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Original Research

Muscle Synergy during Double-Leg Attack maneuver: A Comparison between Elite and Sub-Elite Wrestlers

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ABSTRACT

Freestyle wrestling requires precise and coordinated movement execution, with the Double-Leg Attack technique playing a crucial role in gaining an advantage. Understanding the underlying mechanisms and effects of specialized wrestling training is essential for optimizing performance. Muscle synergy or modular movement control involves coordinated patterns of muscle activation and the organization of muscles into functional units or modules. Exploring these concepts in freestyle wrestling can provide insights into optimizing movement coordination and performance outcomes by studying the synergistic interaction of different muscles. This study investigates the effect of consistent and specialized Freestyle wrestling training on upper limb muscle synergy during the Double-Leg Attack maneuver, specifically comparing elite and sub-elite wrestlers. Thirty-eight junior Iranian male freestyle wrestlers were categorized based on their skill level. Elite group (n = 19) who participated in national or international-level competitions and achieved notable success and sub-elite group (n = 19) actively engaged in training but have not yet reached the same competitive level. We recorded EMG activity from five unilateral upper limb muscles and employed a non-negative matrix factorization (NMF) algorithm to extract the muscle synergy composition and temporal activation patterns during the Double-Leg Attack maneuver. In both the elite and sub-elite groups, three distinct muscle synergies (Syn1, Syn2, and Syn3) were identified

and extracted. Notably, both groups showed impressive coherence within their respective groups in terms of spatial structures and temporal activation patterns of muscle synergies during the Double-Leg Attack technique. However, it was observed that elite wrestlers exhibited significantly higher values in temporal activation patterns compared to their sub-elite counterparts (P=0.000). The findings of this study highlight the importance of consistent and specialized Freestyle wrestling training in optimizing muscle synergy during the Double-Leg Attack technique. Significant differences observed in the temporal activation patterns suggest that elite wrestlers possess a higher level of temporal precision and coordination, which may contribute to their competitive advantage. These findings provide valuable insights for wrestlers and coaches to guide training strategies focused on enhancing muscle synergy and temporal coordination for improved performance in Freestyle wrestling.
Keywords: Freestyle Wrestling, Double-Leg Attack, Motor Module Composition, Spatial Structures, Temporal Activation Patterns

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INTRODUCTION

Freestyle wrestling is a highly dynamic and physically demanding sport that requires precise movement coordination and rapid execution of techniques. The effectiveness of specific wrestling maneuvers, such as the Double-Leg Attack Technique, is crucial in gaining an advantageous position and securing victory. The successful application of these techniques relies not only on physical attributes like strength and agility but also on the coordinated activation of underlying muscle groups. Understanding the underlying mechanisms and adaptations associated with this technique is essential for comprehending the effects of consistent and specialized wrestling training on performance.

Motor modules, also known as muscle synergies, provide valuable insights into the neural control of movement. These structures consist of groups of muscles that work together in a specific manner, with a fixed spatial structure and a time-varying activation pattern [1]. Motor modules act as fundamental units that translate desired movements into biomechanical outputs [2–6]. They can be scaled, shifted, and combined to coordinate intentional, goal-directed actions [7,8]. Investigating the characteristics and differences in muscle synergies among athletes of different skill levels is crucial for understanding superior performance in sports.

Long-term training can lead to structural and organizational changes in motor modules, particularly in individuals with motor impairments [9]. Studies on walking and balance abilities have shown that individuals with impairments exhibit a reduction in the number of motor modules and an increase in the number of muscles working within each module [10–13]. Furthermore, there is broader recruitment of these modules over time and a higher degree of variability in the recruitment pattern [14]. In the context of sports, studies in various disciplines have explored the relationship between skill level and muscle synergies, revealing variations in the characteristics of motor modules, including the number, spatial structure, temporal patterns, and recruitment of modules.

Studies in sports such as cycling [15], badminton [16], and beam walking [9] have demonstrated that experienced athletes exhibit a more significant number of muscle synergies compared to their less experienced counterparts. However, some studies did not find significant differences in the number of muscle synergies among athletes of different skill levels [17–27] but observed variations in other characteristics or variables associated with muscle synergies. For example, novice archers showed differences in the timing and muscle contributions of specific motor modules compared to elite and mid-level archers [17]. Consistent and specialized training can potentially induce changes in the spatial and temporal structure of motor modules, with expert athletes recruiting more modules, exhibiting reduced muscle coactivity, and demonstrating more consistent motor modules during challenging sports tasks.

The objective of our study is to investigate the differences in upper limb muscle synergies between elite and sub-elite wrestlers, providing insights into the motor control mechanisms associated with superior performance. We hypothesize that consistent and specialized wrestling training alters muscle coordination during the Double-Leg Attack maneuver. Specifically, we examine and compare the structure and organization of motor modules between elite and sub-elite wrestlers during this commonly used technique. We expect that elite wrestlers will exhibit more motor modules and demonstrate a higher level of consistency in both spatial structure and temporal patterns during the execution of the Double-Leg Attack maneuver. The findings of this study have the potential to inform training strategies, optimize performance enhancement programs, and contribute to the advancement of freestyle wrestling training methodologies.

MATERIAL AND METHODS

Participants

Thirty-eight junior Iranian male wrestlers without any orthopedic or neurologic abnormalities performed the Double-Leg Attack against a defender. The Elite group comprised 19 wrestlers (age: 16.7 ± 1.0 years; height: 1.73 ± 0.07 meters; mass: 65.0 ± 14.2 kilograms) who have achieved notable success in national and international competitions, while the Sub-elite group comprised 19 talented wrestlers (age: 16.8 ± 0.65 years; height: 1.75 ± 0.05 meters; mass: 67.7 ± 11.0 kilograms) who are actively engaged in training but have not yet reached the same competitive level. The sole defender was a national-level wrestler (age: 17 years; height: 1.74 meters; mass: 72 kilograms) who did not participate in the study as an attacker. Before their participation, all participants provided written informed consent, adhering to the guidelines outlined in the Declaration of Helsinki. Furthermore, the study protocols were reviewed and approved by the ethics committee of the University of Mazandaran.

Experimental Procedures

The target task for this study was designated as the Double-Leg Attack maneuver. In the sport of freestyle wrestling, the initiation of the Double-Leg Attack involves the attacker taking a step toward the opponent using the leading foot from a staggered crouched position. Simultaneously, the attacker lowers their body by flexing the lower extremities while advancing towards the opponent. Upon reaching the desired position, the attacker forcefully propels the upper body into the abdomen of the opponent, simultaneously grasping the back of the knees and exerting a pulling force to bring the opponent down to the ground [28]. Before initiating each leg attack, both the attacker and the defender assumed a staggered position, with their hands in contact with their shoulders or arms, replicating the stance used in a wrestling match (see Figure 1 for reference). This approach is consistent with the methodology employed in a study conducted by Yamashita et al. [29]. To minimize variability and improve the reliability of the collected data during this technique, we implemented a shortened movement task. Wrestlers were provided with standardized instructions to perform the technique, resulting in enhanced repeatability of their performances. Afterward, the quality of the attacks was assessed by a wrestling expert using a rating scale ranging from 1 (poor) to 5 (excellent). Subsequently, seven trials with a rating of at least 4 or 5 were chosen for further analysis.

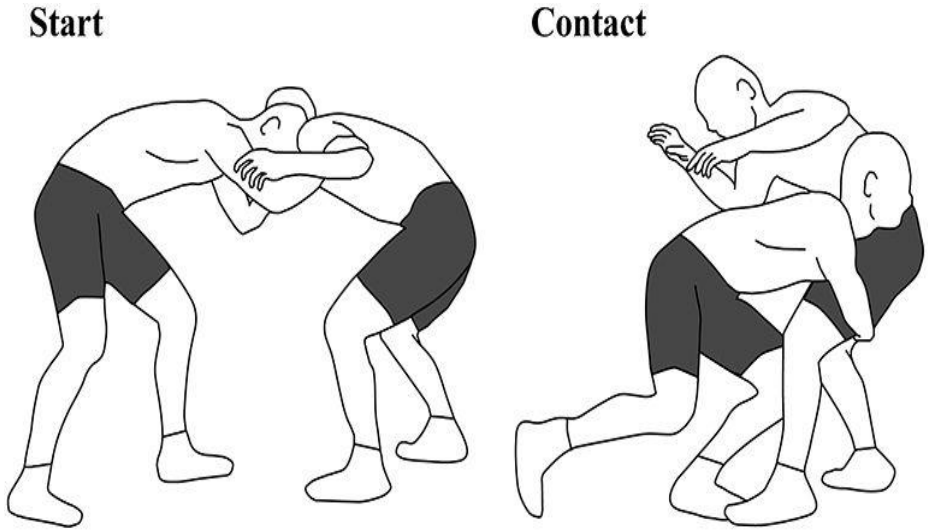

Figure 1. Visual representation illustrating the Double-leg attack from the starting position (left) to the ending position (right).

Data Collection and Processing

Surface EMG activity during Double-Leg Attack was recorded from the five muscles of the preferred upper limb of each participant using a surface EMG system (Biovision, Germany) at a sampling rate of 1000 Hz. The muscles that were recorded included the following: long head of Triceps brachii (TB), Biceps brachii (BB), Pectoralis Major (PM), Deltoid Anterior (DA), and Latissimus dorsi (LD). Bipolar Ag-AgCl electrodes (INTCO, SF06), with a diameter of 10 mm and inter-electrode distance of 20 mm, were used. To ensure minimal impedance, the skin was prepared before electrode application by shaving and cleaning with a mixture of alcohol and ether. Each electrode was placed longitudinally with respect to the underlying muscle fibers arrangement, adhering to the guidelines recommended by SENIAM (Surface EMG for Non-Invasive Assessment of Muscles) for all the muscles, except for the muscles latissimus dorsi (LD) and Pectoralis major (PM) which are not referenced by SENIAM. For LD and PM, the electrode placement followed the recommendations provided by Criswell [30].

The identification of the start and end of the technique in the pilot tests was facilitated by using reflective markers, three synchronized cameras (Basler, Germany) with an EMG device. The biceps muscle activity pattern, as determined by a custom-made MATLAB program, coincided with the start and end of the technique captured by the camera. Consequently, the activation pattern of the biceps muscle served as the criterion for determining the activation period of the muscles during the technique. Refer to the description provided in Figure 2 for further details.

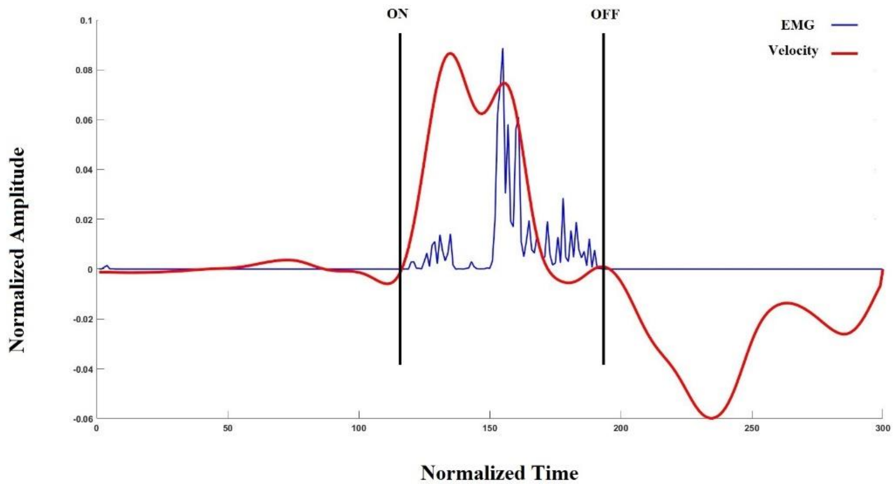

Figure 2 illustrates the determination of the onset and offset of data collection, which was achieved by leveraging the synchronous EMG and kinematic data. Specifically, we examined the resultant velocity of the wrist marker, which was plotted on the linear envelope of the EMG data. As the technique began, the resultant velocity of the wrist marker crossed the zero line and exhibited a significant increase. Conversely, at the end of the technique, the resultant velocity of the wrist marker crossed zero again, but this time displayed a substantial decrease. Notably, we observed that the onset and offset of the biceps muscle coincided with the start and end of the technique, respectively. Consequently, the activation pattern of the biceps muscle served as the criterion for determining the activation period of the muscles during the technique.

Muscle Synergies Extraction

To enhance the quality of the surface electromyography (EMG) data by eliminating signal outliers without excessively impacting the raw data, a Hampel filter was employed as the initial step. The Hampel filter was configured with specific parameters, including a time window of win = 25 and a threshold of $\sigma = 4$ (standard deviations), to accomplish this objective [31]. Subsequently, the EMG signals underwent further processing. Firstly, a bandpass filter was applied using a 4th-order Butterworth filter, restricting the frequency range between 20 and 450 Hz. Following this, the EMG data was subjected to full-wave rectification, effectively converting the signal to its absolute value, and subsequently, a 4th-order zero-lag Butterworth low-pass filter was employed at 8 Hz to obtain the linear envelope. To achieve a consistent time base, the filtered data was time-interpolated with 200 points per individual cycle. To standardize the amplitude scales across subjects, the amplitudes of the EMG waveforms were normalized by dividing by the maximum value for each corresponding subject, resulting in a range of 0 to 1 for all muscle scales. Finally, the calculated data for each subject was organized into a data matrix consisting of five rows (representing five muscles) and 1400 columns (200 points per cycle multiplied by seven cycles).

The Non-negative Matrix Factorization algorithm (NMF) was employed to extract muscle synergies from each cycle of the data matrix containing EMG recordings. The NMF approach assumes that the muscle activation pattern, denoted as M, within each period can be expressed as a linear combination of a limited number of muscle synergy composition vectors or weighing vectors, represented as W_k. Each muscle synergy is recruited by a corresponding synergy recruitment coefficient, denoted as C_k. Thus, Equation 1 describes a specific muscle activation pattern, **M**, in each task.

$$M(t) = \sum_{k=1}^{Ksyng} W_k C_{k(t)} + e \quad (W_k \geq 0\,, C_k \geq 0) \qquad \text{Equation 1}$$

Where the variable **M** represents an initial matrix with dimensions m-by-n, where m corresponds to the number of muscles and n represents the number of time points. The matrix **W** is m-by-k, where k denotes the number of synergies. **W** represents the matrix of muscle synergy composition vectors. The matrix **C**, with dimensions k-by-n, represents the synergy activation coefficients or temporal activation patterns. Lastly, the matrix **e** is m-by-n and represents the residual error matrix. The NMF analysis utilized the Alternating Least Squares (ALS) algorithm, which iteratively updated initial randomly estimated matrices W and C. This iterative process facilitated the convergence of the matrices, leading to a locally optimal matrix factorization. The analysis applied 100 replicates and a maximum of 50 iterations, with the latter representing the default maximum value. For each subject, the analysis was performed iteratively by varying the number of synergies from one to five. The aim was to identify the minimum number of synergies that accounted for more than 90% of the overall variance accounted for (VAF) and more than 75% of the VAF in each muscle. This threshold for selecting the number of synergies was consistent with the approach used in the study by Nishida et al. [32]. To enable comparisons of synergy variables between individuals and groups, all muscle synergy composition vectors (W) and synergy activation coefficients (C) were normalized by their respective norms.

Similarity Analysis

We used cosine similarity (CS) analysis to examine the similarity in motor module composition and temporal activation patterns among wrestlers [33,34]. The cosine similarity (CS) is calculated as the inner product of two paired synergy vectors normalized to the unit norm. This similarity measure quantifies the cosine of the angle between the vectors and ranges from -1 to 1. Values closer to 1 indicate a higher degree of similarity between the vectors, with a value of 0 indicating orthogonality (the vectors are perpendicular to each other) and a value of -1 indicating that the vectors are opposed or have opposite directions. Since the synergy vectors used in this context are nonnegative, the computation of cosine similarity (CS) yields values ranging from 0 to 1. The CS was calculated for each pair of wrestlers by comparing their respective synergy vectors. Two vectors with CS > 0.8 were defined as similar [35,36].

Statistical Analysis

The Shapiro-Wilk test was utilized to evaluate the normal distribution of the data. To compare the evolution of variance accounted for (VAF) with the number of extracted synergies between the two groups, an analysis of variance (ANOVA) for repeated measures was employed [27]. An independent-Samples t-test was used to compare characteristics related to muscle weighing and coefficient activation synergies between the two groups. When the data distribution was not normal, the Mann-Whitney U test was used. All statistical analyses were performed with SPSS version 27. A $p \leq 0.05$ was considered indicative of statistical significance. All analyses were conducted using custom software developed in MATLAB R2023a.

RESULTS

Number of muscle synergies: A non-significant difference ($p = 0.133$) was observed between the two groups regarding the evolution of VAF as a function of the number of muscle synergies. This finding indicates that both groups exhibit similar dimensionality in their EMG data. The results are illustrated in Figure 3 (left). Applying the previously described criteria, muscle synergies ranging from one to four were identified for all conditions and groups. However, in most conditions, the EMG activity was adequately explained by three synergies. The distribution of variation appeared to follow a normal distribution, as depicted in Figure 3 (right). Based on the observation that three synergies adequately accounted for the EMG activity in all conditions, a conclusive number of synergies was set to three. Subsequently, the NMF algorithm was again applied to all conditions using this new number of synergies. The three synergies were arranged in a specific order based on the timing of the prominent peak of their activation patterns. Following this order, the synergies were named Syn1, Syn2, and Syn3.

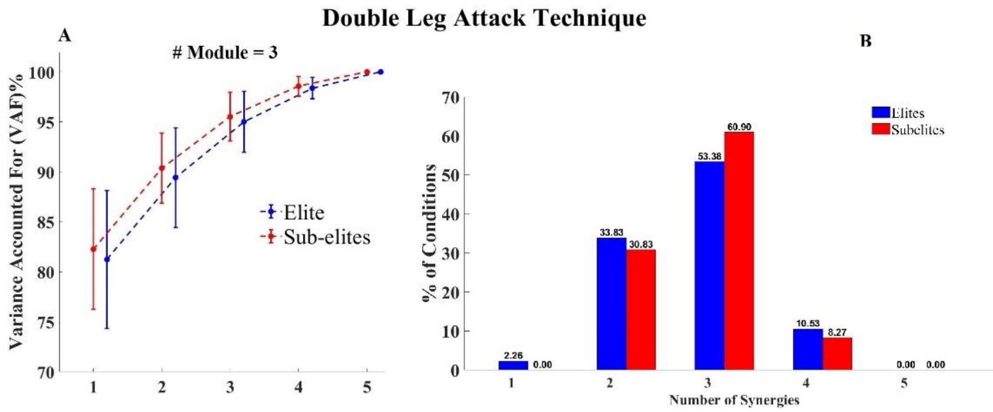

Figure 3. A: The number of motor modules selected accounted for >90% of the overall variability accounted for (VAF) and >75 in each muscle. There was no statistically significant difference in the number of muscle synergies between the groups. **B:** Histogram of the number of synergies determined by the variance accounted for (VAF) threshold criterion. The histogram includes trials for all subjects.

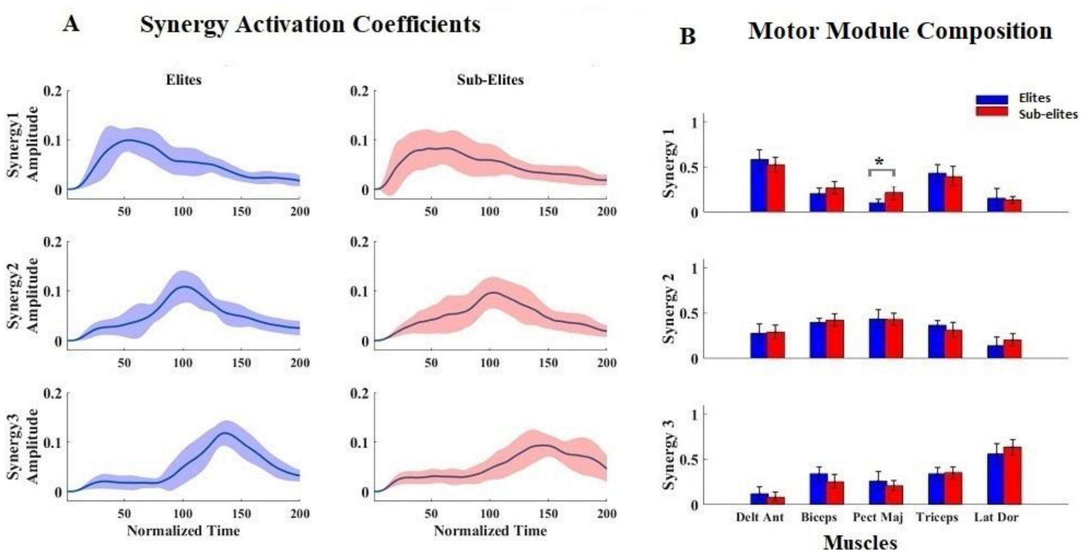

Figure 4. A: Synergy Activation Coefficient or Temporal Activation Patterns of three motor modules during throwing double leg attack. (mean over cycles ± SD). Blue and red represent Elite and Sub-elite wrestlers respectively. **B:** Representative of muscle weighting synergies extracted from elite and sub-elite wrestlers. The values for muscle weighting are presented as mean ± standard deviation (SD). Asterisks (*) indicate significant differences at $p < 0.05$. Blue and red represent Elite and Sub-elite wrestlers, respectively.

Temporal Activation Patterns (Synergy Activation Coefficients): The synergy activation coefficients for elite and sub-elite wrestlers were depicted in Figure 4A. In both groups, the activity of the three temporal activation patterns peaked in sequential order. Cosine similarity (CS) analysis was employed to assess the consistency of synergy activation coefficients. The heat map in Figure 5A displays the similarity in temporal activation patterns across all extracted synergies from all wrestlers. Elite wrestlers demonstrated a notable degree of intra-group similarity across all three temporal activation patterns with a median CS value greater than 0.80, indicating a high level of consistency. In contrast, sub-elite wrestlers exhibited moderate to high similarity within these temporal activation patterns, which was significantly lower compared to the observed similarity in elite wrestlers. (See table 1: A and Figure 6A)

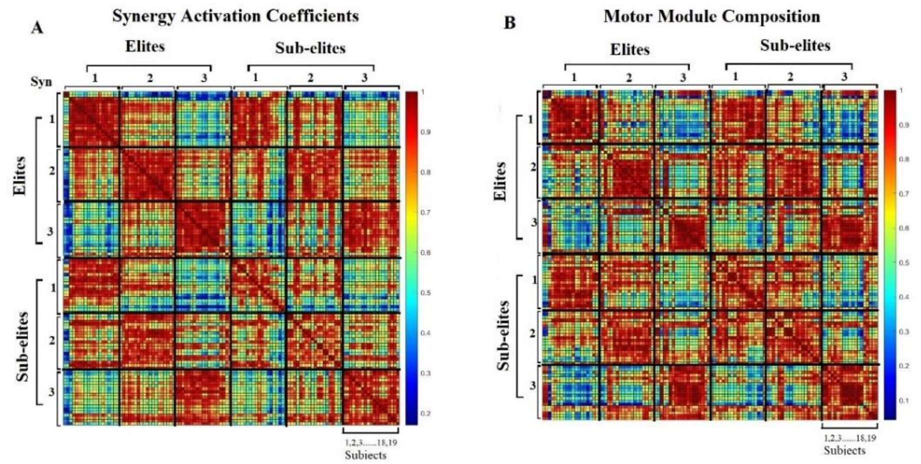

Figure 5. The heat maps in Figure A and B illustrate the interindividual similarity in the synergy activation coefficients and motor module compositions, respectively, among all wrestlers. Each cell in the heat map represents the cosine similarity for a pair of wrestlers, with the diagonal cells representing self-comparisons that are maximally similar. These heat maps provide a visual representation of the similarities between wrestlers in terms of their synergy activation coefficients and motor module compositions.

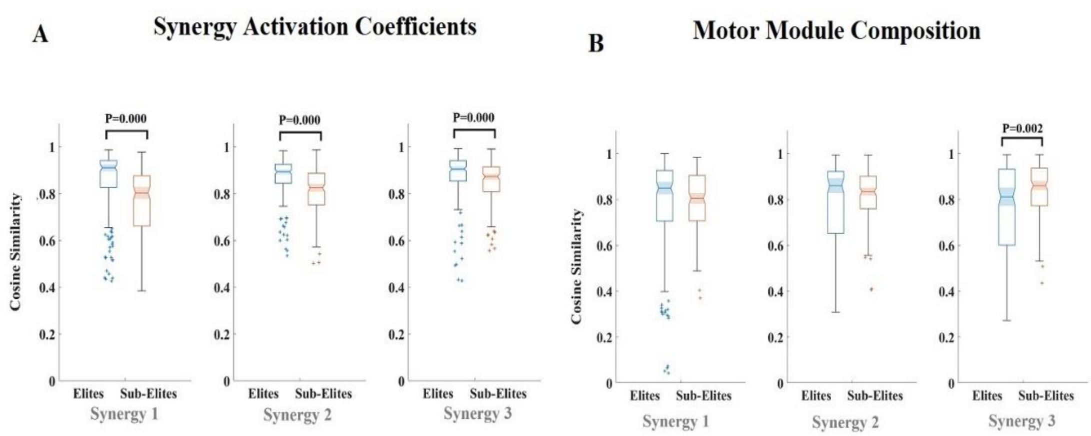

Figure 6. Presents box-plots showcasing the distribution of cosine similarity values between each pair of players within three synergies for elite and sub-elite wrestlers. Panel A compares the interindividual similarity of synergy activation coefficients, while Panel B compares the interindividual similarity of motor module composition. Significant differences between modules are indicated by their respective values.

Motor Module Composition (Muscle synergies weightings): Figure. 3B depicts the motor module composition or spatial structure of the three identified muscle synergies. In Syn1, the primary muscle is the Deltoid anterior, while in Syn3, it is the Latissimus dorsi. Notably, no dominant muscle was observed in

Syn2. Additionally, Pectoralis major, Biceps and, Triceps brachii exhibited varying degrees of activity across all three synergies.
The heat map in Figure 5B displays the similarity in motor module composition across all extracted synergies from all wrestlers. The motor module composition exhibited a high degree of similarity among wrestlers, with a median CS value greater than 0.80. However, for Syn3, sub-elite wrestlers displayed a higher CS value. Overall, no significant differences were found between the groups regarding motor module composition. (See Table 1: B and Figure 6B)

Table 1: Similarity indices (median ± IQR) for each muscle synergy within and between groups.

A: Synergies Activation Coefficients (C)	Intra-group similarity			Inter-group similarity
	Elites	**Sub-elites**	P	
Synergy #1	0.91 ± 0.11	0.80 ± 0.21	**0.000**	0.81 ± 0.14
Synergy #2	0.89 ± 0.08	0.82 ± 0.13	**0.000**	0.84 ± 0.09
Synergy #3	0.90 ± 0.08	0.87 ± 0.10	**0.000**	0.84 ± 0.09
B: Motor Module composition (W)				
Synergy #1	0.85 ± 0.22	0.80 ± 0.20	0.223	0.78 ± 0.17
Synergy #2	0.86 ± 0.27	0.83 ± 0.14	0.723	0.80 ± 0.13
Synergy #3	0.81 ± 0.33	0.86 ± 0.16	**0.002**	0.80 ± 0.17

DISCUSSION

In this study, we provide evidence of the impact of years of specialized wrestling training on the structural modifications of muscle coordination patterns, particularly in a commonly employed technique such as the Double-Leg Attack. Significant differences observed in the temporal activation patterns suggest that elite wrestlers possess a higher level of temporal precision and coordination, which may contribute to their competitive advantage.
Number of Motor Modules: In line with the findings of several other studies [17–27], our study did not reveal a significant difference in the number of synergies between elite and sub-elite groups. However, a few studies conducted in various sports disciplines, such as cycling [15], badminton [16], and beam walking [9], have demonstrated that experienced athletes exhibit a greater number of muscle synergies compared to their less experienced counterparts. Furthermore, it has been shown that motor training during rehabilitation can lead to an increase in the number of motor modules in individuals with sensorimotor deficits [37]. The variability in the number of muscle synergies observed between different groups of expertise in various studies can be attributed to the specific characteristics of the task or sport, participant characteristics, training duration, methodological differences, and individual variability in movement patterns.
Sawers et al. [9] found that experts in beam walking have more motor modules, providing them more flexibility in achieving motor goals. This expanded repertoire allows experts to produce additional biomechanical functions that novices cannot, particularly in maintaining balance on the beam. In contrast to beam walking that is a challenging balance behavior, it seems Double-Leg Attack maneuver characterized by its fast and explosive nature. Therefore, this maneuver is more consistent with constrained athletic activities requiring high power output, such as rowing [24,27], weightlifting [18,19], and powerlifting [26]. It is essential to acknowledge that in our study, the sub-elite participants were actively involved in training. However, they had not yet attained the same level of competitiveness as the elites. It is also worth mentioning that they were not inexperienced individuals. Therefore, the expectation of both groups having an equal number of modules was not far from being met.

Spatial and Temporal Characteristics of Muscle Synergies: Our study revealed that all wrestlers demonstrated a high level of consistency in both the composition and temporal activation patterns of their muscle synergies, as indicated by cosine similarity (CS) values exceeding 0.8. However, notable differences between the two groups were observed solely in the temporal activation patterns. Specifically, elite wrestlers exhibited a significantly higher level of temporal consistency in their muscle activity structure during the exercise, highlighting their superior control and coordination.

In a study by Turpin et al. [27], both experienced and untrained rowers displayed moderate within-group similarity in the weighting of muscle synergies (ranging from 0.64 to 0.75). However, when analyzing synergy activation patterns, both groups exhibited higher levels of intra-group similarity. Specifically, the experienced group had significantly higher similarity values for the first synergy and lower values for the third synergy than the untrained group. Based on these findings, the authors concluded that expertise in rowing is more likely to be linked to adjustments in the mechanical output of muscle synergies rather than differences in the shape and timing of their activations. In another study conducted by Santos et al. [19], the researchers examined the muscle synergy of weightlifters and untrained individuals during the power clean exercise. Intra-group variability for each group was assessed, and it was found that the muscle synergy vectors showed weak to moderate correlations (ranging from 0.34 to 0.52) in both groups. However, the intra-group variability values in the synergy activation coefficients were high (ranging from 0.77 to 0.89) and displayed strong correlations. Interestingly, when comparing the two groups, it was observed that expertise did not significantly impact the synergistic organization of muscle coordination. Overall, when comparing these findings, our study highlights the high consistency and coordination in muscle synergies among elites in the Double-Leg Attack exercise. In contrast, the other studies shed light on the role of expertise in rowing and weightlifting regarding adjustments in muscle synergies' mechanical output and the lack of significant impact on synergistic organization across different expertise levels.

The findings of this study have several potential applications for coaches and athletes in the field of wrestling and other sports. We found consistent and specialized training can influence muscle coordination patterns to optimize training programs. Coaches can use the muscle coordination patterns of elite wrestlers as a reference point for technique refinement. By improving the temporal and spatial consistency of muscle activity, coaches can help athletes execute wrestling maneuvers more precisely and efficiently. Additionally, the differences in muscle coordination patterns between elite and sub-elite wrestlers can be valuable for talent identification purposes, allowing coaches and talent scouts to identify athletes with the potential for elite performance and provide appropriate training and support.

During this project, two critical limitations arose because of the nature of wrestling techniques involving close grappling between two wrestlers and limitations in laboratory equipment availability. One limitation of this study was the absence of kinematic and kinetic data. The synchronous collection of EMG and kinematic data could enhance our understanding of movement analysis. Additionally, the study was limited by including a low number of selected muscles from the unilateral upper limb. A more extensive selection of muscles from the ipsilateral or contralateral limb would have provided a more comprehensive and informative analysis of muscle synergies. Another limitation of our study was the considerable variation in speed and execution time exhibited by the subjects during the performance of the technique. Although we attempted to normalize the time, we recognized this as a significant confounding factor.

CONCLUSION

This study investigated muscle coordination patterns during the Double-Leg Attack maneuver in elite and sub-elite wrestlers. The number of muscle synergies was similar between the two groups. However, notable differences were observed in the temporal consistency of muscle activity. Elite wrestlers demonstrated a high level of consistency, indicating precise and coordinated execution of the maneuver. In contrast, sub-elite wrestlers exhibited more significant interindividual variability, suggesting less precise and coordinated execution and a potential need for further refinement in their muscle coordination. These findings suggest that consistent and specialized training can influence the structure of muscle coordination patterns during wrestling techniques. Overall, this study provides valuable insights that can inform coaching strategies, training programs, performance assessment, technique refinement, injury prevention, and talent identification in wrestling.

Author Contributions: Conceptualization, methodology, HB, ME, IEPA; formal analysis, HB, SEH, IEPA; investigation, HB; resources, HB, IEPA; data curation, ME, HB, SEH, IEPA; writing-original draft preparation, HB, ME, SEH; writing-review and editing, ME, SEH, IEPA; supervision, SEH, IEPA; project administration, ME. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data will be available at request.

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هم‌افزایی عضلانی حین اجرای فن زیر دو خم: مقایسه بین کشتی‌گیران نخبه و معمولی

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چکیده:

مقدمه: اجرای فنون در کشتی آزاد به زمانبندی و هماهنگی حرکتی دقیق نیاز دارد. حمله زیردوخم یک مانور حیاتی برای کسب امتیاز و پیروزی در یک مسابقه کشتی می‌باشد. تحلیل هماهنگی فعالیت‌های عضلانی حین اجرای فنون، نقش مهمی در بهینه‌سازی عملکرد و کشف مکانیزم‌ها و اثرات زیربنایی تمرینات تخصصی کشتی دارد.

هدف این مطالعه با هدف بررسی تاثیر تمرینات مداوم و تخصصی کشتی آزاد بر ساختار هم‌افزایی‌های عضلانی حین اجرای فن زیردوخم انجام شد.

مواد و روش‌ها: ۳۸ کشتی‌گیر جوان مازندرانی بر اساس سطح مهارت و سوابق قهرمانی به دو گروه نخبه (۱۹ نفر) و معمولی (۱۹ نفر) تقسیم شدند. فعالیت الکترومایوگرافی (EMG) پنج عضله اندام فوقانی در سمت برتر ورزشکار ثبت و از الگوریتم NMF برای استخراج هم افزایی‌های عضلانی استفاده شد.

یافته‌ها: تعداد سه هم‌افزایی عضلانی برای هر یک از دو گروه نخبه و معمولی استخراج شد. هم‌افزایی‌های استخراج شده از منظر ساختارهای فضایی و الگوهای زمانی از ثبات بالایی برخوردار بودند. کشتی‌گیران نخبه نسبت به کشتی‌گیران معمولی، به طور قابل توجهی مقادیر بالاتری از ثبات در الگوهای زمانی را نشان دادند.

بحث: یافته های این مطالعه اهمیت آموزش مداوم و تخصصی کشتی آزاد در بهینه سازی هم‌افزایی عضلانی را حین اجرای فن زیردوخم نشان می‌دهد. تفاوت‌های معنی‌دار مشاهده شده در الگوهای فعال سازی زمانی نشان می‌دهد که کشتی گیران نخبه از دقت و هماهنگی زمانی بالاتری برخوردار هستند که ممکن است به مزیت رقابتی آنها کمک کند.

نتیجه‌گیری: یافته‌های این مطالعه می‌تواند بینش‌های ارزشمندی برای کشتی‌گیران و مربیان در طراحی استراتژی های تمرینی متمرکز بر ارتقا هماهنگی عضلانی با هدف بهبود عملکرد در کشتی آزاد فراهم آورد.

واژه های کلیدی: کشتی آزاد، فن زیردوخم، ترکیب ماژول حرکتی، ساختارهای فضایی، الگوهای فعال‌سازی زمانی