Submitted: 26 December, 2025 Accepted: 02 April, 2026 Published: 30 August, 2026 DOI:10.22514/jomh.2026.067

JOMH
Journal of Men's Health

ORIGINAL RESEARCH

Delayed and disorganized muscle activation as a potential injury mechanism in men's basketball jump shots

Zihao Zhao[1], Jinting Yu[1], Zemin Lu[1], Sukwon Kim[1,*], Bin Zhu[1,*]

[1]Department of Physical Education, Jeonbuk National University, 54896 Jeonju, Republic of Korea

***Correspondence**
yuebao486@jbnu.ac.kr
(Bin Zhu);
rockwall@jbnu.ac.kr
(Sukwon Kim)

Abstract

Background: Effective neuromuscular coordination during the basketball jump shot is essential for optimizing performance and reducing injury risk. Inconsistent temporal sequencing of muscle activation may compromise upper-limb joint stability, increasing susceptibility to injury. Although shooting mechanics have been widely studied, the effects of skill level and shooting distance on upper-limb muscle activation timing remain unclear. **Methods**: Twenty male participants (10 skilled, 10 unskilled) performed open jump shots from 5.0 m and 6.8 m. Surface electromyography recorded activity of four upper-limb muscles: anterior deltoid (AD), biceps brachii (BB), triceps brachii (TB), and flexor carpi radialis (FCR). Root mean square (RMS) signals were filtered and normalized. Muscle activation onset was defined as five consecutive data points exceeding 20% of peak RMS amplitude. Temporal activation patterns were analyzed to examine neuromuscular control strategies and potential shoulder injury risk. **Results**: In both groups and at both distances, muscle activation was mainly concentrated in the mid-to-late movement and release phases. Increasing shooting distance delayed the overall activation onset. Skilled players demonstrated earlier activation of key muscles (AD, TB), faster activation rise, earlier peak timing, and generally higher peak amplitudes (AD, BB, TB). In contrast, unskilled players showed earlier but more dispersed activation patterns and relied more on wrist flexor (FCR) activation during long-distance shots. Notably, unskilled players exhibited earlier BB activation at both distances, suggesting a higher risk of subacromial impingement. **Conclusions**: Skilled players exhibit more efficient and protective neuromuscular activation strategies, whereas unskilled players' earlier BB activation may increase shoulder injury risk during jump shooting.

Keywords

Coordination; EMG; Kinetic chain; Injury; Recreational

1. Introduction

The jump shot is a core skill in basketball, essential to both individual scoring and team offensive strategies. This technique is prized for its adaptability, allowing players to execute it effectively in diverse game situations—whether in a controlled half-court offense or in fast-paced, high-pressure environments. The open jump shot, executed without immediate defensive pressure, has become a standardized model for investigating shooting mechanics, as it enables consistent control over biomechanical variables and provides a stable platform for evaluating individual proficiency under ideal conditions.

In recent years, shooting accuracy has emerged as a defining characteristic of successful basketball play, particularly at the elite level. As scoring efficiency has risen in international competitions, there has been a notable emphasis on improving shooting precision through enhanced technical execution, better neuromuscular coordination, and biomechanical optimization [1–3]. This evolution is supported by advances in the scientific study of shooting mechanics, with an increasing focus on biomechanical parameters such as joint angles, angular velocity, and body coordination during critical phases of the jump shot (take-off, flight, and release) [4–6]. These factors, when optimized, lead not only to greater shooting consistency and precision, but also to more economical movement patterns that may reduce mechanical stress on the upper limb over high training volumes.

Like other ballistic movements in sports (*e.g.*, the volleyball serve and tennis forehand), the jump shot is governed by principles of the kinetic chain, where force is transmitted from the lower extremities to the upper body in a highly coordinated sequence [7–9]. The lower limbs initiate force production through leg extension and vertical propulsion, which is subsequently transferred through the trunk and torso to the upper limbs. The upper limbs—particularly the shoulder, elbow, and wrist—play a critical role in refining shot release parameters such as ball velocity, spin, and angle, all of which influence shot trajectory and accuracy [10–12]. When this proximal-to-distal sequencing is disrupted, kinetic-chain efficiency is reduced and local joint loads may increase, a pattern that has been associated with both performance decrements and elevated injury risk in overhead athletes [13–20].

Despite the growing body of research focused on the kinematics and kinetics of basketball shooting, relatively few studies have explored upper-limb muscle activation patterns, particularly across varying skill levels and shot distances. Muscle activation, as measured using surface electromyography (EMG), offers a direct assessment of neuromuscular strategies and can provide valuable insight into how players adapt their motor control systems under different biomechanical demands. Understanding these patterns is crucial, as they can reveal how skilled players maintain fluidity and coordination in their movements, while less-skilled players may struggle with timing, muscle co-contraction, or inefficient activation sequences [21–23]. Such disorganized or delayed activation may alter joint stiffness regulation and impair energy transfer, creating a potential mechanism through which repetitive jump shooting can contribute to upper-limb overuse injury.

Delayed activation refers to a condition in which, during a specific motor task, the activation onset time of key stabilizing or prime mover muscles occurs significantly later than the optimal temporal window required for the movement. This delay compromises joint stability and reduces the efficiency of force transmission. Hodges *et al.* [24] emphasized that the activation of stabilizing muscles is not a reaction to movement, but rather a prerequisite that must occur prior to movement initiation. In other words, the critical factor is not whether muscle activation occurs, but whether it occurs at the appropriate time.

Kibler *et al.*'s [25] research demonstrated that appropriate activation of the scapular musculature must precede humeral motion in order to provide a stable foundation for arm movement. In individuals with shoulder dysfunction or reduced motor control capacity, the activation of the lower trapezius and serratus anterior is significantly delayed, resulting in an inability to stabilize the scapula before humeral movement.

Disorganized muscle activation, by contrast, refers to a lack of stable and repeatable patterns across multiple muscles in terms of timing, amplitude, and coordination. This is characterized by disrupted activation sequences, reduced coordination efficiency, and excessive antagonist co-contraction, which ultimately impairs synergistic function. This phenomenon does not reflect dysfunction of a single muscle, but rather a breakdown in muscle synergies. Beinabaji *et al.* [26] proposed that unskilled or injured athletes exhibit greater variability in synergy structures, whereas skilled athletes demonstrate more stable and consistent muscle coordination patterns.

In particular, comparing muscle activation strategies at different shooting distances is essential for understanding how players adapt their biomechanics to meet the increased demands of longer-range shots. Skilled players typically exhibit more efficient neuromuscular control, including more refined coordination of muscle firing sequences, than novices, who may demonstrate greater reliance on compensatory strategies or less efficient muscle activation patterns [22, 23]. For example, skilled players often display more precise timing of muscle recruitment, with less antagonistic co-contraction between agonist and antagonist muscles, thereby allowing for smoother motion and better energy transfer throughout the kinetic chain [21–23, 27]. In contrast, delayed or excessively clustered activation of key muscles may require last-moment "catch-up" actions at the shoulder or elbow, which can increase joint loading and resemble pathomechanical patterns described in throwing and other overhead sports [13, 14, 16–20].

In throwing-like movements such as the jump shot, delayed or disorganized muscle activation may disrupt the structural stability of muscle synergies, thereby representing a potential risk factor for injury. Kibler *et al.* [28] proposed that alterations in scapular muscle activation patterns can lead to abnormal scapular positioning and increase the risk of impingement of the rotator cuff tendons. Reinold *et al.* [29] further suggested that impaired neuromuscular control of the rotator cuff elevates the risk of overuse injuries during repetitive throwing activities. From the perspective of shoulder joint function, basketball is a sport characterized by a high frequency of overhead actions, including shooting, passing, and blocking. Although shoulder soft-tissue injuries in basketball players are not as prevalent as in pure throwing sports such as baseball, clinical and imaging studies have nonetheless reported narrowing of the subacromial space, tendon pathological changes, and associated pain symptoms in basketball players. These findings indicate that subacromial impingement syndrome (SIS)-related pathology exists within the basketball population and may negatively affect shoulder health and athletic performance [30]. The contributing factors to SIS can be broadly divided into two components: temporal consistency of muscle activation and relative activation delay.

Therefore, the aim of the present study is to investigate upper-limb muscle activation sequences during open jump shots executed at two distances—5.0 meters and 6.8 meters—by skilled and unskilled male basketball players. This study utilizes surface EMG to examine the activation of four major muscles: the biceps brachii, triceps brachii, flexor carpi radialis, and anterior deltoid. These muscles are integral to the shooting motion, with the biceps and triceps governing arm flexion and extension, the flexor carpi radialis influencing wrist stability and control, and the anterior deltoid providing shoulder stability and power during shot release. By comparing muscle activation across different player skill levels and shot distances, this study aims to identify skill-dependent patterns of neuromuscular control and to determine how delayed or disorganized sequencing may function as a potential injury mechanism in basketball jump shots. The findings are expected to provide a biomechanical basis not only for performance evaluation, but also for developing evidence-based training strategies that address neuromuscular timing to enhance both shooting efficiency and upper-limb injury prevention.

2. Materials and methods

2.1 Participants

Ten male collegiate basketball players (age: 22.3 ± 1.25 years; height: 184.6 ± 3.06 cm; body mass: 75.1 ± 4.9

kg; training experience: 6.5 ± 1.6 years) and ten recreational basketball players (age: 21.9 ± 1.64 years; height: 181.9 ± 3.88 cm; body mass: 71.7 ± 5.0 kg) were recruited between 15 July 2024, and 30 May 2025 from a local university. The recreational players engaged in basketball activities two to three times per week and had no history of lower-limb or other musculoskeletal injuries prior to the study. Based on a G*Power 3.1.9.2 software (Heinrich Heine University Düsseldorf, Düsseldorf, NRW, Germany) analysis (α = 0.05, β = 0.80), the minimum detectable effect size was estimated to be $f \approx 0.33$. G*Power analysis indicated that a total sample size of at least 20 participants was required to achieve adequate statistical power. The experimental protocol was approved by the Institutional Review Board of Jeonbuk National University, Jeonju, Korea (approval code: JBNU2024-09-015-002). Prior to participation, all participants were informed of the study procedures and provided written informed consent.

2.2 Procedure

During the experiment, each participant performed jump shots at two distances (5 m and 6.8 m). To ensure that both feet were in contact with the force plates at take-off, a movable basketball hoop was used, and the distance between the participant and the hoop was determined by adjusting the position of the hoop (Fig. 1). Prior to data collection, participants completed a standardized warm-up, including shooting practice, to familiarize themselves with the experimental setup. Based on biomechanical event markers, the shooting phase was defined according to ball position and body kinematic data and was divided into four stages: sinking stage, lifting ball stage, take-off stage, and release stage (Fig. 2) [21]. Each participant completed three valid trials at each shooting distance. For a trial to be considered valid, the jump shot had to be performed as a dynamic two-foot take-off jump shot; standing shots or shots executed without a jump after

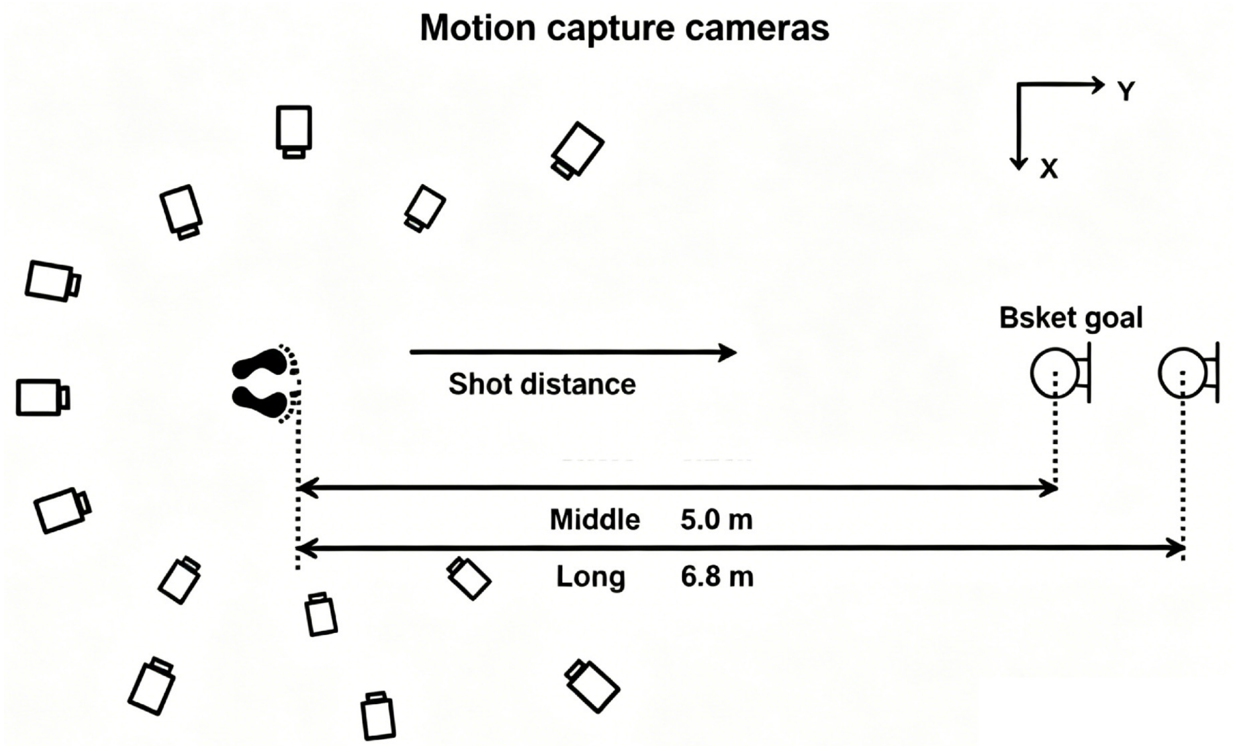

FIGURE 1. Experimental setup. Jump shot distances are at 5 meters (middle) and 6.8 meters (long).

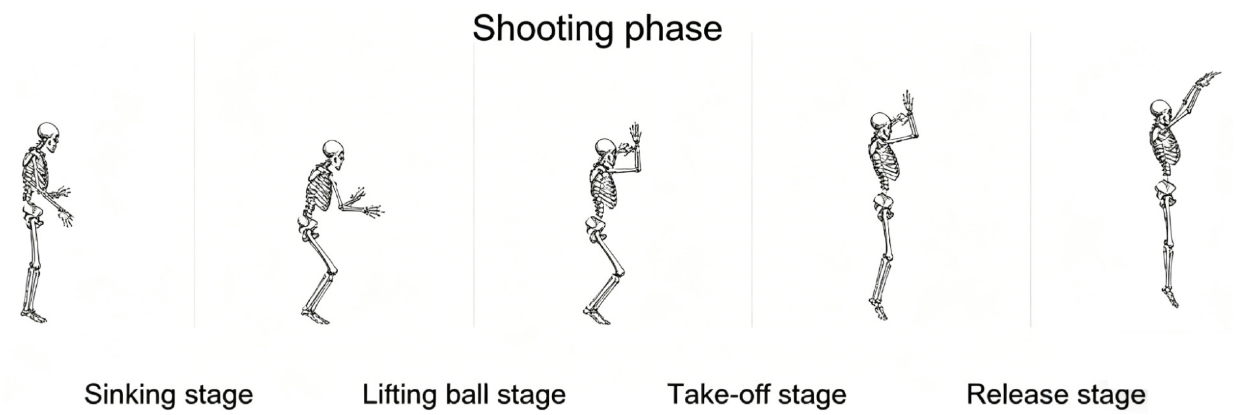

FIGURE 2. Delineation of shooting phases.

a run-up stop were excluded. Ball release was required to occur during the ascending phase of the jump or near the peak of the jump, and shots released during the descending phase were excluded. No additional adjustment steps, trunk rotations, or other movements that could alter shooting rhythm were permitted prior to the jump shot. A successful trial was defined as a smooth and continuous jump-shot motion without interruptions and without obvious deviations from typical competitive shooting mechanics. A rest interval of 2 minutes was provided between trials to minimize the effects of fatigue.

2.3 Data collection

Kinematic data were captured using a 13-camera motion capture system (Motive 2.2.0, OptiTrack, Natural Point, Inc., Corvallis, OR, USA) operating at a sampling frequency of 240 Hz. Surface electromyography (sEMG) data were simultaneously recorded using a Trigno Wireless EMG system (Trigno Avanti, Delsys, Natick, MA, USA) with a sampling frequency of 1200 Hz. Reflective markers were placed on anatomical landmarks following the full-body Plug-in Gait model to construct a 7-segment biomechanical model in Visual3D (v2024.10.4, Charnwood Dynamics Ltd., Leicestershire, UK). The coordinate system was defined with the x-axis pointing forward, the y-axis pointing to the left side of the participant, and the z-axis oriented vertically upward.

Four right-side muscles were monitored: anterior deltoid (AD), biceps brachii (BB), triceps brachii (TB), and flexor carpi radialis (FCR). EMG electrodes were placed in accordance with the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines. All EMG and motion data were synchronized via the acquisition system and stored for offline analysis.

2.4 Mathematical and statistical methods

A motion capture system was employed to process the video recordings of each participant's jump shot trials. From these recordings, the most technically effective shot per athlete was selected for further analysis. Using the motion capture software, the three key phases of the shooting action—ball-holding and cushioning, push-off and take-off, and ball release—were identified and annotated by frame. The system subsequently exported the relevant motion data, providing the raw kinematic inputs necessary for biomechanical analysis of the shooting technique.

Surface EMG signals were processed to extract meaningful neuromuscular activation patterns. The raw EMG signals were first smoothed using a Savitzky-Golay filter, which attenuated high-frequency noise and enhanced the signal envelope for clearer temporal analysis. Following smoothing, all EMG data were time-normalized to 100 equidistant points, representing 1% to 100% of the total movement duration. This normalization ensured temporal consistency across trials and participants, facilitating reliable inter-group comparisons [31].

Muscle activation onset was detected using a windowed threshold method [32]. A muscle was considered active if its root mean square (RMS) amplitude exceeded 20% of the peak RMS value (within the selected trial) for at least five consecutive time points—corresponding to approximately 0.5 milliseconds in real-time. Although a minimum activation duration of 0.01 seconds was pre-defined, this was not applied under the time-normalized framework. To ensure temporal consistency of muscle activation and to reduce false-positive onset detection caused by signal noise or transient fluctuations, this study required the RMS amplitude to exceed the predefined threshold for at least five consecutive time points (≈0.5 s). Previous studies have demonstrated that incorporating a minimum duration criterion substantially improves the reliability and validity of EMG onset detection [33]. This thresholding approach, consistent with established Visual3D-based EMG processing protocols, ensured both reliability and reproducibility in identifying activation timing, thereby enabling robust cross-muscle and cross-group comparisons in neuromuscular control strategies. Each signal was processed using Savitzky-Golay filtering and subsequently normalized to the respective muscle's peak RMS amplitude, facilitating inter-muscle temporal comparison. The X-axis represents a time-normalized shooting cycle divided into 100 evenly spaced intervals, corresponding to the full duration from preparation to follow-through.

For the assessment of SIS injury risk, this study primarily focused on temporal consistency of muscle activation. Temporal consistency was quantified using the standard deviation (SD) and the coefficient of variation (CV) of activation onset time (Eqns. 1,2):

$$SD_{onset}^{AD} = std(T_{onset}^{AD}) \tag{1}$$

$$SD_{\Delta T} = std(\Delta T_{AD-BB}) \tag{2}$$

A smaller SD indicates more stable and consistent activation timing, whereas a larger SD reflects greater unpredictability and variability in activation timing (Eqn. 3).

$$CV_{\Delta T} = \frac{SD_{\Delta T}}{|\Delta T|} \times 100\% \tag{3}$$

When the CV is less than 20%, temporal consistency is considered high; when the CV ranges from 20% to 40%, temporal consistency is considered moderate; and when the CV exceeds 40%, temporal consistency is considered low.

All statistical analyses were performed using IBM SPSS Statistics (v.27, International Business Machines Corp., Armonk, NY, USA). Initially, the sEMG RMS data were assumed to follow a normal distribution. The Kolmogorov-Smirnov test was applied to examine the normality of sEMG activation data under the 5 m and 6.8 m shooting conditions. The results indicated that all p-values were greater than 0.05, suggesting that the data met the assumption of normality and that the null hypothesis was accepted. Accordingly, independent-samples t-tests were used to compare between-group differences in sEMG data between high- and low-level players. Under the assumptions of normality and independence between groups, this parametric test was employed to analyze intergroup differences in sEMG RMS values of each muscle at different shooting distances.

3. Results

3.1 5 m distance shooting

During the 5 m jump-shot task, the anterior deltoid (AD) of both high- and low-level players was activated during the lifting ball stage, with activation onset occurring at approximately 39%–45% of the normalized movement cycle (Fig. 3). The activation onset time of high-level players was later than that of low-level players. In contrast, the peak activation time of high-level players occurred earlier than that of low-level players, indicating a more advanced and temporally concentrated shoulder power output during the ball release phase.

Low-level players exhibited biceps brachii (BB) activation at the initial stage of the movement, with relatively pronounced activation during the lifting ball stage (Fig. 4). This activation subsequently decreased and then increased markedly again during the release phase. In comparison, high-level players primarily activated the BB during the lifting ball stage, with relatively stable activation during the ball-lifting phase and a significant increase only during the release phase.

During the jump-shot task, no obvious differences were observed in the overall activation patterns of the flexor carpi radialis (FCR) between high- and low-level players. However, the activation onset time of high-level players (High Start) was significantly earlier than that of low-level players (Fig. 5).

The triceps brachii (TB) also exhibited differences between high- and low-level players during the 5 m jump shot. The activation onset time of high-level players (High Start) was earlier than that of low-level players (Low Start) (Fig. 6). The activation intensity of high-level players increased rapidly during the release phase and reached a peak of approximately 0.27% max, which was notably higher than that of low-level players (approximately 0.23% max).

3.2 6.8 m distance shooting

During the 6.8 m jump-shot task, the AD of both high- and low-level players began to be activated in the middle to late stages of the movement. Compared with the 5 m condition, the overall activation of the AD shifted toward the later phase of the movement. The activation onset time of high-level players was earlier than that of low-level players (Fig. 7).

In the 6.8 m jump shot, low-level players exhibited BB activation at the initial stage of the movement and maintained a relatively high activation level during the lifting ball stage,

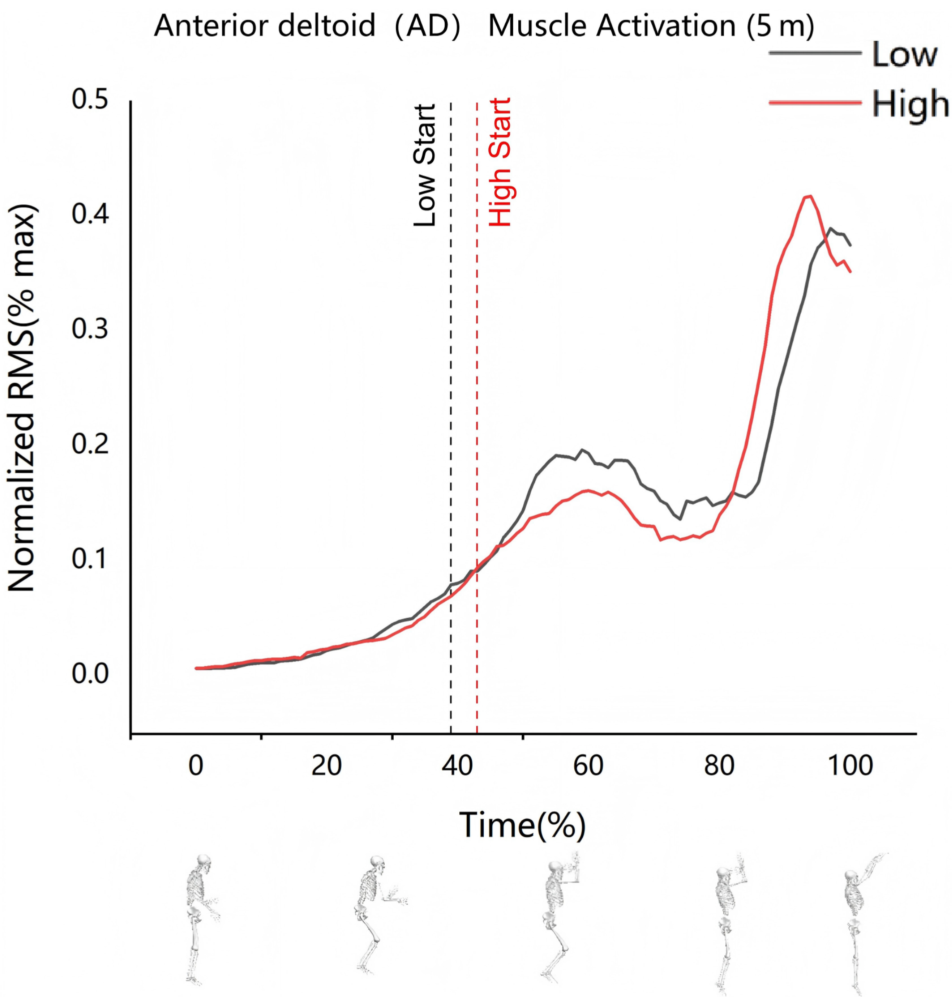

FIGURE 3. Anterior deltoid activation (5 m shooting). Low Start: The position where activation begins at a low level. High Start: The position where activation begins at a high level. RMS: root mean square.

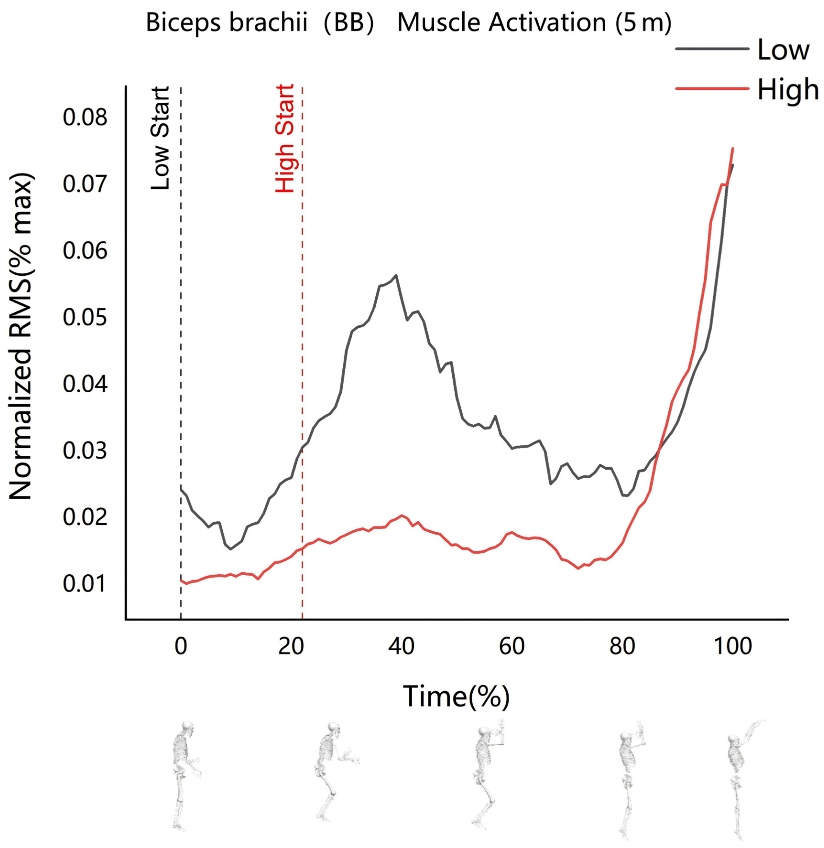

FIGURE 4. Biceps brachii activation (5 m shooting). Low Start: The position where activation begins at a low level. High Start: The position where activation begins at a high level. RMS: root mean square.

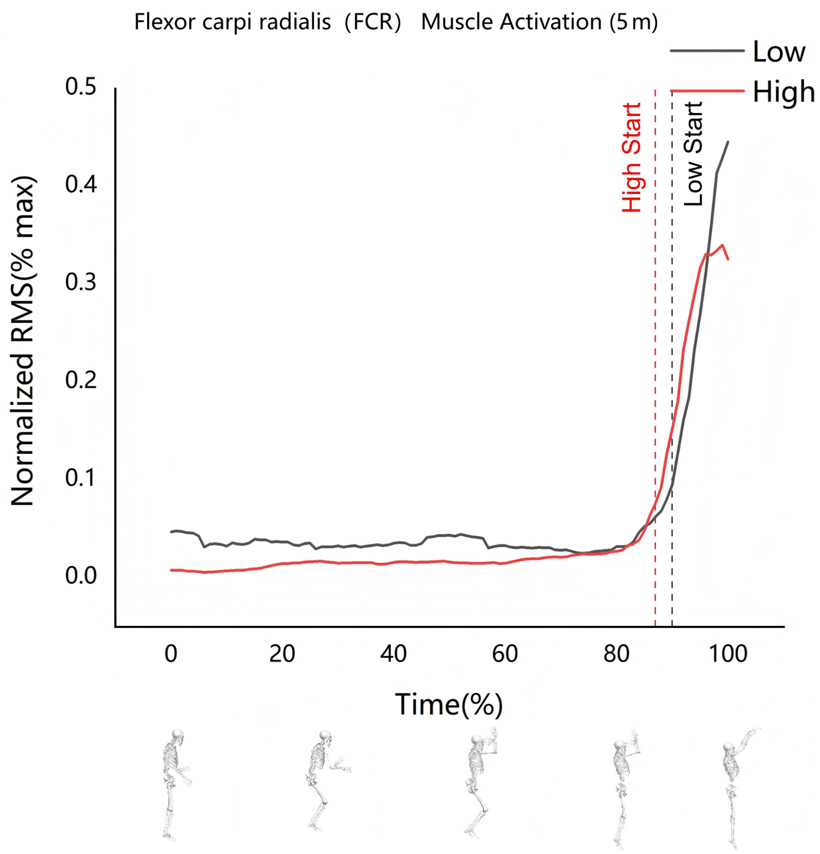

FIGURE 5. Flexor carpi radialis activation (5 m shooting). Low Start: The position where activation begins at a low level. High Start: The position where activation begins at a high level. RMS: root mean square.

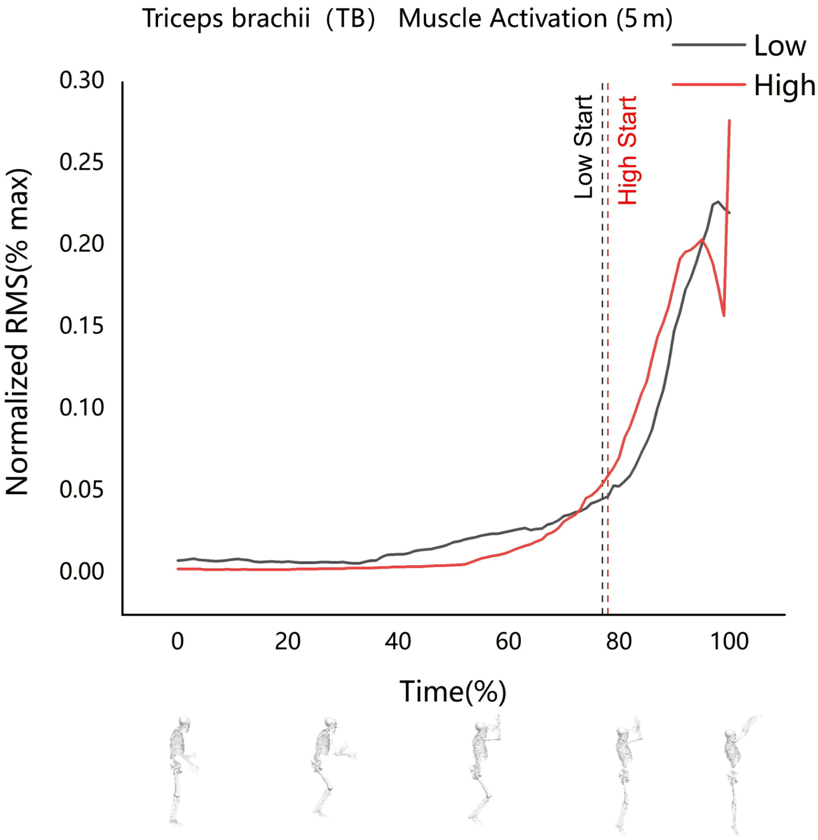

FIGURE 6. Triceps brachii activation (5 m shooting). Low Start: The position where activation begins at a low level. High Start: The position where activation begins at a high level. RMS: root mean square.

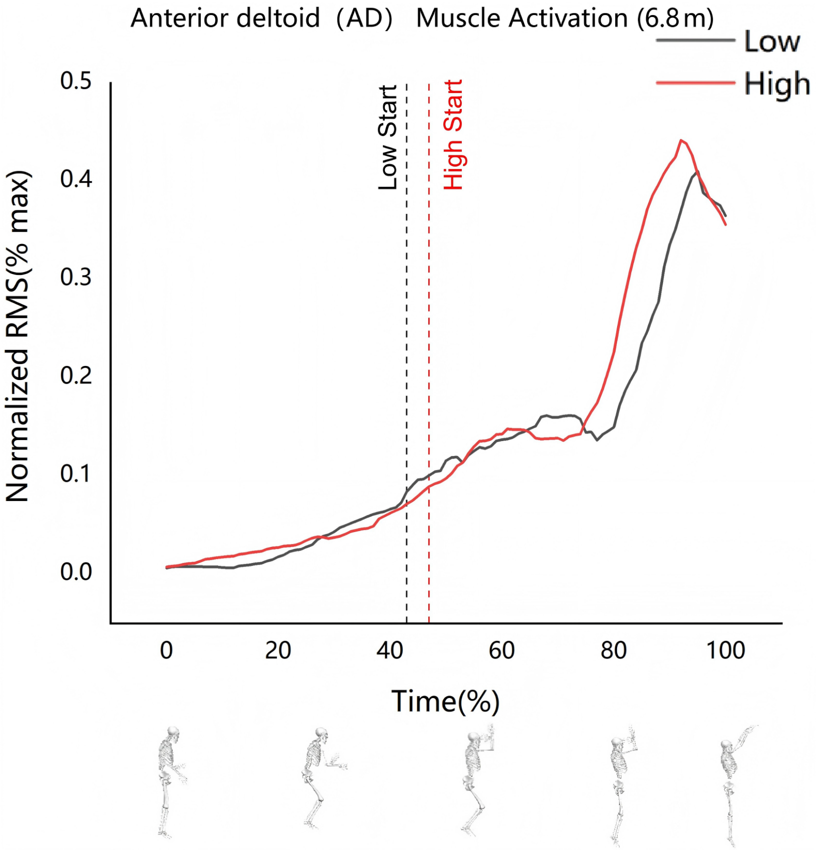

FIGURE 7. Anterior deltoid activation (6.8 m shooting). Low Start: The position where activation begins at a low level. High Start: The position where activation begins at a high level. RMS: root mean square.

followed by a slight decrease in the middle phase and a marked increase again during the release phase (Fig. 8). In contrast, high-level players showed low and stable BB activation during the first half of the movement, with pronounced activation mainly concentrated during the release phase. Moreover, the activation onset time of high-level players was clearly later than that of low-level players.

During the 6.8 m jump-shot task, both high- and low-level players maintained low and stable activation levels of the FCR during the early to middle stages of the movement, with primary activation concentrated during the release phase. The activation onset time of high-level players was slightly earlier than that of low-level players (Fig. 9).

The TB demonstrated clear intergroup temporal differences during the 6.8 m jump shot. The activation onset time of high-level players (High Start) was earlier than that of low-level players (Low Start), and high-level players exhibited a steeper increase in activation during the release phase (Fig. 10).

Based on the statistical results in Table 1, regardless of whether the jump shots were performed at 5 m or 6.8 m, no significant differences were observed between high- and low-level players in the activation sequence of the anterior deltoid, flexor carpi radialis, and triceps brachii. Only the biceps brachii showed significant differences between groups at both shooting distances.

3.3 Assessment of the risk of subacromial impingement (SIS) injury

Tables 2 and 3 presents the temporal characteristics and variability of surface EMG activation in four muscles during the 5 m jump-shot task for high- and low-level players. Under the 5 m shooting condition, clear differences were observed between groups in muscle activation timing variables associated with SIS.

Low-level players exhibited greater dispersion in the activation onset times of the AD, BB, and TB. Specifically, the standard deviations and coefficients of variation of activation onset times for these muscles were higher in low-level players than in high-level players, indicating lower temporal consistency of muscle activation.

Tables 4 and 5 presents the temporal characteristics and variability of surface EMG activation in the four muscles during the 6.8 m jump-shot task for high- and low-level players. Under the 6.8 m shooting condition, temporal differences in shoulder muscle activation became more pronounced. Low-level players exhibited greater variability in the activation onset times of the anterior deltoid, biceps brachii, and related synergistic muscles, with temporal consistency indices markedly lower than those observed in high-level players.

4. Discussion

This study examined the upper-limb muscle activation sequences during jump shooting at two distances (5.0 m and 6.8 m) in high-skill and recreational male basketball players.

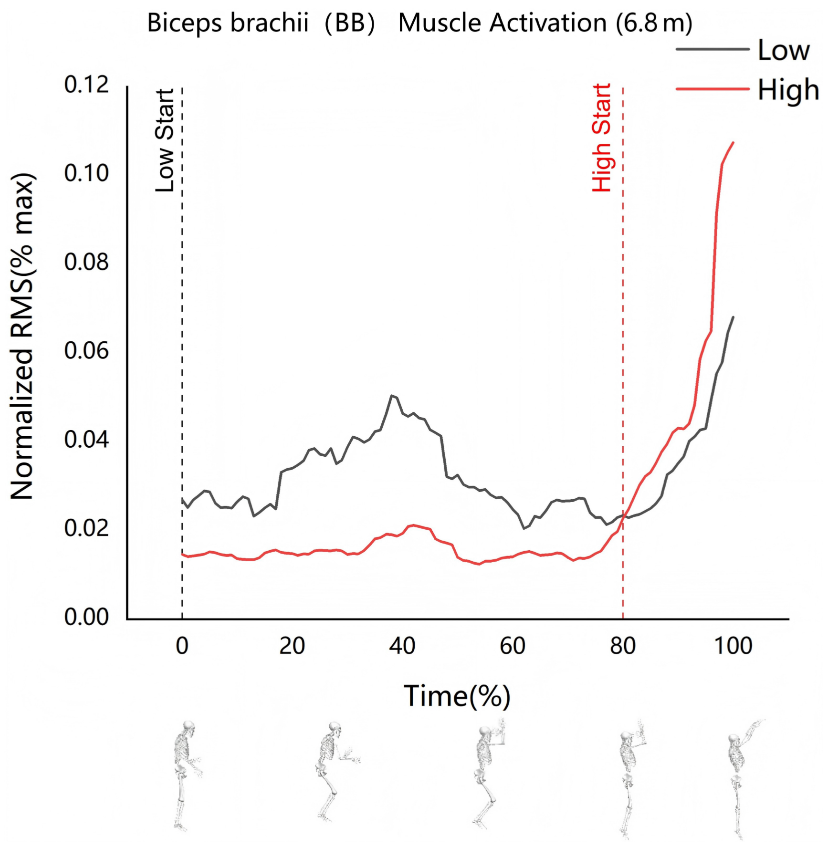

FIGURE 8. Biceps brachii activation (6.8 m shooting). Low Start: The position where activation begins at a low level. High Start: The position where activation begins at a high level. RMS: root mean square.

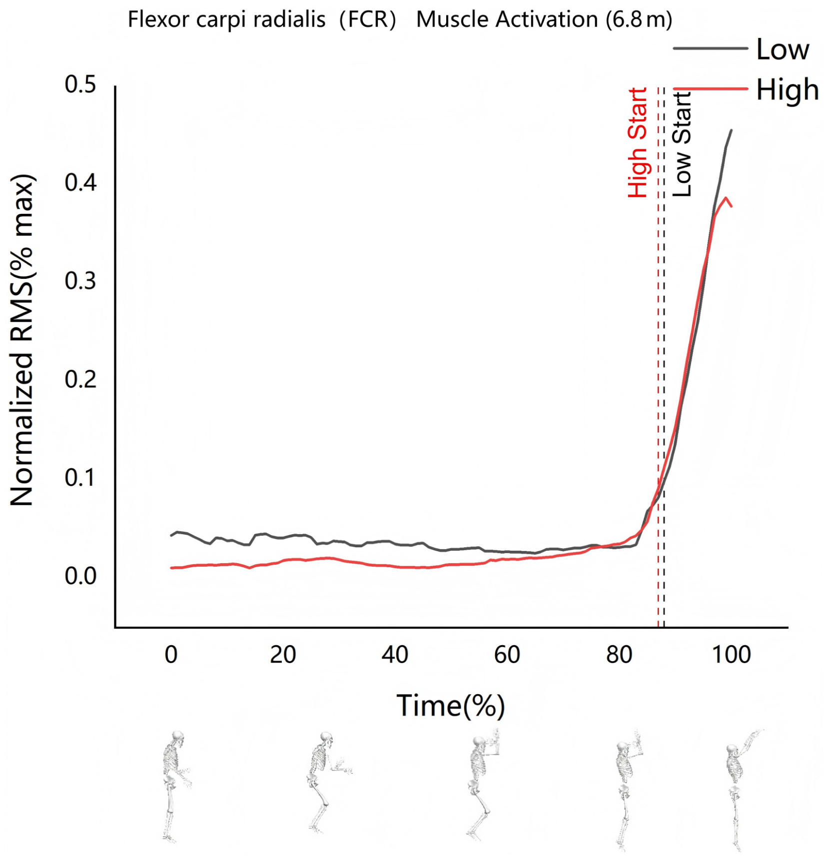

FIGURE 9. Flexor carpi radialis activation (6.8 m shooting). Low Start: The position where activation begins at a low level. High Start: The position where activation begins at a high level. RMS: root mean square.

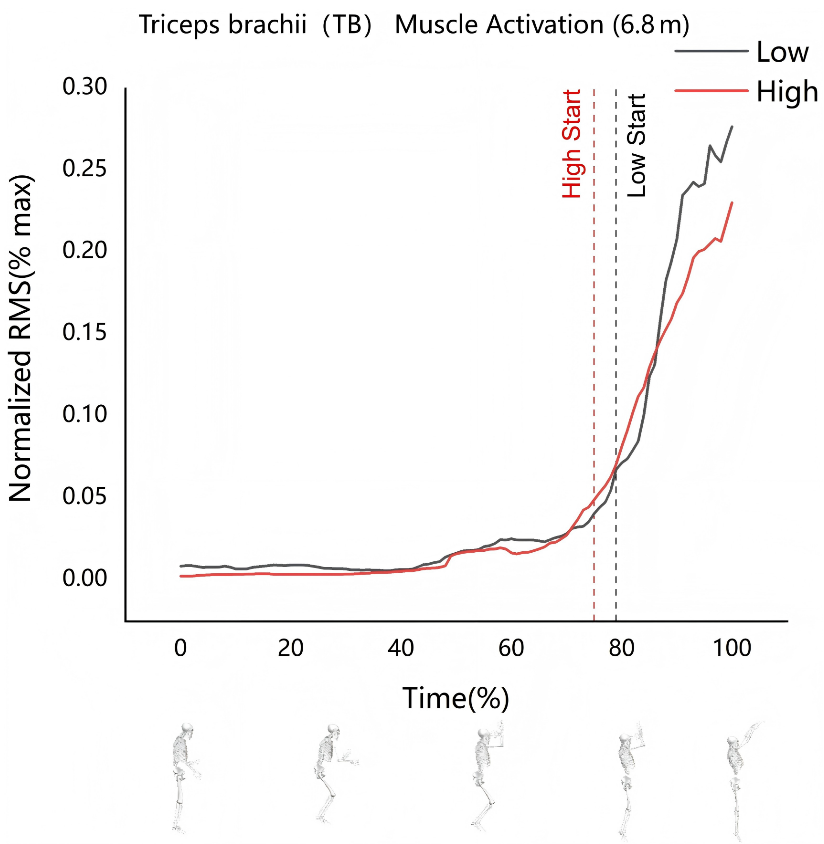

FIGURE 10. Triceps brachii activation (6.8 m shooting). Low Start: The position where activation begins at a low level. High Start: The position where activation begins at a high level. RMS: root mean square.

TABLE 1. Statistical test results for RMS surface electromyography data sets of high- and low-level athletes at 5 m and 6.8 m distances.

	5 m		6.8 m	
	T	*p*-value	T	*p*-value
AD	0.09	0.93	0.80	0.43
BB	7.30	<0.001	4.53	<0.001
FCR	1.18	0.24	1.10	0.27
TB	0.14	0.89	0.68	0.50

AD: Anterior deltoid; BB: Biceps brachii; FCR: Flexor carpi radialis; TB: Triceps brachii; T: Statistical measure representing the magnitude of difference in mean values between high and low level groups. $p < 0.001$ *indicates statistically significant differences between groups.*

TABLE 2. Temporal consistency of muscle activation onset in low-level players during 5 m jump shots.

	Mean_Onset	SD_Onset	CV_Onset, %
AD	41.778	11.077	26.515
BB	17.500	17.558	100.332
FCR	80.778	30.182	37.364
TB	83.444	8.8333	10.586

Mean activation onset time (Mean_Onset), standard deviation (SD_Onset), and coefficient of variation (CV_Onset, %) of the anterior deltoid (AD), biceps brachii (BB), flexor carpi radialis (FCR), and triceps brachii (TB) in low-level players during 5 m basketball jump shots. Activation onset is expressed as a percentage of the normalized movement cycle (0–100%).

TABLE 3. Temporal consistency of muscle activation onset in high-level players during 5 m jump shots.

	Mean_Onset	SD_Onset	CV_Onset, %
AD	46.333	19.506	42.100
BB	31.222	38.759	124.14
FCR	79.444	23.702	29.834
TB	78.889	11.769	14.918

Mean activation onset time (Mean_Onset), standard deviation (SD_Onset), and coefficient of variation (CV_Onset, %) of the anterior deltoid (AD), biceps brachii (BB), flexor carpi radialis (FCR), and triceps brachii (TB) in high-level players during 5 m basketball jump shots. Activation onset is expressed as a percentage of the normalized movement cycle (0–100%).

TABLE 4. Temporal consistency of muscle activation onset in low-level players during 6.8 m jump shots.

	Mean_Onset	SD_Onset	CV_Onset, %
AD	52.556	17.444	33.191
BB	22.333	31.333	140.302
FCR	80.778	30.182	37.364
TB	83.444	8.8333	10.586

Mean activation onset time (Mean_Onset), standard deviation (SD_Onset), and coefficient of variation (CV_Onset, %) of the anterior deltoid (AD), biceps brachii (BB), flexor carpi radialis (FCR), and triceps brachii (TB) in low-level players during 6.8 m basketball jump shots. Activation onset is expressed as a percentage of the normalized movement cycle (0–100%).

TABLE 5. Temporal consistency of muscle activation onset in high-level players during 6.8 m jump shots.

	Mean_Onset	SD_Onset	CV_Onset, %
AD	47.222	20.480	43.370
BB	36.778	38.551	104.822
FCR	78.556	24.673	31.409
TB	75.000	11.769	15.691

Mean activation onset time (Mean_Onset), standard deviation (SD_Onset), and coefficient of variation (CV_Onset, %) of the anterior deltoid (AD), biceps brachii (BB), flexor carpi radialis (FCR), and triceps brachii (TB) in high-level players during 6.8 m basketball jump shots. Activation onset is expressed as a percentage of the normalized movement cycle (0–100%).

EMG analyses of the anterior deltoid (AD), biceps brachii (BB), triceps brachii (TB), and flexor carpi radialis (FCR) revealed no marked between-group differences in overall temporal patterns, except for a significant difference in the activation behavior of the BB. Importantly, these findings can be interpreted not only from a performance perspective, but also in relation to potential injury mechanisms. In particular, the disorganized activation patterns observed in the lower-skill group may reflect reduced shoulder stability during repetitive shooting, thereby increasing injury risk [16, 17, 28, 29, 34–36].

4.1 5 m distance shooting

Under the 5 m jump-shot condition, high- and low-skill players generally exhibited a similar sequential structure in the activation onset of the major upper-limb muscle groups; however, level-dependent differences were still evident in the timing of key muscles [37]. For the AD, both groups initiated activation during the ball-raising phase, indicating consistent temporal demands associated with shoulder flexion in short-distance jump shooting. Nevertheless, high-skill players demonstrated a slightly later AD onset but an earlier peak activation time compared with low-skill players, suggesting a tendency to concentrate shoulder output closer to the release phase without prematurely activating the shoulder musculature. This “later onset–earlier peak” temporal characteristic reflects a more streamlined and goal-directed neuromuscular control strategy.

The BB showed the most pronounced between-group temporal differences under the 5 m condition. Low-skill players exhibited early BB activation at the initial phase of the movement, maintained relatively high activity during the ball-raising phase, and demonstrated a second marked increase during the release phase, forming a premature and biphasic activation pattern, consistent with the findings of Wagner *et al.* [38]. In contrast, high-skill players primarily activated the BB during the ball-raising phase, with minimal early involvement, and only showed a pronounced increase near the release phase. This indicates that high-skill players avoid premature reliance on elbow flexors during short-distance shooting, thereby reducing unnecessary antagonist interference.

For the FCR, although the overall activation patterns were similar between groups, high-skill players exhibited a significantly earlier activation onset than low-skill players. This earlier recruitment of wrist stabilizers suggests that high-skill players begin preparing for fine wrist and hand control prior to release, whereas low-skill players tend to delay wrist activation until closer to the release phase.

The TB also demonstrated a trend toward earlier activation onset in high-skill players. As the primary driver of elbow extension, earlier TB activation facilitates smooth proximal-to-distal energy transfer during the release phase. In contrast, delayed TB onset in low-skill players may result in temporal compression of elbow extension during release. Kibler *et al.* [25] noted that early activation of wrist and elbow musculature provides a stable force-transmission platform for the release phase, rather than passive late-stage involvement.

Overall, during 5 m jump shooting, high-skill players exhibited later shoulder activation but earlier activation of distal stabilizing and propulsive muscles (FCR and TB), whereas low-skill players tended to activate the elbow flexor (BB) earlier, reflecting fundamental differences in movement organization strategies.

Although no statistically significant differences were observed in the overall muscle activation sequence between groups during 5 m jump shooting, analysis of activation timing and intermuscular coordination suggests that low-skill players may exhibit a higher potential risk for SIS.

Low-skill players demonstrated early BB activation during the initial phase of the movement and sustained elevated activity during the ball-raising phase. Previous studies have shown that the long head of the biceps tendon can exert a superior pull on the humeral head during shoulder flexion and elevation; persistent early activation may therefore increase superior humeral head translation and reduce the subacromial space [39, 40]. Such inappropriate temporal activation has been identified as an important neuromuscular risk factor for SIS.

In contrast, high-skill players delayed substantial BB activation until the ball-raising or release phase, while their AD activation, although initiated slightly later, peaked closer to the release phase. This strategy of minimizing premature antagonist involvement and concentrating shoulder output within critical phases contributes to maintaining shoulder joint dynamic stability [31]. Studies have shown that appropriate shoulder–scapular rhythm and muscle activation timing can effectively reduce mechanical compression of subacromial structures such as the supraspinatus tendon and subacromial bursa [41].

Furthermore, earlier activation of the FCR and TB in high-skill players indicates that distal stability and elbow extension drive are established prior to release, which may reduce compensatory loading at the shoulder joint during the terminal phase and indirectly lower subacromial impingement risk [42].

4.2 6.8 m distance shooting

Under the 6.8 m jump-shot condition, as shooting distance increased, the overall upper-limb muscle activation timing shifted toward later phases of the movement compared with the 5 m condition. This shift is consistent with the increased power output demands associated with long-distance shooting [43]. However, clear between-group differences in activation onset timing remained evident. The AD in both groups began activation during the mid-to-late phases of the movement, reflecting increased demands for late-phase shoulder force production during long-distance shots. Notably, high-skill players exhibited earlier AD activation than low-skill players, supporting the notion that long-distance shooting requires earlier organization of shoulder flexion output [44]. This suggests that high-skill players recruit shoulder flexors earlier to meet increased distance demands, whereas low-skill players demonstrate delayed shoulder involvement.

The BB remained the most discriminative muscle under the 6.8 m condition. Low-skill players again exhibited early BB activation during the initial movement phase, maintained high activity during ball raising, and showed further enhancement during release, indicating persistent and premature elbow flexor involvement. In contrast, high-skill players maintained low and stable BB activation during the first half of the movement, with marked activation only during release, and significantly later onset compared with low-skill players. Hirashima *et al.* [45] reported that premature elbow flexor activation disrupts proximal-to-distal sequencing and increases internal energy dissipation. These findings suggest that even under long-distance conditions, high-skill players suppress early elbow flexor involvement to avoid unnecessary interference within the shooting kinetic chain.

For the FCR, both groups maintained low activation levels during the early-to-mid phases, with substantial activation primarily occurring during release. However, high-skill players still demonstrated slightly earlier activation onset, indicating earlier preparation for wrist stabilization and force transmission during long-distance shooting.

TB activation timing exhibited more pronounced between-group differences under the 6.8 m condition. High-skill players not only initiated TB activation earlier, but also displayed a steeper increase during the release phase, indicating earlier and more concentrated elbow extension drive. Low-skill players showed delayed TB activation, potentially requiring elbow extension output within a shorter time window. This observation aligns with findings from baseball and basketball studies by Fleisig *et al.* [46] and Escamilla *et al.* [16], which suggest that skilled athletes initiate elbow extensor activation earlier to ensure temporal continuity and stability during release.

Overall, during 6.8 m jump shooting, high-skill players exhibited earlier involvement of shoulder and elbow extensor musculature combined with delayed elbow flexor activation, whereas low-skill players demonstrated premature elbow flexor involvement and relatively delayed proximal drive.

With increasing shooting distance under the 6.8 m condition, the demand for force output significantly increased, requiring the shoulder joint to perform under larger ranges of motion and higher loads, thereby amplifying the potential risk of SIS.

Low-skill players continued to exhibit early and sustained BB activation during 6.8 m jump shooting. This premature and persistent BB activity may further exacerbate superior shear forces on the humeral head during long-distance shooting, particularly under combined shoulder flexion and internal rotation, leading to significant compression of the subacromial space [47]. Reinold *et al.* [29] emphasized that poor neuromuscular control of elbow flexors and shoulder flexors during repetitive overhead activities is a key risk factor for subacromial impingement and rotator cuff pathology.

In contrast, although high-skill players initiated AD activation earlier to meet increased distance demands, they maintained delayed BB activation primarily concentrated during the release phase. This temporal adjustment indicates that high-skill players preserve a more appropriate division of labor among shoulder musculature under increased load, avoiding compensatory force generation via elbow flexors or anterior shoulder muscles [48].

Moreover, earlier initiation and rapid amplification of TB activation in high-skill players suggest that more kinetic energy is transferred through elbow extension and the distal kinetic chain, thereby reducing peak shoulder loading at release. Previous basketball and baseball studies have consistently shown that excessive concentration of power output at the shoulder joint without effective proximal-to-distal sequencing significantly increases stress exposure of subacromial structures [16].

Accordingly, during 6.8 m jump shooting, low-skill players may exhibit a higher potential risk of SIS due to premature BB activation and increased compensatory shoulder loading.

This study has several limitations. First, the sample size was relatively small and limited to male participants, which may restrict the generalizability of the findings. Second, the experimental task involved open jump shots without defensive pressure, which may not fully represent real-game conditions. Third, only four upper-limb muscles were analyzed, and the absence of trunk and lower-limb measurements limits interpretation of the kinetic chain.

Additionally, the use of a single “best trial”, rather than averaging multiple trials, may reduce reliability. Furthermore, the study primarily focused on activation onset timing without examining inter-joint coordination patterns.

5. Conclusions

This study compared upper-limb muscle activation timing during 5 m and 6.8 m jump shooting between high- and low-skill basketball players and analyzed the findings from the perspective of potential subacromial impingement risk. The results showed that although the overall activation sequences of the anterior deltoid, flexor carpi radialis, and triceps brachii did not differ significantly between groups at either distance, the activation timing of the biceps brachii consistently differed between skill levels and exhibited similar trends under both shooting conditions.

Low-skill players demonstrated early and sustained biceps brachii activation at both shooting distances. This activation pattern may promote superior humeral head translation, reduce the subacromial space, and consequently increase the potential risk of SIS [49, 50].

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

ZHZ, JTY and SK—designed the research study. ZHZ, JTY, BZ and ZML—performed the research; analyzed the data. SK and BZ—provided help and advice on design, experimental set-up, interpretation, and resources. ZHZ, JTY, BZ and SK—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study complies with the Declaration of Helsinki. The study protocol was explained to all participants, and they signed a formal informed consent form. The protocol of this study was approved by the Jeonbuk National University Institutional Review Board (JBNU2024-09-015-002) and was performed in accordance with relevant guidelines/regulations.

ACKNOWLEDGMENT

The authors gratefully acknowledge all participants for their voluntary involvement and cooperation throughout the study. We sincerely thank the collegiate and recreational basketball players for their time, effort, and commitment to the experimental procedures. The authors also wish to acknowledge the graduate student researchers who assisted with data collection and management of the experimental sessions. Their contributions were invaluable to the successful completion of this study.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest. Sukwon Kim is serving as one of the Guest editors of this journal. We declare that Sukwon Kim had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to WYS.

REFERENCES

[1] Tran CM, Silverberg LM. Optimal release conditions for the free throw in men's basketball. Journal of Sports Sciences. 2008; 26: 1147–1155.
[2] Cabarkapa D, Cabarkapa DV, Ciccone AB, Whiting SM, Philipp NM, Eserhaut DA, *et al*. Acute influence of resistance exercise on basketball shooting mechanics and accuracy. Frontiers in Sports and Active Living. 2023; 5: 1272478.
[3] Botsi V, Bourdas DI, Travlos AK, Bakirtzoglou P, Gofas DC, Ktistakis IE, *et al*. Comparative analysis of 2-point jump shot and free throw kinematics in high- and low-level U18 male basketball players. Journal of Functional Morphology and Kinesiology. 2024; 9: 278.
[4] Rojas FJ, Cepero M, Oña A, Gutierrez M. Kinematic adjustments in the basketball jump shot against an opponent. Ergonomics. 2000; 43: 1651–1660.
[5] Bourdas DI, Travlos AK, Souglis A, Gofas DC, Stavropoulos D, Bakirtzoglou P. Basketball fatigue impact on kinematic parameters and 3-point shooting accuracy: insights across players' positions and cardiorespiratory fitness associations of high-level players. Sports. 2024; 12: 63.
[6] Slegers N, Lee D, Wong G. The relationship of intra-individual release variability with distance and shooting performance in basketball. Journal of Sports Science and Medicine. 2021; 20: 508–515.
[7] Urbin MA, Fleisig GS, Abebe A, Andrews JR. Associations between timing in the baseball pitch and shoulder kinetics, elbow kinetics, and ball speed. The American Journal of Sports Medicine. 2013; 41: 336–342.
[8] Parmar A, Scott M, Brand C, Jones TW. An assessment of the contractile properties of the shoulder musculature in elite volleyball players using tensiomyography. International Journal of Sports Physical Therapy. 2020; 15: 1099–1109.
[9] Reeser JC, Fleisig GS, Bolt B, Ruan M. Upper limb biomechanics during the volleyball serve and spike. Sports Health. 2010; 2: 368–374.
[10] Podmenik N, Supej M, Debevec H, Erčulj F. Common movement patterns of the jump shot while increasing the distance from the basket in elite basketball players. Journal of Human Kinetics. 2021; 78: 29–39.
[11] Tran BN, Yano S, Kondo T. Coordination of human movements resulting in motor strategies exploited by skilled players during a throwing task. PLOS ONE. 2019; 14: e0223837.
[12] Button C, MacLeod M, Sanders R, Coleman S. Examining movement variability in the basketball free-throw action at different skill levels. Research Quarterly for Exercise and Sport. 2003; 74: 257–269.
[13] Chu SK, Jayabalan P, Kibler WB, Press J. The kinetic chain revisited: new concepts on throwing mechanics and injury. PM&R. 2016; 8: S69–S77.
[14] Almansoof HS, Nuhmani S, Muaidi Q. Role of kinetic chain in sports performance and injury risk: a narrative review. Journal of Medicine and Life. 2023; 16: 1591–1596.
[15] Davids K, Glazier P, Araújo D, Bartlett R. Movement systems as dynamical systems: the functional role of variability and its implications for sports medicine. Sports Medicine. 2003; 33: 245–260.
[16] Escamilla RF, Andrews JR. Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. Sports Medicine. 2009; 39: 569–590.
[17] Owens LP, Coyles G, Khaiyat O. Alterations to the kinetic chain sequence after a shoulder injury in throwing athletes. Orthopaedic Journal of Sports Medicine. 2024; 12: 23259671241288889.
[18] Kibler WB, Wilkes T, Sciascia A. Mechanics and pathomechanics in the overhead athlete. Clinics in Sports Medicine. 2013; 32: 637–651.
[19] Laudner KG, Myers JB, Pasquale MR, Bradley JP, Lephart SM. Scapular dysfunction in throwers with pathologic internal impingement. Journal of Orthopaedic & Sports Physical Therapy. 2006; 36: 485–494.
[20] Seroyer ST, Nho SJ, Bach BR Jr, Bush-Joseph CA, Nicholson GP, Romeo AA. Shoulder pain in the overhead throwing athlete. Sports Health. 2009; 1: 108–120.
[21] Fan P, Yang Z, Wang T, Li J, Kim Y, Kim S. Neuromuscular control strategies in basketball shooting: distance-dependent analysis of muscle synergies. Journal of Sports Science and Medicine. 2024; 23: 571–580.
[22] Yang Z, Kim Y, Zhao Z, Feng W, Wang J, Kim S. Effect of basketball shooting distance and skill level on muscle activity and joint energy production of upper extremity. Molecular & Cellular Biomechanics. 2025; 22: 550.
[23] Nuzzo JL, Taylor JL, Gandevia SC. CORP: measurement of upper and lower limb muscle strength and voluntary activation. Journal of Applied Physiology. 2019; 126: 513–543.
[24] Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine. 1996; 21: 2640–2650.
[25] Kibler WB, Sciascia A, Dome D. Evaluation of apparent and absolute supraspinatus strength in patients with shoulder injury using the scapular retraction test. The American Journal of Sports Medicine. 2006; 34: 1643–1647.
[26] Beinabaji H, Eslami M, Hosseininejad S, Paeen Afrakoti IE. Muscle synergy during double-leg attack maneuver: a comparison between elite and sub-elite wrestlers. Journal of Advanced Sport Technology. 2023; 7: 11–24.
[27] Ozawa Y, Uchiyama S, Ogawara K, Kanosue K, Yamada H. Biomechanical analysis of volleyball overhead pass. Sports Biomechanics. 2021; 20: 844–857.
[28] Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. Journal of the American Academy of Orthopaedic Surgeons. 2003; 11: 142–151.
[29] Reinold MM, Wilk KE, Fleisig GS, Zheng N, Barrentine SW, Chmielewski T, *et al*. Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. Journal of Orthopaedic & Sports Physical Therapy. 2004; 34: 385–394.
[30] Girometti R, De Candia A, Sbuelz M, Toso F, Zuiani C, Bazzocchi M. Supraspinatus tendon US morphology in basketball players: correlation with main pathologic models of secondary impingement syndrome in young overhead athletes. Preliminary report. La Radiologia Medica. 2006; 111: 42–52.
[31] Burden A. How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. Journal of Electromyography and Kinesiology. 2010; 20: 1023–1035.
[32] Hodges PW, Bui BH. A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography. Electroencephalography and Clinical Neurophysiology. 1996; 101: 511–519.

[33] Merlo A, Farina D, Merletti R. A fast and reliable technique for muscle activity detection from surface EMG signals. IEEE Transactions on Biomedical Engineering. 2003; 50: 316–323.

[34] Li S, Luo Y, Cao Y, Li F, Jin H, Mi J. Changes in shooting accuracy among basketball players under fatigue: a systematic review and meta-analysis. Frontiers in Physiology. 2025; 16: 1435810.

[35] Li J, Kim Y, Li H, Zhu B, Kim S. Arm joint coordination of collegiate basketball athletes and recreational players when shooting behind the 3-point line. Journal of Human Kinetics. 2025; 96: 129–143.

[36] Mir IA, Mohd Jamali MNZ, Humayra S, Chong KW, Amalnerkar T, Sirajudeen MS. Partial versus full range of motion triceps strength training on shooting accuracy among recreational basketball players: a randomized controlled trial. BMC Sports Science, Medicine and Rehabilitation. 2025; 17: 41.

[37] van den Tillaar R, Ettema G. Is there a proximal-to-distal sequence in overarm throwing in team handball? Journal of Sports Sciences. 2009; 27: 949–955.

[38] Wagner H, Pfusterschmied J, Klous M, von Duvillard SP, Müller E. Movement variability and skill level in sports. Sports Biomechanics. 2012; 11: 495–508.

[39] Hess SA. Functional stability of the glenohumeral joint. Manual Therapy. 2000; 5: 63–71.

[40] Lewis JS. Rotator cuff tendinopathy/subacromial impingement syndrome: is it time for a new method of assessment? British Journal of Sports Medicine. 2009; 43: 259–264.

[41] Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Physical Therapy. 2000; 80: 276–291.

[42] Hirashima M, Kadota H, Sakurai S, Kudo K, Ohtsuki T. Sequential muscle activity and its functional role in the upper extremity and trunk during overarm throwing. Journal of Sports Sciences. 2002; 20: 301–310.

[43] Elliott B, Fleisig G, Nicholls R, Escamilia R. Technique effects on upper limb loading in the tennis serve. Journal of Science and Medicine in Sport. 2003; 6: 76–87.

[44] Okazaki VHA, Rodacki ALF. Increased distance of shooting on basketball jump shot biomechanics. Journal of Sports Science and Medicine. 2012; 11: 231–237.

[45] Hirashima M, Kudo K, Watarai K, Ohtsuki T. Control of 3D limb dynamics in unconstrained overarm throws of different speeds performed by skilled baseball players. Journal of Neurophysiology. 2007; 97: 680–691.

[46] Fleisig GS, Barrentine SW, Zheng N, Escamilla RF, Andrews JR. Kinematic and kinetic comparison of baseball pitching among various levels of development. Journal of Biomechanics. 1999; 32: 1371–1375.

[47] Michener LA, McClure PW, Karduna AR. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. Clinical Biomechanics. 2003; 18: 369–379.

[48] Aguinaldo AL, Buttermore J, Chambers H. Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. Journal of Applied Biomechanics. 2007; 23: 42–51.

[49] Akl AR, Hassan A, Elgizawy H, Tilp M. Quantifying coordination between agonist and antagonist elbow muscles during backhand cross-court shots in adult female squash players. International Journal of Environmental Research and Public Health. 2021; 18: 9825.

[50] Lees A. Technique analysis in sports: a critical review. Journal of Sports Sciences. 2002; 20: 813–828.

How to cite this article: Zihao Zhao, Jinting Yu, Zemin Lu, Sukwon Kim, Bin Zhu. Delayed and disorganized muscle activation as a potential injury mechanism in men's basketball jump shots. Journal of Men's Health. 2026; 22(8): 42-55. doi: 10.22514/jomh.2026.067.