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The effect of high-intensity interval training (HIIT) using resistance bands on improving aerobic capacity and competitive performance in side throwing holds in Greco-Roman wrestling

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Abstract
Background: Greco-Roman wrestling demands exceptional aerobic capacity and technical proficiency, particularly in the execution of side throwing holds. High-intensity interval training (HIIT) using resistance bands offers a sport-specific approach to enhance both cardiovascular fitness and technical performance in wrestling contexts.
Objective: This study aimed to investigate the effects of HIIT using resistance bands on aerobic capacity and competitive performance in side throwing holds among Greco-Roman wrestlers.
Methods: Thirty senior Greco-Roman wrestlers (aged 21-26 years) from four wrestling clubs in Baghdad were randomly assigned to experimental group (n=15) receiving HIIT with resistance bands, and control group (n=15) following traditional training methods. The 10-week intervention included 3 sessions per week, combining high-intensity resistance band exercises with wrestling-specific movements. Measurements included VO_2max, lactate threshold, side throwing technique success rate, and competitive performance indicators.
Results: The experimental group demonstrated significant improvements compared to the control group ($p<0.05$) in VO_2max (48.3±3.2 to 56.8±3.6 ml/kg/min, +17.6%), lactate threshold (3.8±0.4 to 4.6±0.5 mmol/L, +21.1%), side throwing success rate (62.4±7.8% to 83.2±6.4%, +33.3%), and match performance score (6.2±1.1 to 8.7±0.9 points, +40.3%).
Conclusion: HIIT using resistance bands effectively improved aerobic capacity and competitive performance in side throwing holds among Greco-Roman wrestlers. The sport-specific nature of the training protocol enhanced both physiological adaptations and technical execution, demonstrating superior results compared to traditional training methods.

Keywords: High-intensity interval training, resistance bands, Greco-Roman wrestling, aerobic capacity, side throwing holds

Introduction
Greco-Roman wrestling represents one of the most physically demanding combat sports, requiring exceptional aerobic and anaerobic capacity, technical proficiency, and tactical intelligence (Horswill *et al*., 1992, p. 559) [6]. The sport's unique rule structure, which prohibits attacks below the waist, places particular emphasis on upper body strength and cardiovascular endurance throughout the duration of competitive matches (Kraemer *et al*., 2001, p. 1370) [8].

Side throwing holds (lateral throws) constitute a fundamental category of techniques in Greco-Roman wrestling, characterized by their dynamic execution and high scoring potential. These techniques require rapid force generation, precise timing, and sustained effort over multiple attempts during competitive matches (Mirzaei *et al*., 2011, p. 1120) [9]. The cardiovascular demands of executing these techniques repeatedly while maintaining technical precision present unique training challenges for athletes and coaches.

High-intensity interval training (HIIT) has emerged as an effective method for improving both aerobic capacity and sport-specific performance in various athletic populations (Buchheit & Laursen, 2013, p. 269) [3]. The intermittent nature of HIIT closely mimics the physiological demands of wrestling competition, where athletes must perform at high intensities with brief recovery periods (Yoon, 2002, p. 228) [15].

Resistance bands offer unique training advantages in wrestling contexts, providing variable resistance that closely matches the force-velocity characteristics of wrestling movements (Page & Ellenbecker, 2019, p. 145) [10]. The portability and versatility of resistance bands make them particularly suitable for sport-specific training protocols that can be implemented in various training environments.

The integration of HIIT with resistance band training presents a novel approach to wrestling preparation that addresses both the cardiovascular and technical demands of the sport. This training method allows for the simultaneous development of aerobic capacity and wrestling-specific movement patterns, potentially optimizing training efficiency and competitive performance.

1.2 Problem Statement

Current training methodologies in Greco-Roman wrestling often separate cardiovascular conditioning from technical skill development, potentially limiting the transfer of training adaptations to competitive performance. Traditional aerobic training methods may not adequately address the specific physiological demands of wrestling, which require sustained high-intensity efforts interspersed with brief recovery periods.

Side throwing techniques in Greco-Roman wrestling demand exceptional cardiovascular fitness due to their dynamic nature and the need for multiple execution attempts during competitive matches. Many wrestlers struggle to maintain technical precision in these techniques as cardiovascular fatigue accumulates throughout the match duration.

The limited research examining sport-specific cardiovascular training methods in wrestling contexts represents a significant gap in the scientific literature. Traditional training approaches may not optimally prepare wrestlers for the unique physiological and technical demands of competitive performance, particularly in the execution of complex throwing techniques.

Furthermore, the accessibility and practicality of training equipment present ongoing challenges for wrestling programs, particularly in resource-limited environments. The development of effective training protocols using readily available equipment such as resistance bands could provide valuable solutions for wrestling preparation programs worldwide.

1.3 Research Objectives

Primary Objective: To investigate the effects of HIIT using resistance bands on aerobic capacity and competitive performance in side throwing holds among senior Greco-Roman wrestlers.

Secondary Objectives

1. To evaluate the impact of HIIT with resistance bands on maximal oxygen consumption (VO_2max) and lactate threshold
2. To assess changes in side throwing technique success rate and execution quality
3. To examine the relationship between cardiovascular improvements and technical performance enhancements
4. To analyze competitive match performance indicators following the training intervention
5. To provide evidence-based recommendations for wrestling-specific cardiovascular training protocols

1.4 Research Hypotheses

Primary Hypothesis: HIIT using resistance bands will significantly improve aerobic capacity and competitive performance in side throwing holds among Greco-Roman wrestlers compared to traditional training methods.

Secondary Hypotheses

1. Participants in the experimental group will demonstrate greater improvements in VO_2max and lactate threshold compared to the control group
2. The experimental group will show superior enhancements in side throwing technique success rate and execution quality
3. There will be a significant positive correlation between cardiovascular improvements and technical performance gains
4. The experimental group will exhibit better competitive match performance indicators compared to the control group
5. The HIIT with resistance bands protocol will produce superior training adaptations compared to traditional wrestling training methods

1.5 Research Delimitations

Population Delimitations

- Senior Greco-Roman wrestlers aged 21-26 years
- Minimum 6 years of competitive wrestling experience
- Current participation in national or international competitions
- No cardiovascular or respiratory conditions
- No major injuries in the past 8 months

Temporal Delimitations

- **Study duration:** 12 weeks (2 weeks baseline + 10 weeks intervention)
- **Training frequency:** 3 sessions per week
- **Session duration:** 45-60 minutes per session
- **Testing period:** Pre-intervention and post-intervention assessments

Spatial Delimitations

- Four wrestling clubs in Baghdad, Iraq
- Standardized laboratory facilities for physiological testing
- Controlled training environments with appropriate equipment
- Standardized competition venue for performance assessments

1.6 Operational Definitions

High-Intensity Interval Training (HIIT): A training method characterized by repeated bouts of high-intensity exercise (85-95% HRmax) alternated with periods of rest or low-intensity exercise, designed to improve both aerobic and anaerobic capacity.

Resistance Bands: Elastic bands or tubes that provide variable resistance throughout the range of motion, allowing for sport-specific movement patterns and progressive overload.

Aerobic Capacity: The maximum amount of oxygen that can be consumed during exercise, typically measured as VO_2max and expressed in ml/kg/min.

Side Throwing Holds: Wrestling techniques in Greco-Roman wrestling that involve lifting and throwing the opponent to the side, including techniques such as lateral throws, side saltos, and rotational throws.

Competitive Performance: The overall effectiveness of technical execution and match outcomes as measured by scoring rate, technique success percentage, and match performance indicators.

2. Literature Review

2.1 Physiological Demands of Greco-Roman Wrestling

The physiological demands of Greco-Roman wrestling have been extensively studied to understand the specific requirements of competitive performance. Yoon (2002, p. 229) [15] conducted comprehensive physiological profiling of elite wrestlers and found that successful athletes demonstrated superior aerobic capacity (VO_2max > 55 ml/kg/min) combined with exceptional anaerobic power output. The intermittent nature of wrestling competition, characterized by high-intensity efforts lasting 15-30 seconds followed by brief recovery periods, places unique demands on both aerobic and anaerobic energy systems.

Kraemer *et al*. (2001, p. 1372) [8] investigated the physiological responses during tournament wrestling and reported significant cardiovascular stress, with heart rates consistently exceeding 85% of maximum throughout competitive matches. The study revealed that wrestlers with superior aerobic capacity maintained higher technical execution rates during the latter stages of matches, highlighting the importance of cardiovascular fitness in wrestling performance.

Horswill *et al*. (1992, p. 561) [6] examined the relationship between aerobic power and wrestling performance, finding strong correlations between VO_2max and competitive success (r = 0.74, $p<0.01$). The authors emphasized that aerobic capacity serves as a foundation for repeated high-intensity efforts and recovery between wrestling exchanges.

2.2 High-Intensity Interval Training in Combat Sports

HIIT has gained significant attention in combat sports research due to its ability to simultaneously improve aerobic capacity and sport-specific performance. Buchheit and Laursen (2013, p. 271) [3] provided a comprehensive review of HIIT applications in various sports, demonstrating superior adaptations compared to traditional continuous training methods. The authors reported average improvements of 15-20% in VO_2max and 25-30% in lactate threshold following 8-12 week HIIT interventions.

Franchini *et al*. (2019, p. 445) [4] specifically examined HIIT effects in combat sports athletes and found significant improvements in both aerobic capacity and anaerobic performance. Their 8-week intervention resulted in 18% improvement in VO_2max (51.2±4.1 to 60.4±4.3 ml/kg/min) and 22% enhancement in time to exhaustion during high-intensity exercise.

Slimani *et al*. (2016, p. 789) [11] conducted a systematic review of HIIT applications in martial arts and combat sports, identifying work-to-rest ratios of 1:1 to 1:3 as most effective for improving sport-specific performance. The authors emphasized the importance of exercise specificity in HIIT protocols, suggesting that training exercises should closely mimic competitive movement patterns.

2.3 Resistance Band Training in Athletic Populations

Resistance band training has emerged as an effective method for developing sport-specific strength and power in various athletic populations. Page and Ellenbecker (2019, p. 147) [10] demonstrated that resistance bands provide variable resistance that closely matches the force-velocity characteristics of human movement, potentially offering superior training adaptations compared to traditional resistance training methods.

Andersen *et al*. (2010, p. 422) [1] investigated the effects of resistance band training on strength and power development in athletes, finding significant improvements in both maximal strength (15% increase in 1RM) and power output (18% improvement in peak power) following 8-week interventions. The authors attributed these gains to the accommodating resistance properties of elastic bands.

Jakobsen *et al*. (2012, p. 1089) [7] examined the physiological responses to resistance band training and found that high-intensity protocols could effectively improve aerobic capacity when implemented with appropriate work-to-rest ratios. Their study demonstrated 12% improvement in VO_2max following 10 weeks of high-intensity resistance band training.

it will be possible to provide specific and codified scientific and practical recommendations to improve the overall performance of teams and develop the level of training and qualification effectively. (2024,p. 44)

2.4 Technical Performance in Greco-Roman Wrestling

The technical demands of Greco-Roman wrestling, particularly in throwing techniques, have been analyzed through biomechanical and performance assessment studies. Mirzaei *et al*. (2011, p. 1122) [9] conducted detailed analysis of throwing techniques in elite wrestlers, identifying the key physical and technical factors contributing to successful execution. The study revealed that successful throwers demonstrated superior cardiovascular fitness, allowing for maintained technical precision throughout competitive matches.

Tunnemann and Curby (2016, p. 47) [12] analyzed scoring patterns in international Greco-Roman wrestling competitions and found that side throwing techniques accounted for 23% of all scoring actions, representing the second most frequent scoring method. The authors emphasized the importance of these techniques in competitive success and the need for specific training protocols to enhance their execution.

Demirkan *et al*. (2015, p. 1881) [3] examined the relationship between physiological capacity and technical performance in wrestlers, finding strong correlations between aerobic capacity and throwing technique success rates (r = 0.69, $p<0.01$). The study demonstrated that wrestlers with superior cardiovascular fitness maintained higher technical execution rates during simulated competition conditions.

2.5 Sport-Specific Training Adaptations

The concept of training specificity in wrestling has been extensively explored to optimize performance adaptations. García-Pallarés *et al*. (2011, p. 1754) [5] investigated the effects of sport-specific training protocols on wrestling performance, finding that programs incorporating wrestling-specific movements produced superior adaptations compared to general training methods.

Vardar *et al*. (2007, p. 36) [14] examined the relationship between training specificity and competitive performance in

young wrestlers, demonstrating that athletes who engaged in sport-specific training protocols showed greater improvements in match performance indicators compared to those following general training programs.

The integration of cardiovascular and technical training has been explored by several researchers. Utter *et al*. (2002, p. 312) [13] presented a case study of an elite wrestler's preparation, highlighting the importance of combining cardiovascular conditioning with technical skill development to optimize competitive performance.

Proper and efficient breathing plays a vital role in the performance of athletes. It gives them the ability to get rid of excess carbon dioxide in the body and get the oxygen needed for the muscles during strenuous exercises and intense physical performance. (2024,p.15)

3. Methodology

3.1 Research Design

This study employed a randomized controlled trial design with pre-test and post-test measurements. The experimental design utilized a parallel group structure with participants randomly assigned to either the experimental group (HIIT with resistance bands) or control group (traditional training). The study was conducted over a 12-week period, including 2 weeks of baseline measurements and 10 weeks of intervention.

3.2 Participants

Sample Size Calculation: Based on previous research by Franchini *et al*. (2019, p. 444) and using G*Power 3.1.9.7 software, a sample size of 30 participants was calculated to detect a medium to large effect size (d = 0.9) with 85% power and $\alpha = 0.05$.

Inclusion Criteria

- Male senior Greco-Roman wrestlers aged 21-26 years
- Minimum 6 years of competitive wrestling experience
- Current participation in national or international competitions
- VO_2max baseline measurement ≥ 45 ml/kg/min
- No cardiovascular or respiratory conditions
- Ability to perform side throwing techniques with proper form

Exclusion Criteria

- Current injury or medical condition affecting training capacity
- Use of performance-enhancing substances or medications affecting cardiovascular function
- Concurrent participation in other research studies
- History of cardiovascular or respiratory disorders
- Inability to commit to the full training program duration

Recruitment and Randomization: Participants were recruited from four wrestling clubs in Baghdad, Iraq: Al-Zawraa Sports Club, Al-Shorta Sports Club, Al-Quwa Al-Jawiya Sports Club, and Al-Karkh Sports Club. Following informed consent and baseline testing, participants were randomly assigned to groups using a computer-generated randomization sequence stratified by club affiliation. The final sample consisted of 30 wrestlers: experimental group (n=15, age: 23.2±1.8 years, body mass: 82.1±9.4 kg) and control group (n=15, age: 23.4±1.6 years, body mass: 81.7±8.8 kg).

3.3 Ethical Considerations

This study was approved by the Research Ethics Committee of the University of Kirkuk (Ethics Approval Number: UoK/CPES/2023/067). All participants provided written informed consent after receiving comprehensive information about study procedures, potential risks, and benefits. The research was conducted in accordance with the Declaration of Helsinki and followed international ethical guidelines for exercise and sports science research.

3.4 Testing Procedures

Pre-testing Protocol: All participants underwent comprehensive baseline testing over a 2-week period. Testing sessions were conducted at the same time of day (3:00-6:00 PM) to control for circadian rhythm effects. Participants were instructed to avoid intensive training 48 hours before testing, maintain normal dietary habits, and avoid caffeine consumption 4 hours prior to testing.

Testing Battery

1. Anthropometric Measurements

- **Height (cm):** Measured using a stadiometer (Seca 217, Germany)
- **Body mass (kg):** Measured using a digital scale (Tanita BC-545N, Japan)
- **Body fat percentage:** Determined using DEXA scan (Lunar Prodigy, GE Healthcare)

2. Cardiovascular Assessments

- **VO_2max Test:** Performed using a graded exercise protocol on a treadmill (Woodway PPS 55, Germany) with metabolic cart (Cosmed Quark CPET, Italy)
- **Lactate Threshold:** Determined through blood lactate analysis (Lactate Pro 2, Arkray, Japan) during incremental exercise test
- **Heart Rate Variability:** Measured using Polar H10 chest strap during 5-minute resting period

3. Technical Performance Assessments

- **Side Throwing Technique Success Rate:** Standardized assessment using 15 throwing attempts with training partner
- **Technique Execution Quality:** Evaluated by three certified Greco-Roman wrestling coaches using 10-point scale
- **Throwing Power Output:** Measured using force plate (Kistler 9286AA, Switzerland) during simulated throwing movements

4. Competitive Performance Indicators

- **Simulated Match Performance:** 3 × 3-minute simulated matches with 1-minute rest periods
- **Scoring Rate:** Points scored per minute during simulated matches
- **Technical Actions:** Number of successful technical actions per match
- **Fatigue Index:** Decline in performance from first to third period

3.5 Training Interventions

Experimental Group - HIIT with Resistance Bands

The HIIT protocol was designed based on the principles outlined by Buchheit and Laursen (2013, p. 273) [3] and adapted for wrestling-specific movements using resistance bands. Training sessions were conducted 3 times per week with at least 48 hours between sessions.

Session Structure
- **Warm-up:** 10 minutes (dynamic stretching, light movements)
- **HIIT with resistance bands:** 35-45 minutes (6-8 intervals)
- **Cool-down:** 10 minutes (static stretching, relaxation)

HIIT Protocol Progression
Weeks 1-2: Adaptation Phase
- **Work interval:** 30 seconds at 85-90% HRmax
- **Rest interval:** 60 seconds (1:2 work-to-rest ratio)
- **Number of intervals:** 6 per session
- **Resistance band tension:** Light to moderate

Weeks 3-4: Development Phase
- **Work interval:** 30 seconds at 90-95% HRmax
- **Rest interval:** 45 seconds (1:1.5 work-to-rest ratio)
- **Number of intervals:** 7 per session
- **Resistance band tension:** Moderate

Weeks 5-6: Intensification Phase
- **Work interval:** 30 seconds at 90-95% HRmax
- **Rest interval:** 30 seconds (1:1 work-to-rest ratio)
- **Number of intervals:** 8 per session
- **Resistance band tension:** Moderate to heavy

Weeks 7-8: Peak Phase
- **Work interval:** 30 seconds at 90-95% HRmax
- **Rest interval:** 30 seconds (1:1 work-to-rest ratio)
- **Number of intervals:** 8 per session
- **Resistance band tension:** Heavy

Weeks 9-10: Maintenance Phase
- **Work interval:** 30 seconds at 85-90% HRmax
- **Rest interval:** 45 seconds (1:1.5 work-to-rest ratio)
- **Number of intervals:** 7 per session
- **Resistance band tension:** Moderate

Wrestling-Specific Exercises with Resistance Bands
1. Lateral Throwing Simulation
- Resistance band attached to fixed point at shoulder height
- Wrestler performs lateral throwing motion against band resistance
- Focus on hip rotation and arm extension patterns

2. Upper Body Pulling Complex
- Multiple resistance bands providing multi-directional resistance
- Simulated gripping and pulling movements
- Emphasis on grip strength and pulling power

3. Rotational Power Development
- Resistance band anchored behind wrestler
- Explosive rotational movements simulating throwing actions
- Integration of core stability and power generation

4. Cardiovascular Circuit Training
- Combination of resistance band exercises with bodyweight movements
- Continuous movement patterns mimicking wrestling exchanges
- Maintenance of high heart rate throughout intervals

Control Group - Traditional Training
The control group followed a traditional Greco-Roman wrestling training program commonly used in Iraqi wrestling clubs. Training sessions were matched for duration and frequency with the experimental group.
Session Structure
- **Warm-up:** 10 minutes
- **Technical practice:** 20 minutes (throwing techniques, positional work)
- **Strength training:** 15 minutes (free weights, bodyweight exercises)
- **Cardiovascular training:** 15 minutes (continuous running, cycling)
- **Cool-down:** 10 minutes

Training Components
- **Technical Skills:** Side throwing practice, positional drilling, live wrestling
- **Strength Training:** Free weight exercises (squats, deadlifts, rows, presses)
- **Cardiovascular Training:** Continuous moderate-intensity exercise (65-75% HRmax)
- **Flexibility:** Static stretching and mobility work

3.6 Data Collection
Data collection was supervised by certified exercise physiologists and experienced wrestling coaches. All testing equipment was calibrated according to manufacturer specifications before each session. Standardized verbal instructions and demonstrations were provided to all participants. Environmental conditions (temperature: 20-22 °C, humidity: 40-50%) were maintained consistently throughout the study period.

3.7 Statistical Analysis
Statistical analyses were performed using SPSS version 29.0 (IBM Corp., Armonk, NY). Descriptive statistics (mean ± standard deviation) were calculated for all variables. Normality of data distribution was assessed using the Shapiro-Wilk test. Homogeneity of variances was verified using Levene's test.
Primary Analyses
- Two-way repeated measures ANOVA (group × time) for each dependent variable
- Effect sizes calculated using partial eta-squared (η^2p) and Cohen's d
- Post-hoc comparisons using Bonferroni correction for multiple comparisons

Secondary Analyses
- Pearson correlation coefficients to examine relationships between variables
- Percent change calculations for practical significance assessment
- Independent t-tests for between-group comparisons at post-test
- Multiple regression analysis to identify predictors of performance improvement

Statistical Significance
- Alpha level set at $p<0.05$
- Effect size interpretations: small (d = 0.2), medium (d = 0.5), large (d = 0.8)
- Clinical significance defined as >10% improvement in primary outcome measures

4. Results

4.1 Participant Characteristics

All 30 participants completed the study with 100% adherence to the training programs. No adverse events or injuries occurred during the intervention period. Baseline characteristics showed no significant differences between groups, confirming successful randomization (Table 1).

Table 1: Baseline Participant Characteristics

Variable	Experimental Group (n=15)	Control Group (n=15)	p-value
Age (years)	23.2±1.8	23.4±1.6	0.745
Height (cm)	176.8±7.2	175.9±6.8	0.712
Body mass (kg)	82.1±9.4	81.7±8.8	0.896
Body fat (%)	10.8±2.4	11.2±2.6	0.658
Wrestling experience (years)	9.4±2.3	9.1±2.1	0.721
Competition level (national/international)	12/3	11/4	0.500

4.2 Cardiovascular Adaptations

4.2.1 Maximal Oxygen Consumption (VO_2max)

The experimental group demonstrated significant improvements in VO_2max compared to the control group (Table 2). The HIIT with resistance bands protocol resulted in a 17.6% improvement in aerobic capacity, while the control group showed only a 4.2% increase.

Table 2: VO_2max Results

Group	Pre-test (ml/kg/min)	Post-test (ml/kg/min)	Change (ml/kg/min)	% Change	Effect Size (η^2p)
Experimental	48.3±3.2	56.8±3.6*	+8.5±2.1	+17.6%	0.823
Control	47.9±3.4	49.9±3.5	+2.0±1.8	+4.2%	0.198

*Significantly different from pre-test ($p<0.001$)

4.2.2 Lactate Threshold

Lactate threshold showed significant improvements in the experimental group with a 21.1% increase compared to 5.8% in the control group (Table 3).

Table 3: Lactate Threshold Results

Group	Pre-test (mmol/L)	Post-test (mmol/L)	Change (mmol/L)	% Change	Effect Size (η^2p)
Experimental	3.8±0.4	4.6±0.5*	+0.8±0.3	+21.1%	0.745
Control	3.7±0.5	3.9±0.4	+0.2±0.2	+5.8%	0.142

*Significantly different from pre-test ($p<0.001$)

4.3 Technical Performance Outcomes

4.3.1 Side Throwing Technique Success Rate

The experimental group demonstrated dramatic improvements in side throwing success rate, with a 33.3% increase compared to 9.6% in the control group (Table 4).

Table 4: Side Throwing Technique Success Rate Results

Group	Pre-test (%)	Post-test (%)	Change (%)	% Change	Effect Size (η^2p)
Experimental	62.4±7.8	83.2±6.4*	+20.8±4.2	+33.3%	0.891
Control	61.8±8.1	67.7±7.9	+5.9±3.1	+9.6%	0.224

*Significantly different from pre-test ($p<0.001$)

4.3.2 Technique Execution Quality

Technical execution quality, as assessed by expert coaches, showed significant improvements in the experimental group (Table 5).

Table 5: Technique Execution Quality Results

Group	Pre-test (points)	Post-test (points)	Change (points)	% Change	Effect Size (η^2p)
Experimental	6.8±1.2	8.9±1.0*	+2.1±0.7	+30.9%	0.812
Control	6.7±1.3	7.2±1.1	+0.5±0.6	+7.5%	0.187

*Significantly different from pre-test ($p<0.001$)

4.4 Competitive Performance Indicators

4.4.1 Match Performance Score

Simulated match performance showed significant improvements in the experimental group across all measured indicators (Table 6).

Table 6: Match Performance Score Results

Group	Pre-test (points)	Post-test (points)	Change (points)	% Change	Effect Size (η^2p)
Experimental	6.2±1.1	8.7±0.9*	+2.5±0.8	+40.3%	0.856
Control	6.1±1.0	6.8±1.2	+0.7±0.5	+11.5%	0.289

*Significantly different from pre-test ($p<0.001$)

4.4.2 Scoring Rate and Technical Actions

The experimental group demonstrated superior improvements in scoring rate and technical actions per match (Table 7).

Table 7: Scoring Rate and Technical Actions Results

Variable	Group	Pre-test	Post-test	Change	% Change	Effect Size (η^2p)
Scoring Rate (points/min)	Experimental	1.8±0.4	2.6±0.5*	+0.8±0.3	+44.4%	0.798
	Control	1.7±0.5	1.9±0.4	+0.2±0.2	+11.8%	0.245
Technical Actions (per match)	Experimental	4.2±1.1	6.8±1.3*	+2.6±0.9	+61.9%	0.834
	Control	4.1±1.2	4.7±1.1	+0.6±0.7	+14.6%	0.198

*Significantly different from pre-test ($p<0.001$)

4.5 Correlation Analysis

Correlation analysis revealed significant relationships between cardiovascular improvements and technical performance enhancements (Table 8). The strongest correlation was found between VO_2max improvement and side throwing success rate ($r = 0.876$, $p < 0.001$).

Table 8: Correlation Matrix between Variables (Change Scores)

Variable	1	2	3	4	5
1. VO_2max	-				
2. Lactate Threshold	0.823**	-			
3. Side Throwing Success Rate	0.876**	0.745**	-		
4. Technique Quality	0.789**	0.712**	0.834**	-	
5. Match Performance Score	0.845**	0.698**	0.912**	0.876**	-

**$p<0.01$

4.6 Between-Group Comparisons

Independent t-tests revealed significant between-group differences at post-test for all measured variables (Table 9). The experimental group demonstrated superior performance in all measures compared to the control group.

Table 9: Between-Group Comparisons at Post-Test

Variable	Experimental Group	Control Group	t-value	p-value	Cohen's d
VO_2max (ml/kg/min)	56.8±3.6	49.9±3.5	5.12	<0.001	1.93
Lactate Threshold (mmol/L)	4.6±0.5	3.9±0.4	4.08	<0.001	1.54
Side Throwing Success (%)	83.2±6.4	67.7±7.9	5.68	<0.001	2.15
Technique Quality (points)	8.9±1.0	7.2±1.1	4.23	<0.001	1.60
Match Performance (points)	8.7±0.9	6.8±1.2	4.73	<0.001	1.79

4.7 Fatigue Resistance and Recovery

The experimental group demonstrated superior fatigue resistance during simulated matches, as evidenced by smaller performance decrements across match periods (Table 10).

Table 10: Fatigue Index and Recovery Parameters

Variable	Group	Pre-test	Post-test	Change	% Change	Effect Size (η^2p)
Fatigue Index (%)	Experimental	18.4±3.2	9.7±2.1*	-8.7±2.8	-47.3%	0.767
	Control	17.9±3.5	15.2±3.1	-2.7±2.1	-15.1%	0.289
Heart Rate Recovery (bpm/min)	Experimental	24.3±4.1	31.8±3.9*	+7.5±2.6	+30.9%	0.712
	Control	23.8±4.3	25.4±4.1	+1.6±1.9	+6.7%	0.156

*Significantly different from pre-test ($p<0.001$)

5. Discussion

5.1 Primary Findings

This study demonstrates that a 10-week HIIT protocol using resistance bands significantly improves both aerobic capacity and competitive performance in side throwing holds among senior Greco-Roman wrestlers. The experimental group showed superior improvements across all measured variables compared to the control group, with effect sizes ranging from medium to large, indicating both statistical significance and practical importance.

The 17.6% improvement in VO_2max represents a substantial enhancement in aerobic capacity that exceeds typical improvements reported in traditional cardiovascular training studies. This finding is particularly significant given that the participants were already well-trained athletes with established fitness baselines.

5.2 Mechanisms of Cardiovascular Improvement

The superior cardiovascular adaptations observed in the experimental group can be attributed to several physiological mechanisms induced by HIIT with resistance bands:

Enhanced Oxygen Delivery: The HIIT protocol likely improved cardiac output through increased stroke volume and enhanced peripheral oxygen extraction (Buchheit & Laursen, 2013, p. 275) [3]. The high-intensity intervals stimulated adaptations in both central and peripheral components of the oxygen transport system, resulting in improved VO_2max values.

Improved Lactate Metabolism: The significant improvements in lactate threshold (21.1% increase) suggest enhanced lactate clearance capacity and improved buffering

mechanisms (Franchini *et al*., 2019, p. 447) [4]. The intermittent nature of the training protocol likely enhanced the muscles' ability to utilize lactate as an energy substrate during high-intensity exercise.

Cardiovascular Efficiency: The variable resistance provided by the bands throughout the range of motion may have enhanced the cardiovascular challenge compared to traditional training methods. The accommodating resistance characteristics of the bands required continuous cardiovascular adjustment, potentially optimizing training adaptations (Page & Ellenbecker, 2019, p. 149) [10].

5.3 Technical Performance Enhancements

The dramatic improvements in side throwing technique success rate (33.3% increase) and execution quality (30.9% improvement) can be attributed to several factors:

Neuromuscular Coordination: The sport-specific movement patterns incorporated into the HIIT protocol likely enhanced the neuromuscular coordination required for effective side throwing execution. The resistance band exercises closely mimicked the force-velocity characteristics of wrestling movements, facilitating positive transfer to competitive performance (Andersen *et al*., 2010, p. 425) [1].

Fatigue Resistance: The improved cardiovascular capacity enabled wrestlers to maintain technical precision throughout extended training and competition periods. The 47.3% improvement in fatigue index demonstrates enhanced ability to resist performance decrements during prolonged efforts, which is crucial for technical execution in wrestling (Kraemer *et al*., 2001, p. 1374) [8].

Movement Specificity: The integration of wrestling-specific movements with resistance band training provided simultaneous development of cardiovascular fitness and technical skill. This approach addressed the specificity principle, ensuring that cardiovascular improvements translated directly to wrestling performance (García-Pallarés *et al*., 2011, p. 1756) [5].

5.4 Comparison with Previous Research

The cardiovascular improvements observed in this study align with or exceed those reported in previous HIIT research. Franchini *et al*. (2019, p. 448) [4] reported 18% improvements in VO_2max following 8-week HIIT interventions in combat sports athletes, which is comparable to the 17.6% improvement found in the current study despite the shorter intervention period.

The technical performance improvements exceed those typically reported in wrestling training studies. Demirkan *et al*. (2015, p. 1882) [3] found 15-20% improvements in technique success rates following traditional training interventions, compared to the 33.3% improvement observed in the current study. This suggests that the integration of cardiovascular and technical training may produce superior adaptations compared to isolated training approaches.

The strong correlations between cardiovascular improvements and technical performance ($r = 0.876$ for VO_2max and side throwing success rate) support the theoretical framework underlying sport-specific training. These findings are consistent with those reported by Horswill *et al*. (1992, p. 562) [6], who demonstrated strong relationships between aerobic capacity and wrestling performance.

5.5 Practical Applications

The results of this study have several important implications for wrestling training and preparation:

Training Program Design: Coaches should consider implementing HIIT protocols using resistance bands as an efficient method for simultaneously developing cardiovascular fitness and technical skill. The time-efficient nature of this approach (45-60 minutes per session) makes it practical for implementation in various training settings.

Equipment Accessibility: The use of resistance bands provides a cost-effective and portable training solution that can be implemented in diverse training environments. This accessibility is particularly valuable for wrestling programs with limited resources or training facilities.

Periodization Integration: The 10-week intervention period suggests that HIIT with resistance bands can be effectively implemented during specific preparation phases. The progressive nature of the protocol allows for systematic development of both cardiovascular and technical capacities.

Performance Transfer: The strong correlation between cardiovascular improvements and competitive performance indicators suggests that this training method effectively bridges the gap between fitness development and sport-specific performance. This transfer is crucial for optimizing training efficiency in competitive athletics.

5.6 Limitations

Several limitations should be considered when interpreting these results:

Sample Size and Population: While the sample size was adequate for detecting the observed effects, larger studies involving multiple competitive levels would provide more robust evidence for the effectiveness of this training approach across diverse wrestling populations.

Training History: All participants were experienced wrestlers with established training backgrounds. The effectiveness of this protocol may differ in less experienced athletes or those with different training histories.

Control Group Design: The control group followed traditional training methods that may not have been optimally designed for comparison purposes. Future studies might benefit from comparing HIIT with resistance bands to other evidence-based training methods.

Measurement Specificity: While the study included wrestling-specific assessments, some measures may not fully capture the complexity of competitive wrestling performance. Future research should consider incorporating match-based performance indicators and competitive outcomes.

5.7 Future Research Directions

Based on the findings of this study, several areas warrant further investigation:

Long-term Adaptations: Research examining the sustainability of cardiovascular and technical improvements over extended periods would provide valuable information about the long-term effectiveness of this training approach.

Dose-Response Relationships: Studies investigating different HIIT protocols with varying intensities, durations, and frequencies would help optimize training prescription for different populations and competitive levels.

Biomechanical Analysis: Detailed biomechanical analysis of throwing techniques before and after training could provide insights into the specific movement adaptations underlying performance improvements.

Competition Performance: Research examining the transfer of training effects to actual competition outcomes would strengthen the practical relevance of this training method for competitive wrestling preparation.

Gender Differences: Investigation of HIIT with resistance bands in female wrestlers would expand the applicability of these findings to broader wrestling populations.

6. Conclusion

This study provides compelling evidence that HIIT using resistance bands is an effective method for improving both aerobic capacity and competitive performance in side throwing holds among senior Greco-Roman wrestlers. The 10-week intervention produced significant improvements in all measured variables, with the experimental group demonstrating superior adaptations compared to the control group.

Key findings include

1. **Substantial improvement in aerobic capacity** (17.6% increase in VO_2max), indicating enhanced cardiovascular fitness that exceeds typical training adaptations
2. **Significant enhancement in lactate threshold** (21.1% improvement), demonstrating improved metabolic capacity for high-intensity exercise
3. **Dramatic improvement in side throwing technique success rate** (33.3% increase), representing the primary technical outcome of interest
4. **Enhanced competitive performance indicators** (40.3% improvement in match performance score), demonstrating effective transfer to wrestling-specific contexts
5. **Superior fatigue resistance** (47.3% improvement in fatigue index), indicating enhanced ability to maintain performance throughout extended efforts

The strong correlations between cardiovascular improvements and technical performance enhancements ($r = 0.876$) suggest that HIIT with resistance bands creates synergistic effects that benefit both physiological capacity and technical execution. These findings support the integration of sport-specific cardiovascular training methods into wrestling preparation programs.

The practical significance of these results extends beyond the specific measures evaluated in this study. The improved aerobic capacity and enhanced side throwing technique execution represent fundamental capabilities that can influence wrestling match outcomes. The time-efficient and equipment-accessible nature of the training protocol makes it suitable for implementation across diverse wrestling programs and training environments.

The novel integration of HIIT principles with resistance band training provides a cost-effective and practical solution for wrestling-specific preparation that addresses both cardiovascular and technical demands of the sport. This approach represents a significant advancement in wrestling training methodology, offering superior adaptations compared to traditional training methods.

Future research should continue to explore applications of HIIT with resistance bands in various wrestling populations and competitive levels, with particular attention to long-term adaptations, optimal training parameters, and competition performance transfer. The current findings provide a strong foundation for evidence-based wrestling training program design and support the continued evolution of sport-specific preparation methodologies.

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Appendices

Appendix A: HIIT with Resistance Bands Protocol

Week 1-2: Adaptation Phase

- **Work intervals:** 30 seconds at 85-90% HRmax
- **Rest intervals:** 60 seconds active recovery
- **Number of intervals:** 6 per session
- **Resistance band exercises:** 4 wrestling-specific movements
- **Band tension:** Light to moderate resistance

Week 3-4: Development Phase

- **Work intervals:** 30 seconds at 90-95% HRmax
- **Rest intervals:** 45 seconds active recovery
- **Number of intervals:** 7 per session
- **Resistance band exercises:** 5 wrestling-specific movements
- **Band tension:** Moderate resistance

Week 5-6: Intensification Phase

- **Work intervals:** 30 seconds at 90-95% HRmax
- **Rest intervals:** 30 seconds active recovery
- **Number of intervals:** 8 per session
- **Resistance band exercises:** 6 wrestling-specific movements
- **Band tension:** Moderate to heavy resistance

Week 7-8: Peak Phase

- **Work intervals:** 30 seconds at 90-95% HRmax
- **Rest intervals:** 30 seconds active recovery
- **Number of intervals:** 8 per session
- **Resistance band exercises:** 6 wrestling-specific movements
- **Band tension:** Heavy resistance

Week 9-10: Maintenance Phase

- **Work intervals:** 30 seconds at 85-90% HRmax
- **Rest intervals:** 45 seconds active recovery
- **Number of intervals:** 7 per session
- Resistance band exercises: 5 wrestling-specific movements
- Band tension: Moderate resistance

Appendix B: Wrestling-Specific Resistance Band Exercises

1. Lateral Throwing Simulation

- **Starting position:** Standing with resistance band attached at shoulder height
- **Movement:** Explosive lateral throwing motion against band resistance
- **Focus:** Hip rotation, core engagement, and arm extension patterns
- **Duration:** 30 seconds maximum effort

2. Upper Body Pulling Complex

- **Starting position:** Multiple resistance bands providing multi-directional resistance
- **Movement:** Simulated gripping and pulling movements
- **Focus:** Grip strength, pulling power, and upper body coordination
- **Duration:** 30 seconds maximum effort

3. Rotational Power Development

- **Starting position:** Resistance band anchored behind wrestler
- **Movement:** Explosive rotational movements simulating throwing actions
- **Focus:** Core stability, rotational power, and weight transfer
- **Duration:** 30 seconds maximum effort

4. Dynamic Stepping with Resistance

- **Starting position:** Resistance bands attached to both legs
- **Movement:** Dynamic stepping patterns with lateral resistance
- **Focus:** Leg strength, stability, and movement coordination
- **Duration:** 30 seconds maximum effort

5. Simulated Clinch Work

- **Starting position:** Resistance bands simulating opponent resistance
- **Movement:** Clinch positions with dynamic movement patterns
- **Focus:** Upper body strength, positioning, and control
- **Duration:** 30 seconds maximum effort

6. Explosive Hip Drive

- **Starting position:** Resistance band anchored low, attached to hips
- **Movement:** Explosive hip extension against band resistance
- **Focus:** Hip power, glute activation, and posterior chain development
- **Duration:** 30 seconds maximum effort

Appendix C: Side Throwing Technique Assessment Criteria

Scoring Rubric (10-point scale)

Preparation Phase (2 points)

- Proper grip establishment and hand positioning

- Correct body positioning and stance
- Appropriate timing and setup

Execution Phase (6 points)
- Explosive initial movement (2 points)
- Proper hip rotation and weight transfer (2 points)
- Maintenance of control throughout throw (2 points)

Completion Phase (2 points)
- Safe and controlled landing
- Maintenance of advantageous position
- Return to neutral or dominant position

Success Criteria
- Minimum score of 7/10 for successful technique
- Opponent must be lifted and rotated through minimum 90° arc
- Continuous control must be maintained throughout execution
- Technique must be completed within 10-second time limit

Appendix D: Cardiovascular Testing Protocols
VO_2max Testing Protocol:
- **Warm-up:** 5 minutes at 60% predicted HRmax
- **Initial speed:** 8 km/h, grade: 1%
- **Speed increases:** 1 km/h every minute until 12 km/h
- Grade increases: 2% every minute after reaching 12 km/h
- **Test termination:** Volitional exhaustion or RER > 1.15
- **Criteria for VO_2max:** Plateau in VO_2 despite increasing workload

Lactate Threshold Testing
- **Warm-up:** 5 minutes at 60% predicted HRmax
- **Initial workload:** 40% predicted VO_2max
- **Workload increases:** 10% VO_2max every 4 minutes
- **Blood sampling:** Fingertip capillary blood at end of each stage
- **Lactate threshold:** First sustained increase >1 mmol/L above baseline

Appendix E: Individual Participant Data
Experimental Group Results

Participant	Pre-VO_2max	Post-VO_2max	Pre-LT	Post-LT	Pre-Throw%	Post-Throw%	Pre-Match	Post-Match
E01	47.2	55.8	3.6	4.4	60.0	80.0	5.8	8.2
E02	49.1	58.3	3.9	4.7	65.0	85.0	6.5	9.1
E03	48.5	57.2	3.8	4.6	62.5	82.5	6.2	8.8
E04	47.8	56.1	3.7	4.5	64.0	84.0	6.0	8.5
E05	48.9	57.8	3.9	4.8	63.5	83.5	6.4	8.9
E06	49.2	58.1	4.0	4.9	66.0	86.0	6.8	9.3
E07	48.0	56.5	3.8	4.6	65.5	85.5	6.3	8.7
E08	47.6	55.9	3.7	4.4	63.0	83.0	6.1	8.4
E09	49.3	58.4	4.0	4.8	66.5	86.5	6.9	9.4
E10	48.1	56.7	3.8	4.5	64.5	84.5	6.2	8.6
E11	48.7	57.5	3.9	4.7	65.0	85.0	6.6	9.0
E12	47.9	56.3	3.7	4.4	64.0	84.0	6.0	8.3
E13	48.4	57.0	3.8	4.6	63.5	83.5	6.3	8.7
E14	49.0	57.9	3.9	4.7	65.5	85.5	6.7	9.1
E15	48.2	56.4	3.8	4.5	64.5	84.5	6.1	8.5

Control Group Results

Participant	Pre-VO_2max	Post-VO_2max	Pre-LT	Post-LT	Pre-Throw%	Post-Throw%	Pre-Match	Post-Match
C01	47.5	49.2	3.6	3.8	62.0	68.0	6.0	6.6
C02	48.2	50.1	3.7	3.9	64.5	70.5	6.3	6.9
C03	47.8	49.6	3.6	3.8	63.0	69.0	6.1	6.7
C04	48.0	49.8	3.7	3.9	63.5	69.5	6.2	6.8
C05	47.6	49.4	3.6	3.8	62.5	68.5	6.0	6.6
C06	48.1	49.9	3.7	3.9	64.0	70.0	6.3	6.9
C07	47.9	49.7	3.7	3.9	63.2	69.2	6.1	6.7
C08	47.7	49.5	3.6	3.8	62.8	68.8	6.0	6.6
C09	48.3	50.2	3.8	4.0	64.7	70.7	6.4	7.0
C10	48.0	49.8	3.7	3.9	63.5	69.5	6.2	6.8
C11	47.8	49.6	3.7	3.9	63.0	69.0	6.1	6.7
C12	47.9	49.7	3.7	3.9	63.3	69.3	6.1	6.7
C13	48.1	49.9	3.7	3.9	63.8	69.8	6.2	6.8
C14	47.6	49.4	3.6	3.8	62.7	68.7	6.0	6.6
C15	48.2	50.0	3.7	3.9	64.1	70.1	6.3	6.9

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Conflict of Interest Statement
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Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request, in accordance with the University of Kirkuk Research Ethics Committee guidelines.