facilitation (PNF), and (4) were published in English in peer-reviewed journals. All study designs were eligible for inclusion. Studies were excluded if they focused on non-hamstring muscle groups, involved surgical or pharmacological interventions, or did not report flexibility or range-of-motion outcomes.

A comprehensive literature search was conducted across PubMed, Scopus, Web of Science, and CINAHL databases from inception to October 2025. Search terms were combined using Boolean operators and included variations of: “hamstring flexibility,” “hamstring stretching,” “static stretching,” “dynamic stretching,” “PNF stretching,” and “range of motion.” The search strategy integrated terms related to the hamstring musculature, stretching interventions, and flexibility outcomes.

Following removal of duplicate records, titles and abstracts were screened for relevance, after which full-text articles were assessed for eligibility. The study selection process adhered to PRISMA ScR 2020 guidelines and is illustrated in Figure 1. A total of eleven studies met the broad inclusion criteria, of which five studies fulfilled the refined eligibility requirements and were included in the final scoping review.

Data extracted from the included studies comprised author details, publication year, country, study design, participant characteristics, type of stretching intervention, stretching parameters, outcome measures related to hamstring flexibility, and key findings. Due to heterogeneity in study designs and outcome measures, results were synthesized using a narrative approach.

## Study Design

A scoping review to synthesise existing evidence of effects of hamstring flexibility in athletic populations. The conduct and reporting of this review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines to ensure methodological transparency and reproducibility.

The scoping review approach was selected to capture the breadth of evidence across diverse study designs, interventions, outcome measures, and athletic populations, consistent with the exploratory nature of the research question.

## Research Question

What is the effectiveness of hamstring flexibility in athletic populations?

## Data Sources and Search Strategy

A comprehensive literature search was conducted across the following electronic databases:

- PubMed
- PEDro

- Google Scholar

The search strategy combined keywords and Boolean operators such as: “hamstring flexibility” AND “athletes” OR “sports” AND “stretching” OR “range of motion” OR “flexibility training.”

### Study Selection

All articles were reviewed manually, Titles and abstracts were screened independently, followed by full-text review to determine eligibility based on predefined inclusion and exclusion criteria.

### Criteria

#### Inclusion Criteria

- Studies involving athletic populations
- Studies assessing hamstring flexibility
- Randomized controlled trials, quasi-experimental studies, and observational studies
- Articles published in English
- Full-text availability

#### Exclusion Criteria

- Studies involving non-athletic or clinical populations
- Case reports, editorials, and narrative reviews
- Studies focusing on lower limb flexibility without specific hamstring assessment

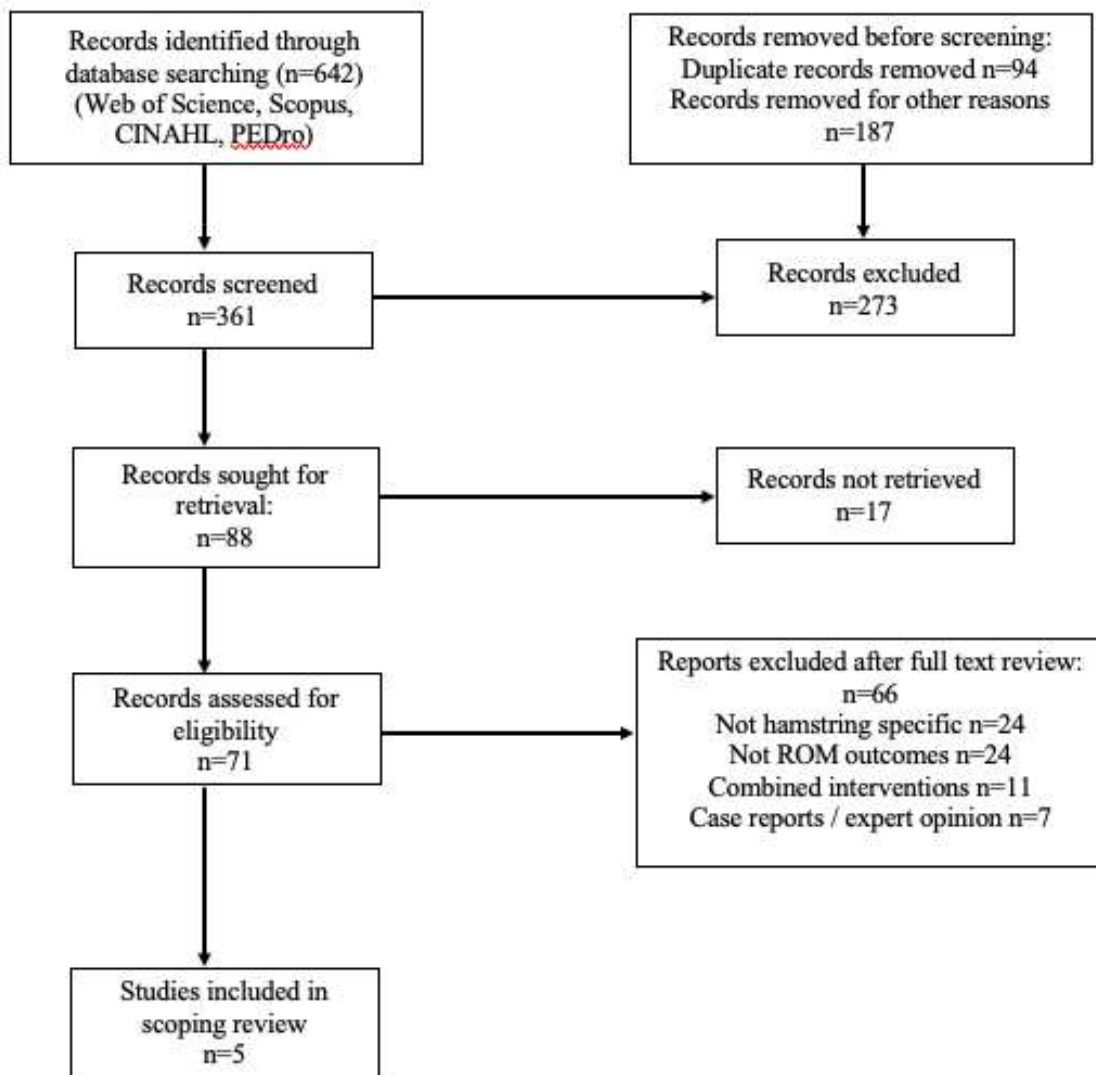
### Literature review

1. Behm D G, Chaouachi A (2011) critically reviewed the acute effects of static and dynamic stretching on performance in trained individuals. They reported that static stretching is effective for increasing joint range of motion, including hamstring flexibility, but prolonged static stretching performed just before activity can temporarily reduce strength, power, and sprint performance. In contrast, dynamic stretching was found to improve flexibility while maintaining or even enhancing neuromuscular performance. The authors highlighted that the type, duration, and timing of stretching are key factors influencing both flexibility and performance, supporting the need for individualized stretching strategies in athletic training and injury prevention programs.<sup>1</sup>
2. Bandy, Irion, and Briggler (1998) examined the effects of stretching duration and frequency on hamstring flexibility. They found that longer stretching times and more frequent sessions led to significantly greater improvements in hamstring range of motion compared to shorter or less frequent protocols. This study provides important evidence for prescribing static stretching parameters and continues to guide flexibility training in both clinical and athletic settings.<sup>4</sup>
3. Funk et al. (2003) examined Impact of prior exercise on hamstring flexibility: a comparison of proprioceptive neuromuscular facilitation and static stretching in trained individuals, with particular emphasis on the influence of prior exercise. The study demonstrated that both stretching techniques significantly improved hamstring range of motion; however, PNF stretching produced greater flexibility gains compared to static stretching. These findings support the effectiveness of targeted stretching interventions for enhancing hamstring flexibility in athletic populations.<sup>(5)</sup>
4. Konrad A, Tilp M. (2014) investigated the underlying mechanisms responsible for Increased range of motion after static stretching is not due to changes in muscle and tendon structures. Their findings

demonstrated that improvements in flexibility, including hamstring range of motion, were not attributable to structural changes in muscle or tendon tissue, but rather to increased stretch tolerance and altered neuromuscular responses. This study provides important mechanistic insight, suggesting that flexibility gains in athletes may result from neural adaptations rather than morphological changes.(7)

5. Medeiros DM, Martini TF. (2018) systematically reviewed the Chronic effects of different stretching techniques on joint range of motion, reporting that static stretching, dynamic stretching, and proprioceptive neuromuscular facilitation were all effective in improving flexibility when performed over time. Although the review focused on ankle dorsiflexion, the authors highlighted that stretching frequency, duration, and method are key determinants of long-term flexibility gains, offering comparative insights that are directly applicable to hamstring flexibility training in athletic populations.(8)

Figure 1



## Result

### Overview of the Evidence Base

The literature includes experimental studies, mechanistic research, and narrative and systematic reviews examining the effects of stretching on hamstring flexibility, muscle–tendon behavior, and performance (Behm & Chaouachi, 2011; Kay & Blazevich, 2012; Freitas & Mil-Homens, 2018). Earlier studies focused mainly on viscoelastic properties, whereas later work emphasized neural mechanisms and performance-related effects (Magnusson et al., 1996; Konrad & Tilp, 2014; Freitas & Mil-Homens, 2018). Hamstring flexibility is typically assessed using joint range of motion or passive torque–angle measures, while performance outcomes include strength, power, sprint ability, and neuromuscular activation (Behm & Chaouachi, 2011; Kay & Blazevich, 2012). Both acute and chronic effects of static, dynamic, and PNF stretching are well represented in the literature (Funk et al., 2003; Sharman et al., 2006; Medeiros & Martini, 2018).

### Acute Effects of Stretching on Flexibility and Performance

Acute stretching consistently increases joint range of motion, including hamstring flexibility (Behm & Chaouachi, 2011; Konrad & Tilp, 2014). Static stretching produces clear short-term gains, but when performed immediately before explosive tasks it is commonly associated with temporary reductions in strength, power, and sprint performance, particularly with longer or more intense protocols (Behm & Chaouachi, 2011; Kay & Blazevich, 2012; Freitas & Mil-Homens, 2018). Dynamic stretching, in contrast, generally preserves or enhances performance while still providing modest improvements in range of motion (Behm & Chaouachi, 2011). Evidence indicates that static stretching exceeding approximately 60 seconds per muscle group is most consistently linked to performance decrements, whereas shorter durations have minimal negative effects (Kay & Blazevich, 2012).

### Mechanisms Underlying Acute Increases in Range of Motion

Mechanistic studies indicate that short-term increases in range of motion are not primarily due to structural changes in muscle or tendon tissue (Magnusson et al., 1996; Konrad & Tilp, 2014). Improvements in flexibility can occur without measurable changes in tissue stiffness, suggesting a dominant role for increased stretch tolerance and neural factors (Konrad & Tilp, 2014). Repeated static stretching reduces passive resistance through stress relaxation but does not produce lasting increases in muscle length (Magnusson et al., 1996). Reviews further support that early flexibility gains are mainly explained by changes in sensory perception, pain tolerance, and reflex activity rather than morphological adaptation (Freitas & Mil-Homens, 2018). This aligns with observations that flexibility can increase rapidly, sometimes alongside transient reductions in performance due to altered neural drive (Behm & Chaouachi, 2011; Kay & Blazevich, 2012).

### Viscoelastic Properties of the Hamstring Muscle

Early work demonstrated that the hamstring muscle–tendon unit exhibits clear viscoelastic behavior, with passive tension decreasing through stress relaxation during repeated static stretching (Magnusson et al., 1996). However, these changes occur without permanent increases in muscle length, reinforcing that short-term flexibility gains are not structural (Magnusson et al., 1996; Konrad & Tilp, 2014). This explains why acute improvements in range of motion tend to diminish without continued stretching exposure (Magnusson et al., 1996; Freitas & Mil-Homens, 2018). Clinically, this supports the need for regular

stretching to achieve and maintain lasting improvements in hamstring flexibility (Bandy et al., 1997; Medeiros & Martini, 2018).

### **Chronic Effects of Stretching on Hamstring Flexibility**

Training studies show that repeated stretching over several weeks leads to more persistent increases in hamstring range of motion (Bandy et al., 1997; Medeiros & Martini, 2018). Both stretching duration and frequency influence the magnitude of improvement, supporting a dose–response relationship (Bandy et al., 1997). A systematic review and meta-analysis further reported that static, dynamic, and PNF stretching can all produce chronic increases in range of motion when applied consistently, with total stretching volume and program design being key determinants (Medeiros & Martini, 2018). Although focused on ankle dorsiflexion, these principles are directly applicable to hamstring training.

### **Comparison of Stretching Modalities**

Comparative studies indicate that different stretching techniques produce varying magnitudes of flexibility gains and distinct neuromuscular effects (Funk et al., 2003; Sharman et al., 2006). Both static and PNF stretching increase hamstring range of motion, but PNF often produces larger immediate gains, likely due to stronger inhibitory effects on the stretched muscle (Funk et al., 2003; Sharman et al., 2006). These effects are explained by mechanisms such as autogenic and reciprocal inhibition, which reduce muscle activation during stretching (Sharman et al., 2006). However, PNF techniques require greater technical skill and supervision, whereas static and dynamic stretching are simpler and more practical for routine use (Behm & Chaouachi, 2011).

### **Flexibility and Injury Risk**

The relationship between flexibility and injury risk is multifactorial and cannot be explained by range of motion alone (Magnusson & Renström, 2006). While marked stiffness may increase injury risk, excessive flexibility does not necessarily provide additional protection and may not be sport-specific (Magnusson & Renström, 2006). Strength, neuromuscular control, and load management are therefore essential components of injury prevention (Magnusson & Renström, 2006). In hamstring conditioning, stretching should be viewed as one element of a broader training program rather than a standalone preventive strategy (Behm & Chaouachi, 2011). This is consistent with evidence showing that flexibility gains do not automatically translate into improved performance or reduced injury risk (Behm & Chaouachi, 2011; Kay & Blazevich, 2012).

### **Integration of Mechanisms and Training Outcomes**

Taken together, the evidence indicates that acute increases in hamstring flexibility are mainly mediated by neural and perceptual factors, whereas chronic gains depend on repeated exposure and adequate training volume (Magnusson et al., 1996; Konrad & Tilp, 2014; Freitas & Mil-Homens, 2018). Static stretching is effective for increasing range of motion but may impair performance if used immediately before explosive activity (Behm & Chaouachi, 2011; Kay & Blazevich, 2012). Dynamic stretching appears more suitable in pre-performance settings, while PNF provides the greatest short-term flexibility gains but requires greater technical expertise (Funk et al., 2003; Sharman et al., 2006).

**Table 1. Summary of Stretching Modalities and Primary Effects**

Stretching modality	Primary effect on ROM	Acute performance effect	Key references
Static stretching	Clear increase in ROM	May reduce strength/power if prolonged	Behm & Chaouachi, 2011; Kay & Blazevich, 2012; Konrad & Tilp, 2014
Dynamic stretching	Moderate increase in ROM	Maintains or improves performance	Behm & Chaouachi, 2011
PNF stretching	Large acute increase in ROM	Variable, technique-dependent	Funk et al., 2003; Sharman et al., 2006

**Table 2. Mechanisms and Training Adaptations Related to Hamstring Flexibility**

Aspect	Main finding	Supporting references
Acute ROM increase	Predominantly neural/stretch tolerance	Magnusson et al., 1996; Konrad & Tilp, 2014; Freitas & Mil-Homens, 2018
Viscoelastic response	Stress relaxation without permanent length change	Magnusson et al., 1996
Chronic adaptation	Sustained ROM increase with sufficient volume/frequency	Bandy et al., 1997; Medeiros & Martini, 2018
Injury risk relation	Flexibility is only one factor among many	Magnusson & Renström, 2006

Overall, the evidence demonstrates that hamstring flexibility is highly responsive to stretching interventions, but the outcomes depend strongly on modality, volume, and timing (Behm & Chaouachi, 2011; Bandy et al., 1997; Medeiros & Martini, 2018). Acute gains in range of motion are largely neural in origin, whereas chronic improvements require consistent training exposure (Magnusson et al., 1996; Konrad & Tilp, 2014; Freitas & Mil-Homens, 2018). Performance considerations are critical, as prolonged static stretching before activity can impair force and power production (Kay & Blazevich, 2012). Consequently, flexibility training for the hamstrings should be strategically integrated into athletic programs to optimize both range of motion and performance outcomes (Behm & Chaouachi, 2011; Sharman et al., 2006).

## Discussion

This scoping review brings together evidence from experimental studies, mechanistic research, and systematic reviews on the effects of stretching on hamstring flexibility, muscle–tendon behavior, and performance. Across studies, several consistent findings emerge: hamstring range of motion can be improved both acutely and over time; short-term gains are mainly driven by neural and perceptual factors rather than structural tissue changes; prolonged static stretching performed just before explosive activity can reduce strength and power; and the effects of stretching depend strongly on the method, volume, and timing used (Behm & Chaouachi, 2011; Kay & Blazevich, 2012; Konrad & Tilp, 2014; Freitas & Mil-Homens, 2018; Medeiros & Martini, 2018).

A key distinction in the literature is between acute and chronic adaptations. Early work showed that repeated static stretching reduces passive resistance through stress relaxation, reflecting viscoelastic

behavior rather than permanent increases in muscle length (Magnusson et al., 1996). Later studies confirmed that short-term increases in range of motion occur without changes in muscle or tendon stiffness and are better explained by increased stretch tolerance and altered neural responses (Konrad & Tilp, 2014). Reviews further suggest that early flexibility gains are largely due to changes in sensory perception and reflex activity, while longer-term training may lead to more stable adaptations (Freitas & Mil-Homens, 2018). This explains why range of motion can improve quickly but requires continued training to be maintained (Magnusson et al., 1996; Freitas & Mil-Homens, 2018).

Evidence from training studies shows a clear dose–response relationship. Bandy et al. demonstrated that both the duration and frequency of stretching influence improvements in hamstring flexibility, with greater gains seen with longer and more frequent stretching (Bandy et al., 1997). Similarly, Medeiros and Martini reported that long-term increases in range of motion depend mainly on total stretching volume and program design rather than the specific technique used (Medeiros & Martini, 2018). These findings highlight the importance of structured and consistent flexibility programs.

Comparisons between stretching methods show that both static and PNF stretching increase hamstring range of motion, but PNF often produces larger immediate gains (Funk et al., 2003). This has been explained by mechanisms such as autogenic and reciprocal inhibition, which reduce muscle activity and allow greater movement during stretching (Sharman et al., 2006). However, PNF techniques are more complex and usually require supervision, whereas static and dynamic stretching are simpler and easier to apply in most settings (Behm & Chaouachi, 2011).

The interaction between stretching and performance is particularly important in the acute setting. Static stretching can temporarily reduce maximal strength, power, and sprint performance when performed immediately before activity, especially when stretching lasts longer than about 60 seconds per muscle group (Behm & Chaouachi, 2011; Kay & Blazevich, 2012). These effects are likely related to short-term changes in neural activation and reflex sensitivity (Kay & Blazevich, 2012; Freitas & Mil-Homens, 2018). In contrast, dynamic stretching generally maintains or improves performance while still producing small increases in range of motion, making it more suitable for warm-up routines in power- and speed-based sports (Behm & Chaouachi, 2011).

The link between flexibility and injury risk is not straightforward. While marked stiffness may increase injury risk, very high flexibility does not necessarily provide extra protection and may not match the demands of a given sport (Magnusson & Renström, 2006). Injury risk depends on multiple factors, including strength, neuromuscular control, coordination, and load management, not flexibility alone (Magnusson & Renström, 2006). This supports the view that stretching should be part of a broader conditioning program rather than used in isolation (Behm & Chaouachi, 2011).

Overall, the evidence suggests that short-term improvements in hamstring flexibility are mainly driven by neural and perceptual adaptations, whereas longer-term gains depend on repeated training with adequate volume and frequency (Magnusson et al., 1996; Konrad & Tilp, 2014; Freitas & Mil-Homens, 2018; Bandy et al., 1997; Medeiros & Martini, 2018). Static stretching is effective for increasing range of motion but should be used carefully around performance, while dynamic stretching is more appropriate in warm-up settings. PNF can be useful when rapid gains are needed, provided appropriate supervision is available (Funk et al., 2003; Sharman et al., 2006). Flexibility training should be integrated with strength and neuromuscular training to support both performance and injury prevention (Magnusson & Renström, 2006).

## Conclusion

This scoping review summarizes current evidence on the effects of stretching on hamstring flexibility, muscle–tendon behavior, and performance. The findings indicate that static, dynamic, and proprioceptive neuromuscular facilitation stretching can all improve hamstring range of motion, with short-term gains largely attributed to neural and perceptual adaptations rather than immediate structural changes. Long-term improvements appear to depend mainly on stretching volume, frequency, and program design. The literature also highlights performance considerations, as prolonged static stretching before activity may temporarily reduce strength and power, whereas dynamic stretching generally preserves or enhances performance. However, most studies focus on acute effects, and further well-designed longitudinal trials are needed to clarify long-term mechanisms and guide evidence-based stretching practice.

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