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Immediate Effects of Combined Stretching Protocols on Scapular Myoelectric Activity and Kinematics in Gymnasts

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ABSTRACT

Background: Stretching is widely used to improve joint range of motion (ROM). This study examined the immediate effects of different stretching protocols on scapular muscle activity and motion in elite gymnasts.

Methods: A semi-experimental crossover design was employed. Fifteen elite gymnasts (mean age: 23.25 ± 2.57 years; height: 170.93 ± 5.88 cm; weight: 64.54 ± 5.06 kg) participated. Each athlete was assessed before and after five stretching conditions: dynamic stretching, static stretching, dynamic followed by static stretching, static followed by dynamic stretching, and no stretching (control). Myoelectric activity was recorded using surface electromyography (EMG), and scapular kinematics were assessed via the Kestrel model motion analysis system. Pre- and post-intervention values were compared to evaluate changes.

Results: Two-way repeated measures ANOVA revealed significant effects of stretching protocols on both muscle activation and scapular kinematics (tilt and rotation) ($p < .05$). Post hoc analysis showed significant differences between pre- and post-test values, as well as among the five stretching conditions ($p < .05$).

Conclusion: Both static and dynamic stretching protocols induced immediate changes in gymnasts' scapular muscle activity and kinematics. These alterations, particularly in muscle activation and scapular tilt, may influence performance and potentially elevate the risk of injury.

Introduction

Due to the complex and continuous movement patterns required in the shoulder region, the shoulder girdle is the most mobile joint system in the human body [1]. The motion of the shoulder complex relies heavily on coordinated muscle activity, which not only enables accurate execution of movements but also maintains dynamic stability across the joints of the shoulder girdle [1]. Among the key contributors to shoulder function are the scapular muscles, which

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control the scapulothoracic joint and play a vital role in optimizing shoulder mechanics [2].

Dysfunction or inhibition of these scapular muscles can significantly alter the position of the glenoid cavity, thereby affecting the alignment and stability of the humeral head within the glenohumeral joint [2]. For instance, excessive activation of scapular stabilizers such as the lower and middle trapezius and the serratus anterior may result in an imbalance that favors the upper trapezius and latissimus dorsi. This imbalance can lead to compensatory scapular positioning and abnormal movement patterns in the shoulder complex [2].

Changes in the timing and coordination of scapular muscle activation can cause compensatory instability, disrupting the synchrony between scapular kinematics and muscular function [3, 4]. When proper scapular stabilization and coordination are lacking during upper limb movements, the rotator cuff muscles may become less effective at maintaining glenohumeral stability [3, 4]. Such imbalances may, paradoxically, enhance the mechanical efficiency of the deltoid muscle, thereby increasing compressive forces between the humeral head and the acromion and potentially elevating the risk of shoulder injuries [3, 4].

Shoulder injuries and pain are among the most prevalent issues in overhead sports [5]. These injuries are frequently attributed to damage or weakness in the rotator cuff muscles, often without adequate consideration of scapular kinematics and positioning [6]. Dysfunction of the scapulothoracic joint plays a critical role in shoulder pathologies and is typically characterized by abnormal scapular positioning and movement [6]. One common manifestation of this dysfunction is the disruption of the scapulohumeral rhythm. Under normal conditions, this rhythm depends on properly activating the scapula’s upward rotators and the coordinated action of force couples to achieve optimal scapular positioning [6].

Given the complexity of shoulder biomechanics, it is unsurprising that the region is susceptible to a wide range of musculoskeletal disorders [7, 8]. Various mechanisms have been proposed to explain these injuries, with biomechanical dysfunction among the most significant contributors [7]. Biomechanical defects refer to deviations in movement patterns or applied forces from the norm, leading to increased mechanical stress on tissues [7]. Injury becomes likely when these tissues cannot withstand or adapt to the excessive load [7]. Such biomechanical issues may arise from repetitive movement patterns that progressively alter tissue tension or from changes in neuromuscular activation induced by external influences [8].

Stretching exercises are commonly included in warm-up routines, with the choice of technique often based on the preferences of athletes or coaches [9]. Among these, static and dynamic stretching are the most frequently used methods. However, numerous studies have reported inconsistent findings regarding their effects on muscle performance [9–11]. Historically, following the World Wars, static stretching was widely believed to improve flexibility and enhance athletic performance [12]. However, from the late 1990s into the early 2000s, emerging evidence highlighted potential adverse effects of static stretching on muscle performance, leading to a decline in popularity and a growing emphasis on dynamic stretching [12, 13].

Research has recently challenged the view that static stretching should be avoided before training or competition. These studies suggest that when static stretching is part of a comprehensive warm-up routine, it does not significantly impair muscle performance [12, 14, 15]. Although dynamic stretching has demonstrated positive effects, some researchers recommend combining static and dynamic methods to maximize adaptive benefits [16, 17]. While several studies have investigated the combined effects of static and dynamic stretching on power, agility, and speed, the specific influence of the order of stretching techniques within a combined routine remains unclear [16].

In a 2018 review, Opplert and Babault emphasized that inconsistent definitions and descriptions of stretching protocols present a significant barrier to reaching consensus on optimal stretching practices [18]. They called for future research to adopt standardized and clearly defined stretching protocols to facilitate more consistent and comparable findings [18]. Given the conflicting evidence and unresolved questions about how stretching exercises affect muscle function and their underlying mechanisms, this study aimed to investigate the immediate effects of different stretching protocols on scapular myoelectric activity in gymnasts.

Methods

Participants

The sample size for this study was determined using G*Power software, based on a previous study that reported an effect size of 0.5, a statistical power of 0.80, and a significance level of 5% [19]. Fifteen elite gymnasts (mean age: 22.25 ± 2.37 years; height: 170.93 ± 5.08 cm; weight: 64.54 ± 5.06 kg) voluntarily participated in the study. All participants had at least five years of experience in tumbling, trained at least three times per week, and had no history of surgical procedures or upper limb or spinal injuries causing persistent pain within the past year.

Before data collection, all participants were fully informed of the study’s objectives, potential risks, and benefits. Written informed consent was obtained from each participant. The study protocol was approved by the Research Ethics Committee of the Sport Science Research Institute (IR.SSRC.REC.1399.136).

Procedures

This study utilized a semi-experimental design with a crossover approach to minimize potential learning and order effects. Participants were randomly assigned to five subgroups, and assessments were conducted across five sessions. Each session involved a different stretching protocol, with a minimum 48-hour washout period between sessions to avoid carryover effects.

Before testing, all participants received standardized instructions on warm-up procedures and stretching techniques. Demographic data were also collected before the intervention began.

Before performing the stretching protocols, all participants completed a standardized warm-up consisting of a five-minute general warm-up (jogging) and a five-minute specific gymnastics warm-up. The gymnastics warm-up included three minutes of plyometric and hopping exercises, followed by two minutes of abdominal exercises, all performed without any stretching movements [11].

For the pre-test, participants performed a pull-up movement according to the guidelines described by Lusk et al. [20]. In the starting position, the participant grasped a horizontal bar with the back of the hands facing toward the body (pronated grip) and the hands positioned at 1.5 times the biacromial width. The participant hung freely from the bar with fully extended elbows and knees flexed at 90 degrees. During the concentric phase, the participant pulled themselves upward until their nose passed above the bar, then returned to the starting position during the eccentric phase [20]. Each participant performed five repetitions. The first and last repetitions were excluded, and the middle three were used as the main trials for analysis [21].

Myoelectric activity of the upper limb muscles—including the serratus anterior, upper trapezius, lower trapezius, and middle trapezius—was recorded using surface electromyography (EMG). Scapular kinematics were simultaneously captured. During each session, participants in each subgroup followed one of the stretching protocols: static stretching, dynamic stretching, static followed by dynamic stretching, dynamic followed by static stretching, or no stretching (control).

In the first session (Condition 1), Subgroup 1 performed static stretching, Subgroup 2 performed dynamic stretching, Subgroup 3 completed static-dynamic stretching, Subgroup 4 did dynamic-static stretching, and Subgroup 5 acted as the control group. All subgroups rotated protocols in subsequent sessions to ensure each participant experienced every stretching condition across the study period (see Figure 1). Following each stretching protocol, participants rested for five minutes before executing the pull-up movement, during which EMG data and scapular kinematics were recorded [19, 21].

Interventions

Following the five-minute warm-up, participants rested for two minutes before beginning their assigned stretching protocol. The static stretching protocol required participants to stretch each target muscle to mild discomfort, holding the position for two sets of 15 seconds, with a 15-second rest between sets. The static stretching exercises included the following: (1) Side-neck stretch: The head was gently tilted toward one shoulder, (2) Overhead reach: Both arms were extended vertically overhead with elbows straight, while maintaining a neutral spine alignment, (3) Cross-body shoulder stretch: One arm was brought across the chest, and the opposite hand gently pushed the elbow toward the body, (4) Triceps stretch: One arm was raised overhead and bent at the elbow, while the opposite hand applied gentle downward pressure to the elbow, and (5) Shoulder extension stretch: With hands clasped behind the back, the arms were extended backward [22, 23].

Participants performed 15 repetitions of each dynamic stretch, ensuring movements remained within a pain-free range of motion. Emphasis was placed on maintaining control and performing the exercises quickly [19]. The dynamic stretching exercises included: Head side-to-side: Starting with the chin level, participants tilted their head toward the left shoulder to draw the ear closer, then returned to center before repeating on the opposite side; Overhead reach: With arms extended overhead and palms together, participants gently stretched the arms upward and slightly backward, then returned to the starting position; Crossover arm swings: Standing with feet shoulder-width apart, participants lifted their arms out to the sides, crossed them in front of the chest fluidly, and returned to the starting position; Arm circles: Facing a wall, participants performed large, controlled arm circles, moving as close to the wall as possible; and Overhead arm swings: Standing with arms by their sides, participants swung their arms upward until fingers pointed toward the sky, then swiftly returned to the starting position before repeating [22, 23].

For the combined protocols, static and dynamic stretches were each performed in one set to equalize the total stretching duration [16, 19]. In the static-dynamic protocol, participants performed static stretches followed by dynamic stretches, each executed in a single set [16, 19]. Conversely, in the dynamic-static protocol, dynamic stretches were performed first, followed by static stretches, again with one set each [16, 19]. Participants in the control group rested for a duration equivalent to the longest stretching protocol [11].

Instrumentation

Before placing the surface electromyography (sEMG) electrodes, the skin at each electrode site was prepared by shaving and gently abrading the area, followed by cleansing with alcohol to reduce impedance. Fixed metallic electrodes were positioned along the muscle fibers on the belly, maintaining a center-to-center distance of 20 mm between electrodes [21, 24]. Electrode placement for the upper trapezius, middle trapezius, lower trapezius, and latissimus dorsi muscles followed the SENIAM guidelines [21, 24]. For the serratus anterior muscle, electrode placement was based on the method described by Park and Yu [25]. Two reference electrodes were placed at the C7 vertebra and around the elbow. All sensor placements adhered to SENIAM recommendations to ensure consistency and accuracy.

The sEMG signals were recorded using a Biometric electromyography system (British Biometric Company) with a sampling rate of 2 kHz. Raw signals were processed and analyzed using the Data Lite software from the same company. Signal amplification was achieved with a bipolar differential amplifier with the following specifications: input impedance of 2 MΩ, standard mode rejection ratio > 100 dB at 60 Hz, gain ×20, and noise < 5 µV. Signals were digitized at 12-bit resolution.

During the pull-up exercise, sEMG data were collected and band-pass filtered between 20 and 400 Hz using a fourth-order Butterworth filter with zero lag. The signals' root mean square (RMS) was calculated in microvolts (µV). All EMG data were normalized using the Maximum Voluntary Contraction (MVC) method. MVC for each muscle was assessed in a separate session before the stretching and testing protocols. Each MVC trial lasted 5 seconds, with a 1-minute rest between trials. Peak EMG values from the movement phase were normalized to the average peak EMG of three MVC trials [26].

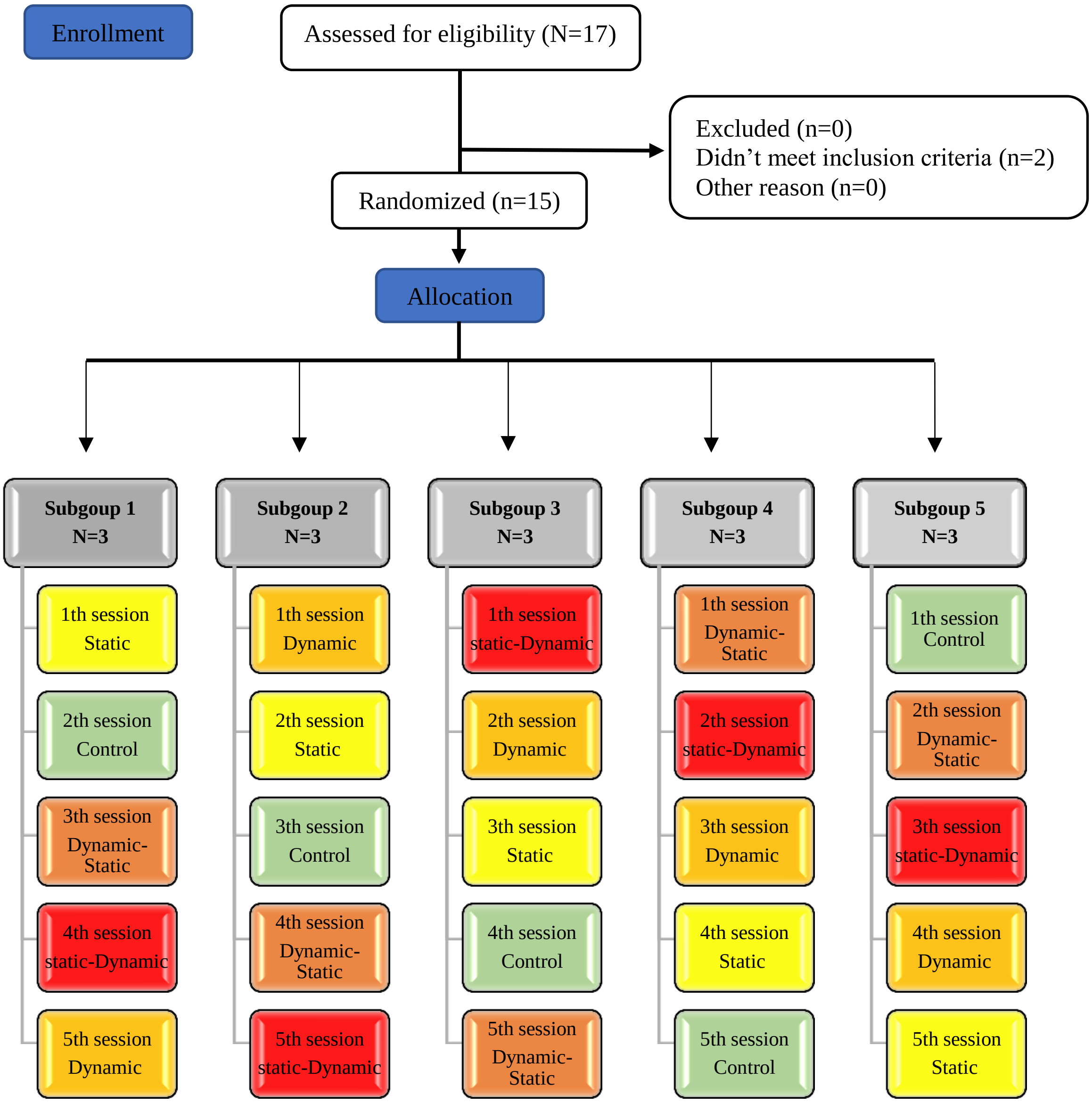

Figure 1: Flowchart

A Kestrel motion analysis system (Motion Analysis Corporation, USA) with 10 cameras was used to measure scapular tilt and rotation. The Acromion Marker Cluster (AMC) technique was applied for unilateral tracking of scapular movement [27, 28]. The AMC consisted of an 'L'-shaped plastic piece, with each side measuring 70 mm in length. Three retroreflective markers were mounted on the AMC: one at each end of the 'L' and one at the junction of the two arms. The AMC was secured to the posterior aspect of the acromion, specifically at the intersection where the acromion meets the scapular spine, using double-sided adhesive tape.

A cluster marker set with elastic straps was affixed to the upper arm to enhance tracking accuracy. Individual retroreflective markers were also placed on key anatomical landmarks following International Society of Biomechanics (ISB) guidelines. These landmarks included the sternal notch (IJ), which marks the deepest point of the sternal notch; the xiphoid process (PX), located at the most caudal point of the sternum; the spinous process of C7 (C7); the spinous process of T8 (T8); the sternoclavicular joint (SC), the most anterior point of the joint; the radial styloid, the most distal point on the radial styloid; and the ulnar styloid, the most distal point on the ulnar styloid[29].

System calibration was performed based on these anatomical markers. To ensure clean and interpretable data, the raw scapular kinematic signals (tilt and rotation) were processed using a zero-lag fourth-order Butterworth low-pass filter with a cutoff frequency of 8 Hz, effectively removing high-frequency noise from the signal [29].

Statistical Analyses

The normality of the data was evaluated using the Shapiro–Wilk test, while Levene's test was applied to assess the homogeneity of variances. A two-way repeated-measures ANOVA was employed to analyze the effects of the five stretching protocols and two time points (pre- and post-intervention) on each dependent variable. When significant main or interaction effects were identified, Bonferroni-adjusted post hoc tests were conducted to determine pairwise differences.

Effect sizes (Cohen's d) were calculated to assess the magnitude of differences, interpreted as follows: trivial (< 0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), and very large (> 2.0). Reliability of the measurements was determined using intraclass correlation coefficients (ICC), with the following classification thresholds: < 0.40 (poor), 0.40–0.74 (satisfactory), and ≥ 0.75 (excellent). The ICC values for all measured variables ranged from 0.70 to 0.99, indicating excellent reliability. A significance level of 0.05 was set for all statistical analyses.

Results

Table 1 presents the mean (± SD) values for the root mean square (RMS) electromyographic activity and scapular kinematic variables, measured before and after implementing each of the five stretching protocols.

The EMG analysis of the serratus anterior muscle revealed statistically significant differences across both the concentric (F = 12.04, P = 0.001) and eccentric (F = 27.69, P = 0.001) phases. Post hoc testing indicated significant differences between pre-test and post-test values for the following protocols: static stretching (concentric [P = 0.014], eccentric [P = 0.001]), dynamic stretching (concentric [P = 0.006], eccentric [P = 0.001]), static-dynamic stretching (concentric [P = 0.002], eccentric [P = 0.004]), and dynamic-static stretching (concentric [P = 0.015], eccentric [P = 0.014]).

Similarly, the EMG analysis of the upper trapezius muscle demonstrated significant differences in concentric (F = 29.49; P = 0.001) and eccentric (F = 51.57; P = 0.001) phases. Post hoc comparisons indicated significant pretest-to-posttest changes following the static stretching (concentric [P = 0.001], eccentric [P = 0.026]), dynamic stretching (concentric [P = 0.001], eccentric [P = 0.001]), and static-dynamic stretching (concentric [P = 0.047], eccentric [P = 0.015]) protocols.

The EMG analysis of the middle trapezius muscle revealed significant differences in both the concentric (F = 29.31; P = 0.001) and eccentric (F = 62.02; P = 0.001) phases. The post hoc analysis showed significant pretest-to-posttest differences following: static stretching (concentric [P = 0.028], eccentric [P = 0.002]), dynamic stretching (concentric [P = 0.001], eccentric [P = 0.001]), static-dynamic stretching (concentric [P = 0.014], eccentric [P = 0.004]), and dynamic-static stretching (concentric [P = 0.025], eccentric [P = 0.014]).

Significant differences were observed in the lower trapezius muscle during concentric (F = 27.75; P = 0.001) and eccentric (F = 51.11; P = 0.001) phases. Post hoc analyses revealed significant pretest-to-posttest changes following: static stretching (concentric [P = 0.001], eccentric [P = 0.026]), dynamic stretching (eccentric [P = 0.013]), static-dynamic stretching (eccentric [P = 0.004]), and dynamic-static stretching (concentric [P = 0.012]) protocols.

Significant differences were observed in the latissimus dorsi muscle during both concentric (F = 11.44; P = 0.001) and eccentric (F = 12.67; P = 0.001) phases. Post hoc analyses showed significant pretest-to-posttest differences after: static stretching (concentric [P = 0.030]), dynamic stretching (concentric [P = 0.039], eccentric [P = 0.013]), static-dynamic stretching (eccentric [P = 0.002]), and dynamic-static stretching (concentric [P = 0.003]) protocols.

The analysis of scapular kinematics revealed significant differences in anterior tilt (F = 3.33; P = 0.041), whereas no significant differences were observed in posterior tilt (F = 0.86; P = 0.441). Post hoc tests showed significant pretest-to-posttest changes following: static stretching (P = 0.047), dynamic stretching (P = 0.033), and static-dynamic stretching (P = 0.007) protocols. No significant differences were found in upward rotation (F = 0.53; P = 0.539) or downward rotation (F = 1.29; P = 0.317).

Analysis comparing the stretching protocols showed no significant differences among the five methods in concentric and eccentric variables during the pretest phase. However, significant differences between the protocols were observed post-intervention, as detailed in Table 2.

Table 1: Absolute Mean Values (SD) of Root-Mean Square, and Scapula Kinematic Before and After All Protocols.

Variables		Phase	Time	Stretching Protocols				
				Static	Dynamic	Static-Dynamic	Dynamic-Static	No-Stretch
Myoelectric Activation (uV)	SA	Concentric	Pre	45.89±18.44	44.83±17.48	46.39±16.90	45.70±17.40	44.33±17.06
			Post	38.66±12.15	51.40±14.27	50.30±17.05	37.34±10.35	47.12±15.82
		Eccentric	Pre	41.87±14.27	40.39±13.51	42.07±13.48	40.93±13.81	41.19±12.32
			Post	35.98±12.93	44.87±14.49	43.89±14.29	35.87±11.51	40.93±12.40
	UT	Concentric	Pre	25.69±7.17	24.29±10.01	24.83±8.5	23.69±9.13	25.22±8.35
			Post	20.20±7.07	39.48±12.07	33.25±15.91	22.54±6.17	25.31±7.51
		Eccentric	Pre	22.47±7.00	20.24±6.32	20.33±6.91	21.11±7.14	21.17±6.37
			Post	17.57±3.69	45.61±14.59	24.80±5.16	21.26±6.53	20.97±6.46
	MT	Concentric	Pre	25.23±11.49	23.47±9.56	24.72±11.70	25.16±9.43	24.36±10.67
			Post	21.09±10.12	45.17±16.99	41.80±18.31	21.29±9.20	24.13±11.23
		Eccentric	Pre	25.21±10.45	24.99±9.93	25.92±9.34	24.92±10.35	25.52±10.10
			Post	22.12±10.54	59.25±19.99	46.74±22.39	21.41±7.45	25.01±9.23
	LT	Concentric	Pre	47.53±19.11	48.03±17.97	47.97±18.85	48.10±18.24	47.10±18.85
			Post	32.33±15.69	51.33±14.81	48.80±18.93	33.26±14.82	47.08±17.90
		Eccentric	Pre	53.17±14.92	49.33±17.30	50.61±15.53	48.34±19.85	51.54±16.83
			Post	29.31±14.69	54.46±15.09	54.07±15.31	39.82±21.48	51.60±16.46
	LD	Concentric	Pre	31.38±12.49	30.32±15.10	29.93±13.17	30.45±14.61	29.47±14.43
			Post	23.52±9.11	36.48±10.31	32.68±8.95	23.92±10.64	29.31±13.81
		Eccentric	Pre	28.69±14.45	29.52±15.65	31.08±16.94	29.01±14.11	30.48±16.39
			Post	27.07±12.69	38.06±13.38	41.84±14.33	26.77±14.10	30.41±14.41
Angle (Degrees)	ST	Concentric	Pre	-15.64±2.63	-15.59±2.91	-15.88±2.79	-15.71±3.07	-15.94±2.65
			Post	-16.89±4.39	-16.54±3.11	-14.88±2.66	-16.25±2.80	-15.88±2.62
		Eccentric	Pre	0.49±1.98	0.50±1.88	0.51±1.69	0.52±1.87	0.52±1.94
			Post	0.40±1.85	0.49±2.04	0.73±2.37	0.69±1.74	0.51±1.92
	SR	Concentric	Pre	-3.06±2.45	-3.31±2.07	-3.17±2.44	-2.69±1.18	-3.11±2.11
			Post	-3.52±2.21	-4.02±2.43	-2.81±2.52	-2/60±2/15	-2.92±2.27
		Eccentric	Pre	-38.90±7.02	-37.55±8.56	-37.95±8.31	-39.08±10.85	-37.55±10.35
			Post	-40.64±8.80	-36.35±8.83	-36.27±8.63	-41.11±10.33	-36.75±10.47

Legend: SA= Serratus Anterior, UT= Upper Trapezius, MT= Middle Trapezius, LT= Lower Trapezius, LD= Latissimus Dorsi, ST= Scapula Tilt, SR= Scapula Rotation

Table 2: Between Group Differences

Between group differences		Phase	Myoelectric Activation										Angle	
			SA		UP		MT		LT		LD		ST	
			P	d	P	d	P	d	P	d	P	d	P	d
Static	D	CON	0.001*	-0.96	0.001*	-1.95	0.001*	-1.79	0.001*	-1.25	0.002*	-1.33	1.000	-0.09
		ECC	0.001*	-0.65	0.001*	-2.62	0.001*	-2.32	0.001*	-1.69	0.036*	-0.84	-	-
	D-S	CON	1.000	0.12	1.000	-0.35	1.000	0.12	1.000	-0.60	1.000	-0.04	1.000	-0.17
		ECC	1.000	0.01	0.196	-0.68	1.000	0.10	1.000	-0.57	1.000	0.02	-	-
	S-D	CON	0.001*	-0.79	0.067	-1.06	0.036*	-1.47	0.001*	-0.95	0.022*	-1.01	0.445	-0.55
		ECC	0.002*	-0.58	0.001*	-1.57	0.037*	-1.41	0.001*	-1.65	0.001*	-1.09	-	-
	C	CON	0.056	-0.60	0.021*	-0.70	0.191	-0.38	0.006*	-0.94	0.315	-0.49	1.000	-0.27
		ECC	0.260	-0.39	1.000	-0.63	0.066	-0.29	0.001*	-1.43	1.000	-0.25	-	-
Dynamic	D-S	CON	0.002*	1.05	0.002*	1.77	0.001*	1.75	0.029*	1.22	0.008*	1.20	1.000	-0.10
		ECC	0.001*	0.69	0.001*	2.15	0.001*	2.51	0.584	0.79	0.008*	0.82	-	-
	S-D	CON	1.000	0.01	1.000	0.44	1.000	0.19	1.000	0.15	1.000	0.39	0.028*	-0.57
		ECC	1.000	0.07	0.003*	1.90	0.341	0.59	1.000	0.03	1.000	-0.27	-	-
	C	CON	0.351	0.22	0.010*	1.42	0.003*	1.46	0.860	0.26	0.551	0.59	0.854	-0.22
		ECC	0.686	0.29	0.001*	2.18	0.001*	2.20	1.000	0.18	0.111	0.55	-	-
Dynamic-Static	S-D	CON	0.006*	-0.92	0.407	-0.89	0.034*	-1.42	0.173	-0.91	0.009*	-1.36	0.654	-0.50
		ECC	0.012*	-.062	0.126	-0.60	0.018*	-1.52	0.524	-0.76	0.002*	-1.06	-	-
	C	CON	0.229	-0.73	1.000	-0.40	0.457	-0.28	0.252	-0.84	0.065	-0.55	1.000	-0.13
		ECC	0.227	-0.42	1.000	0.04	0.051	-0.43	1.000	-0.62	0.690	-0.26	-	-
Static-Dynamic	C	CON	0.268	0.19	0.899	0.64	0.153	1.16	1.000	0.9	1.000	0.29	0.131	0.36
		ECC	0.924	0.22	0.198	0.66	0.144	1.27	1.000	0.16	0.012*	0.80	-	-

Legend: SA= Serratus Anterior, UT= Upper Trapezius, MT= Middle Trapezius, LT= Lower Trapezius, LD= Latissimus Dorsi, ST= Scapula Tilt, D= Dynamic, S=Static, S-D=Static-Dynamic, D-S=Dynamic-Static, C=Control, d=Effect Size, *=significant of between group differences

In the posttest, analysis of the serratus anterior muscle revealed significant differences between multiple stretching protocols. Specifically, there were notable differences between:

- Static stretching and dynamic stretching (concentric [P = 0.001], eccentric [P = 0.001])
- Static stretching and static-dynamic stretching (concentric [P = 0.001], eccentric [P = 0.002])
- Dynamic stretching and dynamic-static stretching (concentric [P = 0.002], eccentric [P = 0.001])
- Static-dynamic stretching and dynamic-static stretching (concentric [P = 0.006], eccentric [P = 0.012]).

For the upper trapezius muscle, significant posttest differences were found between:

- Static stretching and dynamic stretching (concentric [P = 0.001], eccentric [P = 0.001])
- Static stretching and static-dynamic stretching (eccentric [P = 0.001])
- Static stretching and no stretch (concentric [P = 0.006])
- Dynamic stretching and static-dynamic stretching (eccentric [P = 0.003])
- Dynamic stretching and dynamic-static stretching (concentric [P = 0.002], eccentric [P = 0.001])
- Dynamic stretching and no stretch (concentric [P = 0.010], eccentric [P = 0.001]).

Analysis of the middle trapezius muscle also revealed significant differences in the posttest between:

- Static stretching and dynamic stretching (concentric [P = 0.001], eccentric [P = 0.001])
- Static stretching and static-dynamic stretching (concentric [P = 0.036], eccentric [P = 0.037])
- Dynamic stretching and dynamic-static stretching (concentric [P = 0.001], eccentric [P = 0.001])
- Dynamic stretching and no stretch (concentric [P = 0.003], eccentric [P = 0.001])
- Static-dynamic stretching and dynamic-static stretching (concentric [P = 0.034], eccentric [P = 0.018]).

For the lower trapezius muscle, significant differences were noted between:

- Static stretching and dynamic stretching (concentric [P = 0.001], eccentric [P = 0.001])
- Static stretching and static-dynamic stretching (concentric [P = 0.001], eccentric [P = 0.001])
- Static stretching and no stretch (concentric [P = 0.006], eccentric [P = 0.001])
- Dynamic and dynamic-static stretching (concentric [P = 0.029]).

The latissimus dorsi muscle showed significant differences in the posttest between:

- Static stretching and dynamic stretching (concentric [P = 0.002], eccentric [P = 0.036])
- Static stretching and static-dynamic stretching (concentric [P = 0.022], eccentric [P = 0.001])
- Dynamic stretching and dynamic-static stretching (concentric [P = 0.008], eccentric [P = 0.008])
- Static-dynamic stretching and dynamic-static stretching (concentric [P = 0.009], eccentric [P = 0.002])
- Static-dynamic stretching and no stretch (eccentric [P = 0.012]).

Finally, scapula tilt analysis revealed a significant difference between:

- Dynamic stretching and static-dynamic stretching (concentric [P = 0.028]).

Discussion

This study explored the immediate effects of combined stretching protocols on gymnasts' myoelectric activity and scapular kinematics. The results support the hypothesis that static stretching reduces muscle activation. In contrast, dynamic stretching appears to enhance muscle performance.

Static and dynamic stretching exercises involve distinct loading patterns, which likely contribute to different mechanisms driving the acute improvements in range of motion (ROM)[30]. The acute gains observed following static stretching are primarily attributed to increased stretch tolerance and/or changes in the mechanical properties of muscle and connective tissue[30]. While both mechanisms are commonly referenced in the literature, variability in study designs makes it challenging to determine their contributions to ROM enhancement after static stretching. Conversely, dynamic stretching consists of repetitive muscle loading and unloading cycles, typically performed over several minutes[31]. Although dynamic stretching is also recognized for improving ROM, the exact physiological mechanisms underlying these improvements remain poorly understood, with limited research specifically addressing them. It is hypothesized that the repeated muscle lengthening during dynamic stretching may elevate muscle fiber temperature, reduce tissue viscosity, and enhance muscle extensibility, as supported by findings in animal models[14]. Nonetheless, comprehensive data explaining the precise processes behind ROM increases following dynamic stretching are still lacking[14].

Furthermore, the results indicated that static and dynamic stretching significantly increased the anterior tilt of the scapula. Weakness of the serratus anterior muscle, along with altered co-contraction patterns between this muscle and the trapezius muscles, is a significant factor contributing to shoulder injuries in overhead athletes. Such imbalances disrupt scapular kinematics and scapulohumeral rhythm, potentially leading to injury[32]. Several studies suggest that stretching the antagonist muscle can enhance the function of the agonist muscle through two main mechanisms, or a combination thereof. The first mechanism involves increased nerve activation of the agonist muscle, which may improve its performance. The second mechanism is a reduced nerve activation of the antagonist muscle, leading to decreased stiffness and diminished inhibitory forces on the agonist muscle, thereby facilitating its function [33].

Additionally, improvements in agonist torque following antagonist stretching may stem from a mechanical response: disruption of the length-tension relationship in antagonist muscles reduces inhibitory forces, allowing agonist muscles to generate greater internal torque [33]. Umehara et al. (2018) reported that 5 minutes of static stretching targeting the pectoralis minor muscle resulted in significant changes in scapular external rotation and posterior tilt. They attributed these alterations to reduced muscle stiffness in the pectoralis minor, which enhanced scapular range of motion [34]. Individuals with shoulder impingement syndrome often exhibit increased scapular internal rotation, decreased upward rotation, and posterior tilt [35].

The upward and downward rotation of the scapula plays a critical role in optimizing shoulder mechanics during the pull-up exercise. Any disruption in these motions may reduce the subacromial space, a key factor implicated in the development of shoulder impingement syndrome[36]. Studies on shoulder kinematics have shown that individuals with shoulder impingement syndrome often exhibit increased elevation of both the clavicle and scapula, along with reduced arm external rotation. These alterations are likely attributable to disturbances in the coordinated function of muscle force couples and imbalances resulting from aberrant co-contraction patterns among scapular stabilizing muscles [36]. According to the muscle co-contraction theory, static stretching of antagonist muscles may enhance the activation of agonist muscles, facilitate the storage of elastic energy, and reduce excessive co-contraction of the antagonist muscles [33].

One of the primary challenges in analyzing scapular kinematics is the absence of a clearly defined normative range for these movements. Ludwig and Cook (2000) reported that even a 4–6° alteration in scapular positioning could significantly diminish the subacromial space, thereby increasing the risk of impingement. Their findings further indicated that individuals with shoulder impingement syndrome demonstrated a 5.2° increase in internal rotation, a 4.1° reduction in upward rotation, and a 5.8° increase in anterior tilt compared to healthy controls[37]. These kinematic deviations are particularly relevant in athletic populations. Given the repetitive and high-intensity demands placed on the shoulder complex in gymnasts, even minor alterations in scapular motion may significantly elevate injury risk.

Our findings suggest that combining static and dynamic stretching protocols can influence muscle activation in distinct ways. Specifically, static-dynamic stretching was associated with increased myoelectric activation, whereas dynamic-static stretching reduced muscle activation. Traditionally, warm-up routines are structured in three phases: an initial aerobic component, followed by static stretching, and concluding with dynamic skill rehearsal. Although many studies have examined the effects of static stretching in isolation, this does not reflect typical warm-up practices. Even when static stretching is incorporated alongside aerobic activity, dynamic movements, or skill rehearsal, it has often been shown to impact subsequent performance [38] negatively. Kilit et al. (2019) reported that both dynamic stretching and static-dynamic stretching produce a synergistic effect in enhancing athletic performance when compared to static stretching and dynamic-static stretching [39].

Despite these observations, the interaction between static and dynamic stretching remains inconclusive. It is unclear whether the neural excitation associated with dynamic stretching can fully counteract the neural inhibition induced by static stretching, or vice versa. Previous studies have reported mixed outcomes, ranging from performance impairments to improvements, or no observable change at all [12]. One possible explanation is that dynamic stretching following static stretching may stimulate the neuromuscular system sufficiently to mitigate the inhibitory effects of static stretching, thereby restoring or enhancing performance [12]. Some studies suggest that the performance improvements observed when dynamic stretching follows static stretching may be due to the neuromuscular stimulation provided by dynamic movements, which helps counteract the inhibitory effects of static stretching. Conversely, applying static stretching after dynamic stretching may dampen the performance-enhancing effects of the dynamic component[12].

In the present study, static stretching reduced myoelectric activation and increased scapular anterior tilt, whereas dynamic stretching increased myoelectric activation and similarly elevated scapular anterior tilt. Combining static and dynamic stretching also altered muscle activation patterns depending on the sequence employed. These findings indicate that dynamic and static-dynamic stretching may be more effective than static and dynamic-static stretching for promoting muscle activation during gymnastics preparation. However, the increased scapular anterior tilt observed across several protocols may heighten the risk of shoulder injury in gymnasts, underscoring the need for caution when implementing these stretching combinations in practice.

Conclusion

This study demonstrated that both static and dynamic stretching protocols, whether applied individually or in combination, produced immediate changes in elite gymnasts' scapular kinematics and myoelectric activity. Dynamic stretching and static-dynamic protocols enhanced muscle activation, which may be advantageous for gymnastics that demand high muscular performance, such as pull-ups. However, both static and dynamic protocols also increased scapular anterior tilt, which could disrupt the scapulohumeral rhythm and elevate the risk of shoulder injuries, particularly in overhead athletes like gymnasts.

Differences were observed based on the sequence of combined protocols. For example, the static-dynamic protocol increased muscle activation, whereas the dynamic-static protocol led to decreased activation.

Dynamic-based stretching improves muscle performance, yet coaches and athletes should remain cautious about potential injury risks due to altered scapular kinematics.

Future research should explore the long-term effects of these stretching techniques and assess whether multi-protocol conditioning strategies can mitigate adverse kinematic changes while maximizing neuromuscular performance.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Moraes, G.F., C.D. Faria, and L.F. Teixeira-Salmela, Scapular muscle recruitment patterns and isokinetic strength ratios of the shoulder rotator muscles in individuals with and without impingement syndrome. Journal of Shoulder and Elbow Surgery, 2008. 17(1): p. S48-S53.
2. Magee, D.J., et al., Pathology and intervention in musculoskeletal rehabilitation. Vol. 3. 2015: Elsevier Health Sciences.
3. Cools, A.M., et al., Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. British journal of sports medicine, 2014. 48(8): p. 692-697.
4. Cools, A.M., et al., Rehabilitation of scapular muscle balance: which exercises to prescribe? The American journal of sports medicine, 2007. 35(10): p. 1744-1751.
5. Giroto, N., et al., Incidence and risk factors of injuries in Brazilian elite handball players: A prospective cohort study. Scandinavian journal of medicine & science in sports, 2017. 27(2): p. 195-202.
6. Hosseinimehr, S.H., et al., The comparison of scapular upward rotation and scapulohumeral rhythm between dominant and non-dominant shoulder in male overhead athletes and non-athletes. Manual therapy, 2015. 20(6): p. 758-762.
7. Szucs, K., A. Navalgund, and J.D. Borstad, Scapular muscle activation and co-activation following a fatigue task. Medical & biological engineering & computing, 2009. 47(5): p. 487-495.
8. Ludewig, P.M. and J.F. Reynolds, The association of scapular kinematics and glenohumeral joint pathologies. journal of orthopaedic & sports physical therapy, 2009. 39(2): p. 90-104.
9. Serefoglu, A., et al., Effects of static and dynamic stretching on the isokinetic peak torques and electromyographic activities of the antagonist muscles. Journal of sports science & medicine, 2017. 16(1): p. 6.
10. McCrary, J.M., B.J. Ackermann, and M. Halaki, A systematic review of the effects of upper body warm-up on performance and injury. British journal of sports medicine, 2015. 49(14): p. 935-942.
11. Kazemi, O., A. Letafatkar, and P.H. Marchetti, Effect of Stretching Protocols on Glenohumeral-Joint Muscle Activation in Elite Table Tennis Players. International Journal of Sports Physiology and Performance, 2020. 16(1): p. 110-116.
12. Behm, D.G., The science and physiology of flexibility and stretching: implications and applications in sport performance and health. 2018: Routledge.
13. Simic, L., N. Sarabon, and G. Markovic, Does pre-exercise static stretching inhibit maximal muscular performance? A meta-analytical review. Scandinavian journal of medicine & science in sports, 2013. 23(2): p. 131-148.
14. Behm, D.G., et al., Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. Applied physiology, nutrition, and metabolism, 2016. 41(1): p. 1-11.
15. Blazevich, A.J., et al., No effect of muscle stretching within a full, dynamic warm-up on athletic performance. Medicine & Science in Sports & Exercise, 2018. 50(6): p. 1258-1266.
16. Amiri-Khorasani, M., J. Calleja-Gonzalez, and M. Mogharabi-Manzari, Acute effect of different combined stretching methods on acceleration and speed in soccer players. Journal of human kinetics, 2016. 50: p. 179.

17. Amiri-Khorasani, M. and R.E. Ferdinands, The acute effect of stretching on the kinematics of instep kicking in soccer. Sports Technology, 2014. 7(1-2): p. 69-78.
18. Opplert, J. and N. Babault, Acute effects of dynamic stretching on muscle flexibility and performance: an analysis of the current literature. Sports Medicine, 2018. 48(2): p. 299-325.
19. Loughran, M., et al., The effects of a combined static-dynamic stretching protocol on athletic performance in elite Gaelic footballers: A randomised controlled crossover trial. Physical Therapy in Sport, 2017. 25: p. 47-54.
20. Lusk, S.J., B.D. Hale, and D.M. Russell, Grip width and forearm orientation effects on muscle activity during the lat pull-down. The Journal of Strength & Conditioning Research, 2010. 24(7): p. 1895-1900.
21. Dinunzio, C., et al., Alterations in kinematics and muscle activation patterns with the addition of a kipping action during a pull-up activity. Sports Biomechanics, 2018.
22. Torres, E.M., et al., Effects of stretching on upper-body muscular performance. The Journal of Strength & Conditioning Research, 2008. 22(4): p. 1279-1285.
23. Gelen, E., et al., Acute effects of static stretching, dynamic exercises, and high volume upper extremity plyometric activity on tennis serve performance. Journal of sports science & medicine, 2012. 11(4): p. 600.
24. Torres, R.J., et al., Shoulder muscle activation levels during the push-up-plus exercise on stable and unstable surfaces. Journal of sport rehabilitation, 2017. 26(4): p. 281-286.
25. Park, S.-y. and W.-g. Yoo, Differential activation of parts of the serratus anterior muscle during push-up variations on stable and unstable bases of support. Journal of Electromyography and Kinesiology, 2011. 21(5): p. 861-867.
26. Dickie, J.A., et al., Electromyographic analysis of muscle activation during pull-up variations. Journal of Electromyography and Kinesiology, 2017. 32: p. 30-36.
27. Warner, M., P. Chappell, and M. Stokes, Measuring scapular kinematics during arm lowering using the acromion marker cluster. Human movement science, 2012. 31(2): p. 386-396.
28. van Andel, C., et al., Recording scapular motion using an acromion marker cluster. Gait & posture, 2009. 29(1): p. 123-128.
29. Warner, M.B., P.H. Chappell, and M.J. Stokes, Measurement of dynamic scapular kinematics using an acromion marker cluster to minimize skin movement artifact. JoVE (Journal of Visualized Experiments), 2015(96): p. e51717.
30. Morse, C.I., et al., The acute effect of stretching on the passive stiffness of the human gastrocnemius muscle tendon unit. The Journal of physiology, 2008. 586(1): p. 97-106.
31. Fletcher, I.M., The effect of different dynamic stretch velocities on jump performance. European journal of applied physiology, 2010. 109(3): p. 491-498.
32. Neumann, D.A., Kinesiology of the musculoskeletal system-e-book: foundations for rehabilitation. 2016: Elsevier Health Sciences.
33. Sandberg, J.B., et al., Acute effects of antagonist stretching on jump height, torque, and electromyography of agonist musculature. The Journal of Strength & Conditioning Research, 2012. 26(5): p. 1249-1256.
34. Umehara, J., et al., Scapular kinematic alterations during arm elevation with decrease in pectoralis minor stiffness after stretching in healthy individuals. Journal of shoulder and elbow surgery, 2018. 27(7): p. 1214-1220.
35. Borstad, J.D. and P.M. Ludewig, The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. Journal of orthopaedic & sports physical therapy, 2005. 35(4): p. 227-238.
36. Khanmohammadi, K., et al., Electromyographic analysis of shoulder impingement syndrome versus normal subjects. 2011.
37. Ludewig, P.M. and T.M. Cook, Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Physical therapy, 2000. 80(3): p. 276-291.
38. Behm, D.G. and A. Chaouachi, A review of the acute effects of static and dynamic stretching on performance. European journal of applied physiology, 2011. 111: p. 2633-2651.
39. Kilit, B., E. Arslan, and Y. Soylu, Effects of different stretching methods on speed and agility performance in young tennis players. Science & Sports, 2019. 34(5): p. 313-320.