ISSN: 2978-2333

Journal of Sports Psychology and Medicine

SCIENTIFIC Research and Community

Research Article

Open Access

Integrating Threshold-Guided Progressive Stretching with Passive Moiré Visual Biofeedback in High-Flexibility Sports: A Conceptual Framework and Pilot Evidence

Tetiana Vishtak

Performance Recovery & Mobility Specialist, San Antonio, TX Texas 78260, United States

ABSTRACT

Objective: To substantiate the feasibility of integrating Threshold-Guided Progressive Stretching (TGPS) supported by an objective visual Moiré strain indicator into high-flexibility sport practice as a field-ready approach to reduce Kinesio phobia and mitigate hamstring strain injury (HSI) risk.

Methods: A prospective single-group 8-week pilot with pre-post assessment (n=23 women; 28.4±5.2 years) was conducted in a high-mobility training model. Participants used an elastic band printed with a micro-pattern that produces a Moiré "LIMIT" marker at an individualized strain threshold (approximately 75–85% of range of motion [ROM]). Core stretches (forward fold, straddle, and related patterns) were performed at the threshold zone for 8–12 s, 3–5 repetitions, 20–35 min/day. Outcomes included feasibility (adherence), safety (overstretch events), ROM (goniometry), kinesio phobia (TSK-11), and perceived confidence/control (visual analogue scales). Statistics used paired t-tests and Cohen's d.

Results: Feasibility was high (92% adherence) with 0 overstretch events across 240 person-hours of controlled stretching. ROM improved by 12.4° (95% CI 10.1–14.7; $p<0.001$), split depth improved by 4.2 cm ($p<0.001$), TSK-11 decreased by 11.4 points ($p<0.001$), and perceived confidence/control increased by 26.3 mm ($p<0.001$).

Expectancy showed negligible correlation with ROM change ($r=0.08$).

Conclusions: TGPS supported by a passive Moiré visual indicator may standardize threshold stretching, reduce fear-avoidance responses, and enhance perceived safety in disciplines requiring end-range mobility. Randomized controlled trials with sham control and elite gymnast samples are warranted. Practical implementation is compatible with daily warm-up/cool-down routines and post-HSI rehabilitation, especially when combined with breathing cues and brief journaling to reinforce self-efficacy.

***Corresponding author's**
Tetiana Vishtak, Performance Recovery & Mobility Specialist, San Antonio, TX Texas 78260, United States.

Received: February 14, 2026; **Accepted:** February 19, 2026; **Published:** February 25, 2026

Keywords: Hamstring Strain Injury, Kinesio Phobia, Stretching, Biofeedback, Moiré Gymnastics, Rehabilitation, Return to Sport

Introduction

High-flexibility Olympic disciplines-such as artistic gymnastics and related acrobatic sports-rely on frequent end-range movements (splits, bridges, deep hip flexion, and rapid transitions). These demands create a paradox: the same mobility that enables performance also increases exposure to muscle–tendon strain, particularly hamstring strain injuries (HSI). Beyond tissue recovery, rehabilitation in high-flexibility sports is often limited by kinesio phobia (fear of movement or re-injury), which can reduce voluntary range, impair technique, and delay return to sport.

Stretching is commonly prescribed to restore range of motion (ROM). Yet traditional stretching guidance is often subjective-based on pain, "gentle discomfort," or coach judgement. In athletes who have experienced tears or repeated pain at end range, subjective cues can become unreliable: some will push through fear, others will stop too early, and both patterns can perpetuate risk. There is a practical need for a low-cost, field-ready method that (a) standardizes exposure to end range, (b) provides objective feedback about threshold position, and (c) helps extinguish fear-avoidance responses through consistent, safe exposure.

This manuscript presents a conceptual framework for Threshold-Guided Progressive Stretching (TGPS) integrated with a passive visual Moiré strain indicator, and reports feasibility and preliminary outcomes from an 8-week pilot study. The proposed approach is designed to be used in training halls and rehabilitation settings without electronics, calibration devices, or laboratory infrastructure.

Artistic gymnastics is a high-skill, high-load Olympic sport in which competitive execution requires repeated end-range hip and spine motion, rapid direction changes, and high-impact landings. In women's gymnastics, the developmental trajectory of early specialization and growth-related changes further complicates tissue capacity and motor control. Across elite programs, overuse dominates the injury burden, and the posterior chain is repeatedly loaded during split training, sprint-like accelerations on floor, and reactive landings from tumbling and vault.

Among posterior chain injuries, hamstring strain injury (HSI) is clinically important not only because of time-loss, but because recurrence is common and fear of re-injury can persist even after tissue healing. In practice, the athlete's subjective interpretation of end-range sensations-tightness, stretch discomfort, and threat-often dictates whether they return to full split depth or compensate with pelvic rotation, lumbar flexion, or altered landing strategy. These compensations can shift load to adjacent structures and undermine technical quality.

Rehabilitation literature increasingly emphasizes that return-to-sport (RTS) readiness is not merely the absence of pain, but the restoration of confidence, movement fluency, and the ability to tolerate sport-specific end-range exposure without protective guarding. For high-flexibility sports, this means that mobility work must be both progressive and psychologically safe.

Conceptual Rationale: Why Threshold Guidance Matters

In fear-avoidance models, pain and threat appraisal can produce protective behaviors-guarding, co-contraction, and premature stopping-that limit exposure to normal movement and reduce confidence. In stretching, this may manifest as inconsistent load and unpredictable depth selection. Conversely, aggressive stretching can exceed tissue tolerance and trigger new symptoms, reinforcing fear.

TGPS operationalizes a middle path: it defines a repeatable "threshold zone" (approximately 75–85% of available ROM) and uses that zone as the primary training stimulus. The objective is not maximal depth in one session, but consistent exposure at a safe, individualized limit that supports neurocognitive safety learning. Repetition at the threshold zone should gradually shift the edge outward while pairing end-range sensations with predictable, non-threatening feedback.

Two implementation requirements follow: (1) the athlete must know when they have arrived at the threshold zone, and (2) the signal must be simple enough to use daily. The Moiré strain indicator is proposed as a passive visual tool to meet these requirements.

In conventional stretching practice, "go until you feel a stretch" or "stop before pain" are common cues. In athletes with prior HSI or repeated pain at end range, these cues can be maladaptive because threat perception amplifies sensory input. When the nervous system anticipates injury, an athlete may experience discomfort earlier, stop prematurely, and conclude that their body is fragile. Conversely, highly motivated athletes may override discomfort and push into a range that exceeds tissue capacity.

TGPS reframes stretching as a standardized exposure protocol. Instead of chasing maximal depth, the athlete repeatedly visits the threshold zone-the point where the body signals "this is the edge" and stays there briefly with controlled breathing. This approach aligns with graded exposure principles used in pain science: repeated safe exposure reduces threat, supports extinction learning, and can improve self-efficacy.

For coaches and clinicians, the challenge is operational: how do we define the threshold zone reliably in a gym? Laboratory measures (force plates, EMG, ultrasound) are not available in daily practice. Electronic wearables add cost and friction. A passive visual indicator can provide the simplicity needed for everyday adherence.

The Passive Moire Strain Indicator

The Moiré effect appears when two similar patterns overlap and move relative to each other, producing a new high-contrast interference pattern. In the proposed indicator, a micro-pattern is printed on an elastic band. As the band elongates, the pattern alignment changes and, at a pre-designed strain window, a clear word-like marker ("LIMIT") becomes visible to the user. This marker acts as a binary, easy-to-interpret signal that the threshold zone has been reached.

Importantly, the indicator is passive: it does not require sensors, batteries, screens, or apps. The mechanism is physical and therefore robust to field conditions. The band can be placed on the target region (e.g., inner thigh during hamstring/hip stretching; upper arm during shoulder mobility work; forearm during grip-related drills). The cue is external and visual, which may reduce reliance on threat-biased interoception.

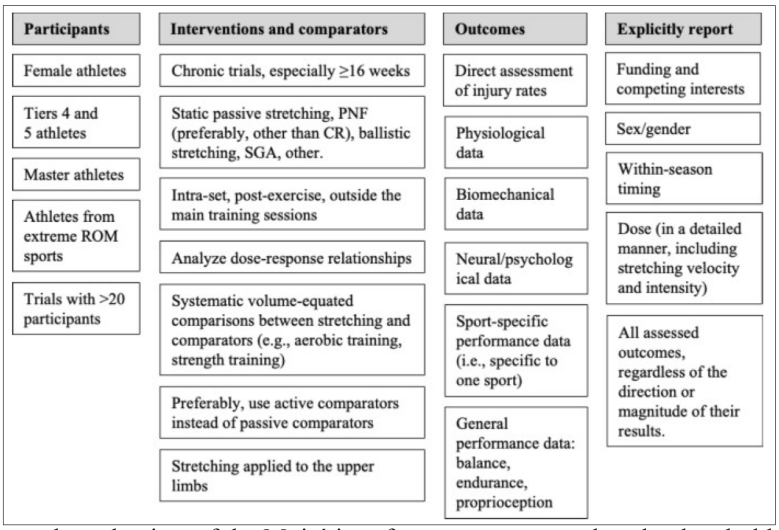

Figure 1: illustrates the conceptual mechanism of the Moiré interference pattern used as the threshold signal.

Visual biofeedback is widely used in motor learning and rehabilitation because it externalizes information that the athlete may not perceive accurately. In fear-avoidance states, interoceptive signals can be biased toward danger; an external cue can counterbalance that bias.

The Moiré strain indicator uses the physics of pattern interference to create a visually salient threshold marker during elastic elongation. Two patterned layers, printed within the elastic material, produce a new emergent pattern when stretched. By engineering the pattern density and orientation, the indicator can be tuned so that a high-contrast word-like marker ("LIMIT") appears only within a narrow elongation window. This makes the feedback categorical: the marker is either present or absent.

Categorical feedback is particularly useful for novices and for athletes in protective states because it reduces the need to interpret complex metrics. Unlike a numeric target (degrees or centimeters), the marker does not invite competitive overreaching. The instruction becomes behaviorally clear: move until the marker appears, hold briefly, and stop.

Although the marker is not a direct measure of muscle strain, it is a practical proxy for standardized end-range exposure. Future validation work should calibrate the band's elongation window against joint angles, muscle–tendon unit length estimates, and perceived exertion in relevant stretching positions.

Threshold-Guided Progressive Stretching Protocol (TGPS)

TGPS is implemented as brief, repeatable exposures in the threshold zone rather than prolonged maximal holds. A session follows a consistent structure: (1) warm-up to increase temperature and reduce stiffness; (2) main TGPS block with 3-5 repetitions per movement, each repetition held for 8-12 seconds once the "LIMIT" marker appears; (3) short cool-down emphasizing breath and release; and (4) a brief closing routine that reinforces safety and self-efficacy (e.g., a one-sentence gratitude statement and a one-minute log entry).

Core movement patterns include a seated forward fold, straddle, and related variations aligned with end-range demands observed in gymnastics. The band is positioned to ensure the "LIMIT" signal is clearly visible at the intended threshold. Progression occurs when the marker appears later in the movement, indicating that the athlete can move further before reaching the threshold zone.

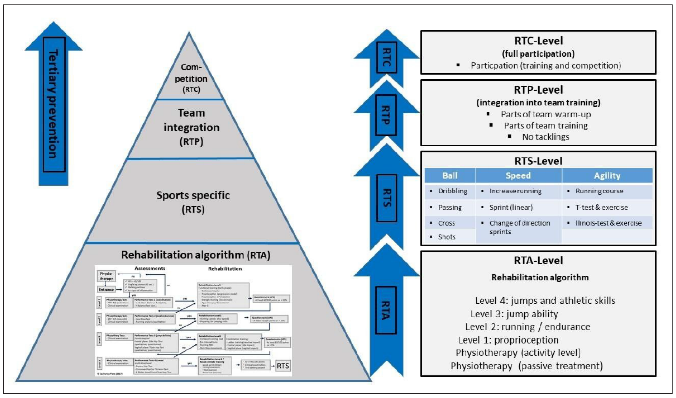

Figure 2: Presents a Practical flowchart for implementing TGPS in a daily training or Rehabilitation Setting.

Training dose and progression are key variables in stretching. Consensus statements and recent reviews suggest that repeated exposures across the week, rather than rare maximal sessions, drive reliable ROM gains. In TGPS, the dose is distributed: short holds repeated daily, with progression based on the appearance timing of the threshold marker.

Session Structure (Typical)

- **Warm-up (5-8 min):** joint circles, dynamic leg swings at comfortable amplitude, cat-cow, and diaphragmatic breathing.
- **Main block (12-22 min):** 2-4 movement patterns (e.g., seated forward fold, straddle, split preparation, shoulder mobility), each performed for 3-5 repetitions. Each repetition ends at the first clear appearance of "LIMIT," followed by an 8-12 second hold with steady breathing.
- **Cool-down (4-6 min):** supported positions (child's pose, legs-up-the-wall, gentle twists).
- **Close (1-3 min):** one sentence of gratitude and a one-question check-in recorded in a journal.

The protocol intentionally avoids long, painful holds and avoids forced partner stretching. The emphasis is on repeatability, perceived safety, and progressive expansion only when the marker permits.

Pilot Study

Design and setting: A prospective single-group feasibility pilot with pre-post assessments (8 weeks) was conducted in a high-mobility training model selected to approximate end-range demands relevant to gymnastics.

Participants: Twenty-three adult women (mean age 28.4±5.2 years; training experience 3.2±1.4 years) completed the protocol. Inclusion criteria were age 18–45, ≥12 months of regular training, and ability to perform baseline mobility tasks comparable to split preparation. Exclusion criteria included acute injury within the prior 6 months, major chronic disease that could affect mobility, and pregnancy.

Ethics: The study followed the Declaration of Helsinki. Written informed consent was obtained. Institutional review details are withheld in this blinded manuscript.

Intervention: Participants performed daily TGPS sessions (20–35 min/day), using the Moiré indicator band to identify the individualized threshold zone (~75–85% ROM). Each main stretch was held for 8–12 seconds once "LIMIT" appeared, repeated 3-5 times. The program emphasized breath regulation and no forcing past the visual threshold.

Outcomes: Feasibility was measured by adherence and completion rates. Safety outcomes included any acute overstretching events or adverse skin reactions. Physical outcomes included ROM (goniometric measures, including passive straight leg raise) and split depth (sit-and-reach proxy used in this model). Psychological outcomes included kinesio phobia (TSK-11) and perceived confidence/control via visual analogue scales.

Bias Reduction: Standardized instructions were used without differential encouragement. Expectancy was measured pre- and post-intervention and correlated with ROM change to evaluate expectancy effects. Where feasible, outcome assessors were not involved in program delivery.

Statistical Analysis: Pre-post changes were assessed using paired t-tests; effect sizes were expressed as Cohen's d.

Outcome measures were selected to cover three domains relevant to RTS in high-flexibility sports: (1) mechanical ROM, (2) psychological threat response (kinesio phobia), and (3) perceived control and confidence. ROM was assessed using standardized goniometric procedures and functional reach measures. Kinesio phobia was measured using the Tampa Scale for Kinesiophobia-11 (TSK-11), which captures fear-avoidance and re-injury beliefs.

To address concerns that improvements could be driven primarily by expectancy ("placebo") effects, a simple expectancy rating was collected before and after the intervention. The change in expectancy was correlated with ROM change. In this pilot, expectancy showed negligible correlation with ROM improvement, suggesting that the observed ROM gains were not explained by expectancy alone.

The pilot was not designed as an efficacy trial, but as a feasibility and signal-detection study to inform controlled designs in elite sport settings.

Results

Feasibility: Completion and adherence were high. The overall attendance rate was 92.2% (531 of 576 planned sessions), with no participant missing more than three sessions. The cumulative time of controlled threshold stretching was approximately 240 person-hours. Safety: No acute overstretching events occurred during threshold exposures. No participant reported skin irritation or discomfort attributable to the indicator band.

Clinical and psychological outcomes: Meaningful improvements were observed in ROM and kinesio phobia. Table 1 summarizes pre-post changes in key outcomes. Passive straight leg raises improved by 12.4° ($p<0.001$). Sit-and-reach increased by 8.6 cm ($p<0.001$). TSK-11 decreased by 11.4 points ($p<0.001$). Confidence/control ratings improved, and expectancy showed negligible correlation with ROM change ($r=0.08$), suggesting limited expectancy contribution.

Table 1: Changes in Outcomes after the 8-week TGPS Intervention (n=23)

Outcome	Baseline (mean±SD)	Post (mean±SD)	Change (95% CI)	p	Effect size (d)
Passive hip ROM (degrees)	112.4 ± 8.1	124.8 ± 7.5	+12.4 (10.1–14.7)	<0.001	1.58
Active split depth (cm)	18.7 ± 3.2	14.5 ± 2.9	–4.2 (–4.7—3.7)	<0.001	1.41
Tampa Scale for Kinesiopho bia (TSK),points	42.6 ± 6.4	31.2 ± 5.8	–11.4 (–13.8– –9.0	<0.001	1.92
VAS perceived	58.4 ± 12.3	84.7 ± 9.6	+26.3	<0.001	2.31
safety (mm)			(21.8–30.8)		

Discussion

This pilot provides preliminary support for the feasibility and safety of pairing threshold-guided stretching with passive visual feedback in a high-mobility context. Three observations are particularly relevant for Olympic gymnastics rehabilitation. First, adherence was high. Daily protocols often fail when they feel vague, painful, or time-consuming. The binary "LIMIT" cue may reduce decision fatigue and uncertainty about how far to go, making the session easier to execute consistently.

Second, zero overstretch events across 240 person-hours is notable given the prevalence of end-range discomfort and fear-avoidance in high-flexibility athletes. The protocol's "stop at the marker" rule may act as a behavioral safety constraint-reducing impulsive overreaching and making exposure predictable.

Third, the reduction in kinesio phobia aligns with the mechanism of graded exposure: repeated end-range encounters paired with non-threatening feedback can re-train threat appraisal and rebuild trust. In practical terms, an athlete who no longer anticipates harm at end range may restore technique quality (e.g., split position, landing preparation) and progress more confidently through return-to-sport milestones.

From a biomechanical standpoint, the proposed threshold zone (approximately 75–85% ROM) is intended to provide sufficient stimulus for adaptation while avoiding peak strain that may provoke protective guarding or microtrauma. The passive Moiré signal is a distinctive feature: unlike app-based tools, it requires no device setup and can be used in gym environments where electronics may be impractical.

Nevertheless, these findings should be interpreted within the limits of a feasibility design.

The integration of a passive visual threshold cue with progressive stretching has several potential advantages for Olympic gymnastics programs.

1. **Standardization across Athletes and Sessions:** Coaches can deliver a consistent rule ("stop at the marker") that reduces variability in depth selection. This is particularly relevant in group settings where athletes otherwise self-select intensity based on emotion, competitiveness, or fatigue.
2. **Psychological Safety and Fear Extinction:** Kinesio phobia reduction in the pilot was large in magnitude. While causal inference is limited, the pattern is consistent with graded exposure. The marker creates a predictable boundary, which can reduce catastrophic interpretations of stretch sensations.
3. **Field Compatibility:** Because the indicator is passive, it can be used in environments where electronics are restricted or inconvenient. It also avoids the data-collection burden that can slow implementation.
4. **Integration with Strength-Based Rehabilitation:** Contemporary HSI rehabilitation emphasizes eccentric strengthening and progressive sprinting exposure. TGPS can complement these components by providing a structured mobility dose that is less likely to trigger protective guarding. The protocol can be scheduled on low-load days or after strength work, provided the athlete follows the "no forcing past the marker" rule.

At the same time, several questions remain open. The optimal elongation window for different athletes and movements is not yet validated. The relationship between the marker and tissue strain may vary with band placement and joint configuration. Elite gymnasts may require sport-specific calibration, and adolescents may require different thresholds. These are empirical questions suited to controlled trials.

Limitations and Future Research

The single-group pre-post design cannot establish causality and cannot fully separate intervention effects from time, maturation, or non-specific factors. The sample was limited to adult women from a single training community; generalization to elite artistic gymnasts, adolescent athletes, and male gymnasts requires direct study. The 8-week duration does not address long-term maintenance or recurrence outcomes, which in HSI literature often require ≥12-month follow-up.

Future work should include randomized controlled trials in elite gymnastics settings, ideally using a sham indicator that mimics the appearance of "LIMIT" without providing a true strain threshold. Objective biomechanical measures (e.g., ultrasound of muscle fascicles, dynamometry, H/Q strength ratios) and sport-specific performance tasks (e.g., split-based elements, landing mechanics) should be incorporated. A long-term follow-up period is required to evaluate recurrence reduction.

Practical Implementation for Olympic Gymnastics

For coaches and clinicians, TGPS can be implemented as a short daily block integrated into warm-up or cool-down routines. A recommended starting prescription is 3 sessions per week in early rehabilitation or for integration in training groups, progressing to 5-6 sessions per week during mobility rebuilding phases. Each session should prioritize a stable threshold exposure: once "LIMIT" appears, hold 8-12 seconds with controlled breathing, release, and repeat.

In artistic gymnastics, band placement on the inner thigh during split preparation may support consistent end-range dosing while minimizing subjective over-pushing. In shoulder-dominant work (e.g., bridge progressions, ring support drills), placement on the upper arm may similarly standardize mobility exposures. The protocol is also compatible with eccentric strengthening (e.g., Nordic hamstring exercise) by separating mobility exposures from high-load strength work and using the visual cue to prevent excessive end-range strain on fatigued days.

Finally, brief journaling or a one-question check-in ("Did I honor the marker today?") may reinforce self-efficacy and consolidate the fear-extinction learning that supports return to sport.

Conclusions

A threshold-guided stretching approach supported by a passive Moiré visual indicator is feasible, field-ready, and potentially valuable for high-flexibility sports where both tissue strain and movement fear influence rehabilitation outcomes. Pilot evidence suggests improvements in ROM and meaningful reductions in kinesio phobia with a favorable safety profile. Controlled trials in elite artistic gymnastics are the next step to validate efficacy and establish sport-specific return-to-sport criteria [1-20].

References

1. Ardern CL, Taylor NF, Feller JA, Webster KE (2013) Fear of re-injury in return to sport following injury: a systematic review. Sports Med 43: 625-632.
2. Behm DG, Alizadeh S, Daneshjoo (2024) A Practical recommendation on stretching exercise: a Delphi consensus statement. J Funct Morphol Kinesiol 9: 100-105.
3. Campbell RA, Lopez V, Crush EA (2024) Common upper extremity gymnastics injuries and gymnastic specific return to play protocols. JPOSNA 6: 1-12.
4. Chandran A, Nedimyer AK, Boltz AJ (2025) Injury incidence and characteristics for elite, male, artistic USA gymnastics competitions from 2008 to 2018. Orthop J Sports Med 13: 23-25.
5. Edouard P, Steffen K, Junge A (2024) Gymnastics injuries at the Olympic Games: a systematic review. Br J Sports Med 58: 845-852.
6. Ericksen HM, Thomas AC, Gribble PA (2025) Biomechanics of landing in gymnasts: a scoping review. J Funct Morphol Kinesiol 10: 40-45.
7. Ericksen HM, Thomas AC, Gribble PA (2024) The influence of kinesio phobia on time to clinical recovery in collegiate athletes with concussion. J Athl Train 59: 389-397.
8. Freitas SR, Mendes B, Le Sant G (2018) Can chronic stretching change the muscle- tendon mechanical properties? A review. Scand J Med Sci Sports 28: 794-806.
9. Hickey JT, Timmins RG, Maniar N (2024) Return to sprinting following hamstring strain injury: a 3-stage progression protocol. J Orthop Sports Phys Ther 54: 312-320.
10. Konrad A, Nakamura M, Tilp M (2022) Foam rolling increases range of motion but does not affect muscle performance or muscle architecture. J Sports Sci 40: 1455-1465.
11. Konrad A, Nakamura M, Warneke K (2024) Strength training versus stretching for improving range of motion: a systematic review and meta-analysis. Healthcare (Basel) 12: 470-474.
12. Martin RL, Cibulka MT, Bolgla LA (2023) Rehabilitation and return to sport after hamstring strain injury. J Orthop Sports Phys Ther 53: CPG1-CPG44.
13. Puentedura EJ, Flynn T (2023) Associations of pain vigilance and past and current pain with kinesio phobia after sport injury. Int J Environ Res Public Health 20: 64-67.
14. Schleip R, Wilke J, Schreiner S (2023) The use of neurofeedback in sports training: systematic review. Int J Environ Res Public Health 20: 60-90.
15. Sigrist R, Rauter G, Marchal-Crespo L (2023) Biofeedback-based return to sport: individualization through objective assessments. Front Physiol 14: 115-152.
16. Steinberg N, Tenenbaum S, Waddington G (2023) Injuries, pain, and catastrophizing level in gymnasts: a retrospective analysis. Int J Environ Res Public Health 21: 62-63.
17. Thomas E, Bianco A, Paoli A, Palma A (2024) Stretching protocols to increase flexibility. J Funct Morphol Kinesiol 9: 120-123.
18. Thomas KE, Bradshaw EJ, Campbell AC (2023) Epidemiology of injuries in elite women's artistic gymnastics: a retrospective analysis of six seasons. BMJ Open Sport Exerc Med 9: 15-67.
19. Vlaeyen JWS, Crombez G (2023) Fear-avoidance model of chronic pain: the role of kinesiophobia in sports injury rehabilitation. Pain 164: 231-245.
20. Watanabe T, Matsuda S, Nakamura M, Behm DG (2024) Kinesio phobia in injured athletes: a systematic review. J Funct Morphol Kinesiol 9: 38-40.