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Comparison of Coordination and Angles of Lower Extremity Joints in Elite Male Athletes in Conventional and Sumo Deadlift Techniques

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ABSTRACT

Background: The deadlift is one of the fundamental exercises in bodybuilding and a key component in powerlifting competitions. This study aimed to compare the coordination and joint angles of the lower extremities in elite male athletes while performing conventional and sumo deadlift techniques.

Methods: Fourteen elite male athletes participated in this study, performing two deadlift techniques at 70% of their one-repetition maximum for six repetitions. Kinematic data were collected using seven high-speed cameras and analyzed with OpenSim software.

Results: The coordination pattern between the lower extremity joints was divided into 10 phases. A dependent t-test was conducted to compare the mean joint angles and continuous relative phase across the 10 phases for both the sumo and conventional techniques. Significant differences were observed in hip, knee, and ankle coordination during the initial, middle, and final phases for both techniques. Additionally, significant differences were found in lower limb joint angles between the two techniques.

Conclusions: Based on the study's findings, it is recommended that athletes and coaches incorporate both techniques in training and competition. For beginners and those prone to injury, the conventional deadlift technique may be more appropriate for initiating lifting exercises.

KEYWORDS: Deadlift, Angular Differentiation, Coordination, Variability

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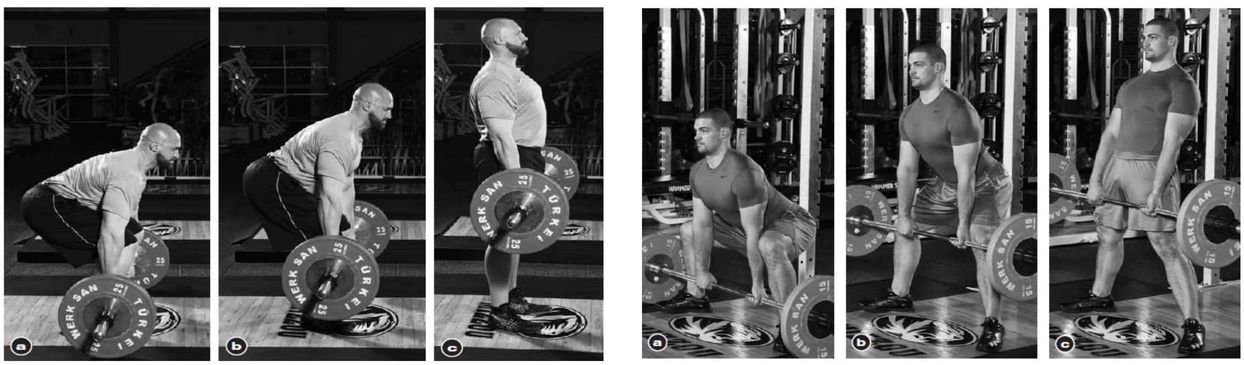
Introduction

The deadlift is regarded as one of the foundational exercises in bodybuilding and one of the three key movements in powerlifting competitions. It is performed in two main styles: conventional and sumo, both of which are used in training and competitions [1]. In professional athletes' training, the deadlift involves a cyclic movement in which the body lifts a weight from the ground by extending the ankle, knee, hip, and elbow joints to reach an upright posture, followed by a return to the starting position. In the conventional technique, the athlete grasps the barbell with their hands placed outside the legs, whereas in the sumo technique, the legs are positioned wider than shoulder-width apart, and the barbell is held with the hands inside the legs (Fig 1).



A B

Figure 1. Execution of Deadlift Techniques: A. Conventional, B. Sumo

In human movement, the degrees of freedom are managed through muscle coordination across one or more joints, with this coordination evolving with experience and skill acquisition [2]. Bernstein (1967) argued that, due to the numerous degrees of freedom in the human body, no movement can be perfectly replicated [3]. This inherent variability has been debated extensively in biomechanical research and movement control. Traditional movement analysis often overlooks intra-person variability, treating it as biological noise in the movement system. However, dynamical systems theory views intra-individual variability as crucial information about the stability of the system's state vector [4,5].

With the increasing level of competition and the pursuit of record-breaking performances, coaches and athletes are focused on identifying and applying factors that optimize skill execution, correct errors, and refine training programs. Even minor improvements can significantly enhance an athlete's performance. Over the past two decades, several studies have examined the execution and comparison of conventional and sumo deadlift techniques [6-11]. Rafael et al. (2000) analyzed 24 male powerlifters in a study titled *Analysis of Sumo and Conventional Style Deadlift*. In this research, kinematic variables (such as limb and joint angles, and lift time) and kinetic variables (including joint torque and mechanical work) were extracted using two Sony HVM200 cameras operating at 60 frames per second [1].

In the last decade, various methods have been developed to examine movement coordination [12-17]. Investigating inter-joint coordination using the continuous relative phase (CRP), which combines joint position and velocity information from two adjacent joints into a single phase, provides deeper insights into movement coordination [18-20]. Consequently, in recent biomechanical research, the CRP has been used to identify injury risk factors [16, 21, 22], analyze joint and limb coordination [12, 23], and study sports technique across different skill levels in various sports [17, 24, 25]. Athletes with superior technique, due to their enhanced neuromuscular coordination, can utilize diverse movement patterns to increase precision and accuracy in executing their techniques [26].

Comparing the coordination and joint angles of the lower extremities in the two deadlift techniques can highlight the technical differences among elite athletes. This, in turn, can guide coaches in developing targeted training programs for key phases of the technique. Furthermore, reduced variability in technique execution may lead to overuse injuries, as the repetitive movement paths could concentrate force on certain joints, leading to excessive strain.

Therefore, coordination and variability indicators can be valuable tools for coaches, athletes, and therapists in identifying and diagnosing overuse injuries associated with conventional and sumo deadlift execution. Various methods, such as vector coding, discrete relative phase, and continuous relative phase, have been employed to assess coordination in the research literature. While movement velocity is a key factor in movement mechanics analysis, only the continuous relative phase method incorporates limb and joint velocity into the calculations, whereas the other methods rely solely on displacement [27]. Thus, the aim of the current study is to compare the coordination and joint angles of the lower extremities in elite male athletes during the execution of conventional and sumo deadlifts.

Material and Methods

The statistical population for this comparative study consisted of elite male weightlifting athletes from Isfahan province. Using the J-power method and based on an independent t-test with a power of 0.8, an alpha level of 0.05, and an effect size of 0.8, a sample of 14 elite male athletes was determined to participate in this research. From this population, considering the inclusion criteria—uninjured elite athletes who had participated in national championships—14 athletes were selected after screening. Their mean age was 29±5.9 years, with a mean height of 178.63±3.29 cm, weight of 83.54±11.16 kg, body mass index (BMI) of 26.15±3.26, and a mean lift of 120.72±25.83 kg. Ethical approval was obtained from the Ethics Committee in Biomedical Research at Kharazmi University of Tehran (Ethics Code: IR.KHU.REC.1400.019).

During the system setup phase, seven high-speed cameras (Qualisys, Sweden) were used to record movement at the Musculoskeletal Disorders Research Center of Isfahan University of Medical Sciences (Figure 2a). These cameras utilize infrared technology, allowing for highly accurate three-dimensional motion capture with proven validity and reliability. The sampling frequency was set to 100 Hz. The cameras were calibrated both statically and dynamically.

A: Arrangement of cameras B: Static and dynamic calibration

Figure 2. Laboratory Set up: A: Camera arrangement, B: Calibration

To standardize and select the participants, demographic information was gathered using a data collection form. Individuals meeting the inclusion criteria were asked to visit the laboratory at the Faculty of Rehabilitation, Isfahan University of Medical Sciences, where the tests were conducted during specified time slots. After explaining the purpose and procedure of the research and obtaining written informed consent from the participants, their height and weight were measured using a Seca stadiometer and scale (Germany). A total of 24 infrared reflective markers, each with a diameter of 1 cm, were placed on anatomical landmarks on both sides of the lower limbs according to the method approved by the University of Strathclyde. Figure 3 illustrates the placement of these markers on the participants' bodies. In this method, anatomical markers and four cluster markers were used, making up a total of 43 markers. However, since the motion capture system data serves as input for the OpenSim software, cluster markers were not required and were therefore omitted in the final analysis.

Figure 3. Subjects Picture with Marker mounted on his body

A four-step process was followed to analyze the data. After validating the data, which was done by cross-referencing previous research findings and leveraging the researcher's expertise, a fourth-order Butterworth low-pass filter with a cutoff frequency of 6 Hz was applied to reduce noise in the raw data. For normalization, aimed at making the data comparable, the joint angles and angular velocities were normalized to the range [-1,1]. During data analysis, raw data were converted into dependent variables by inputting the three-dimensional coordinates of the markers into OpenSim software. The scaling and inverse kinematics steps were performed within the software, and the hip, knee, and ankle joint angles from both sides of the body were extracted for both the conventional and sumo deadlift techniques. Equation 1 was used to calculate angular velocity (20).

$\boldsymbol{\omega_i = \frac{\omega_{i+1} - \omega_{i-1}}{2\Delta t}}$	Equation 1

To calculate the phase diagram of each joint, the displacement and angular velocity were first normalized to the range of -1 to 1, using Equations 2 and 3 (5).

$\boldsymbol{\theta_i' = \frac{2 \times (\theta_i - min(\theta_i))}{max(\theta_i) - min(\theta_i)} - 1}$	Equation 2

$\omega_i' = \dfrac{\omega_i}{max\{\lvert\omega_i\rvert . \lvert-\omega_i\rvert\}}$	Equation 3
$\emptyset_i = \left(\dfrac{\omega_i'}{\theta_i}\right)$	Equation 4

Where, θ' and ω' represent the normalized displacement and angular velocity, respectively, while θ and ω denote the original displacement and angular velocity. The subscript *i* refers to the position of the data within the analyzed cycle. After these steps, Equation 4 was used to obtain the phase angles (5). In this equation, Φ represents the phase angle, and θ' and ω' are the normalized displacement and angular velocity. The continuous relative phase (CRP) was then calculated by subtracting the phase angle of the distal joint from that of the proximal joint (5).

In Equation 5, Ø_A(i) represents the phase angle of the distal joint, and Ø_B(i) refers to the phase angle of the proximal joint. CRP represents the continuous relative phase between the two joints. These steps were repeated exactly for the paired limb or joint, ensuring consistent analysis.

$CRP(i) = \emptyset_A(i) - \emptyset_B(i)$	Equation 5

For the deadlift technique, all coordination data were normalized to 100% (from the start of the deadlift until full standing and placing the weight back on the ground). The continuous relative phase of the hip, knee, and ankle joints during the deadlift movement was calculated. The common values derived from CRP data include the mean during distinct periods of the cycle, where angles were averaged over every 10% of the cycle [5]. In this study, the normalized data were also averaged over every 10% of the cycle, and the entire deadlift cycle was divided into ten phases. In-phase and out-of-phase joint movements were classified according to criteria established in previous literature [17,28].

$-30 < CRP < 30$	in-phase
$30 < CRP < 150$ و $-150 < CRP < -30$	semi- in-phase
$150 < CRP < 180$ و $-180 < CRP < -150$	out-phase

Any movement with a continuous relative phase value between zero and 180 degrees is classified as an out-of-phase movement. Depending on the value's proximity to zero or 180, the movement may be near in-phase or semi-in-phase [5]. The slope of the CRP graph was analyzed to interpret the continuous relative phase. A positive slope indicates that the distal joint is moving faster, while a negative slope indicates that the proximal joint is moving faster in the movement cycle [4].

For statistical analysis, after confirming normal data distribution using the Shapiro-Wilk test, a dependent parametric t-test was employed to compare the mean values between the conventional and sumo deadlift techniques among elite male athletes, with significance set at $p \leq 0.05$.

Results

The results of this research are presented in two parts: (a) the angles of the lower body joints (hip, knee, and ankle) in both conventional and sumo deadlift techniques on both sides of the body of elite athletes, and (b) the coordination of these joints as measured by the continuous relative phase method. The average coefficient of variation (CV) of lower limb joint angles is illustrated in

Figures 3 to 6 and summarized in Table 1. The mean continuous line, variability, and CV of the hip joint angles in three planes of movement (sagittal, frontal, and transverse) on both the left and right sides of the body (Figure 4), as well as the knee and ankle angles in the sagittal plane (Figure 5) during the conventional deadlift, are shown for a full movement cycle, from the start of the deadlift to its completion, among the elite athletes in this study.

Similarly, the mean continuous line, variability, and CV of the hip joint angles in three movement planes (Figure 6), and the knee and ankle angles in the sagittal plane (Figure 7) during the sumo deadlift, are shown for a full movement cycle. The mean CV of the right hip in the sagittal plane was 13.3% higher than that of the left hip in the conventional deadlift technique. For the left hip, the CV in the conventional technique was 4% lower than in the sumo technique. The largest and smallest variations in the sagittal plane were found for the right leg in the conventional technique and the right leg in the sumo technique, respectively. The mean CV of the right hip in the transverse plane was 13 in the conventional technique and 11 in the sumo technique.

In the transverse plane, the average CV of the left hip in the conventional technique was 25% higher than that in the sumo technique. The greatest changes in the average CV in the transverse plane of the hip joint were observed in the right hip during the sumo technique. For the left hip, the average CV in the sumo technique was 61% higher than in the conventional technique. In the sagittal plane of the knee joint, the average CV was higher in the conventional technique compared to the sumo technique. Specifically, the average CV for the right knee in the sumo technique was 6.9% lower, and for the left knee, 2.9% lower than in the conventional technique.

In the sagittal plane of the ankle joint, the mean CV in the sumo technique was significantly higher than in the conventional technique, with the right ankle showing an 81.25% increase and the left ankle showing a 72.12% increase.

Table 1. Average coefficient of variation (CV) of left nd right lower limb angles in sumo amd convention deadlift

Joint	plane	%CV Sumo		%CV Convention	
		left	right	left	right
Hip	Sagital	76	70	73	80
	Transverse	14	11	18	13
	Horizontal	47	116	25	16
Knee	Sagital	68	70	70	75
Ankle	Sagital	183	225	86	95

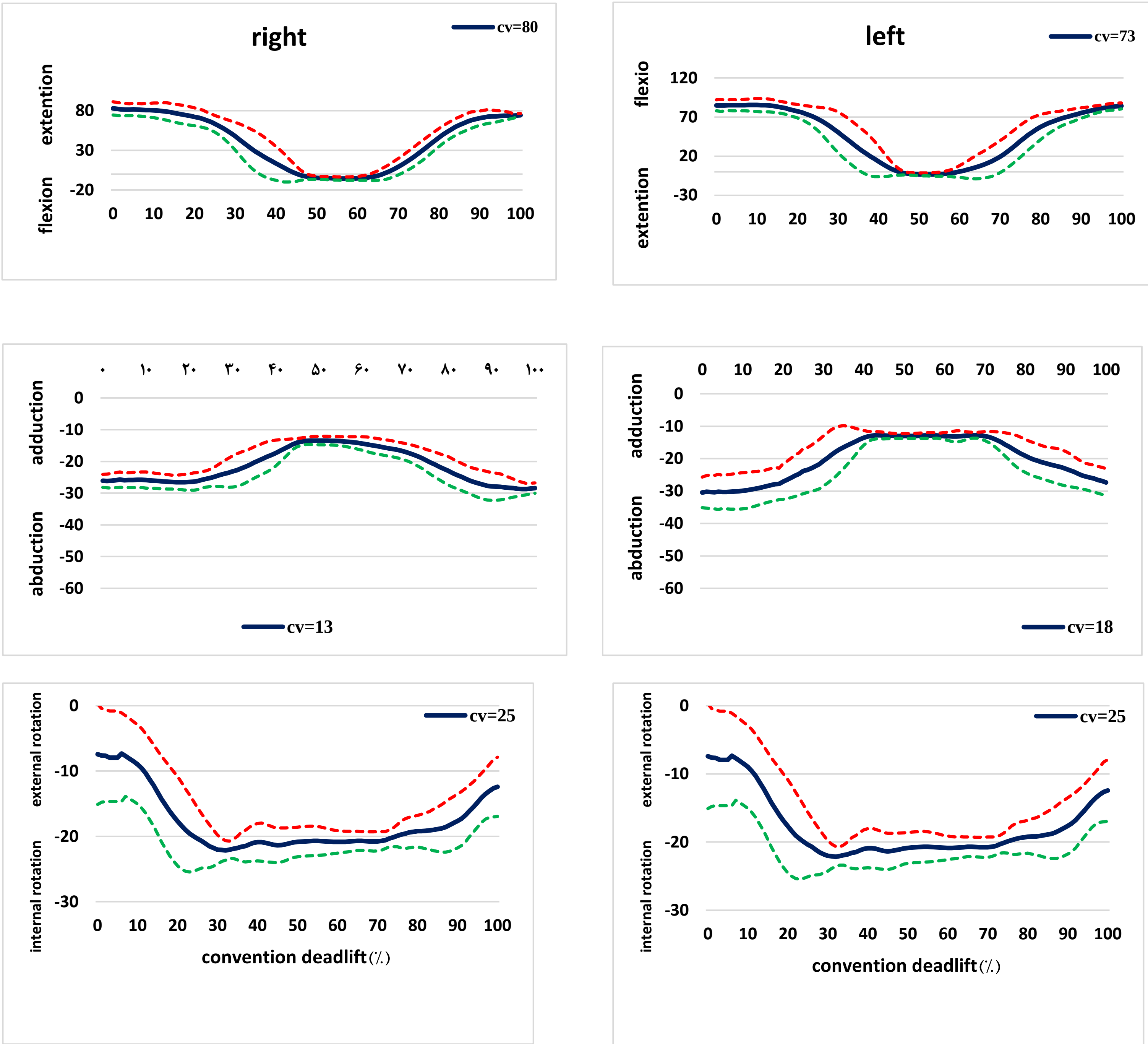


Figure 4. Mean and standard deviation of hip angles in three planes of motion for the convention deadlift technique of elite athletes across the movement cycle (%)

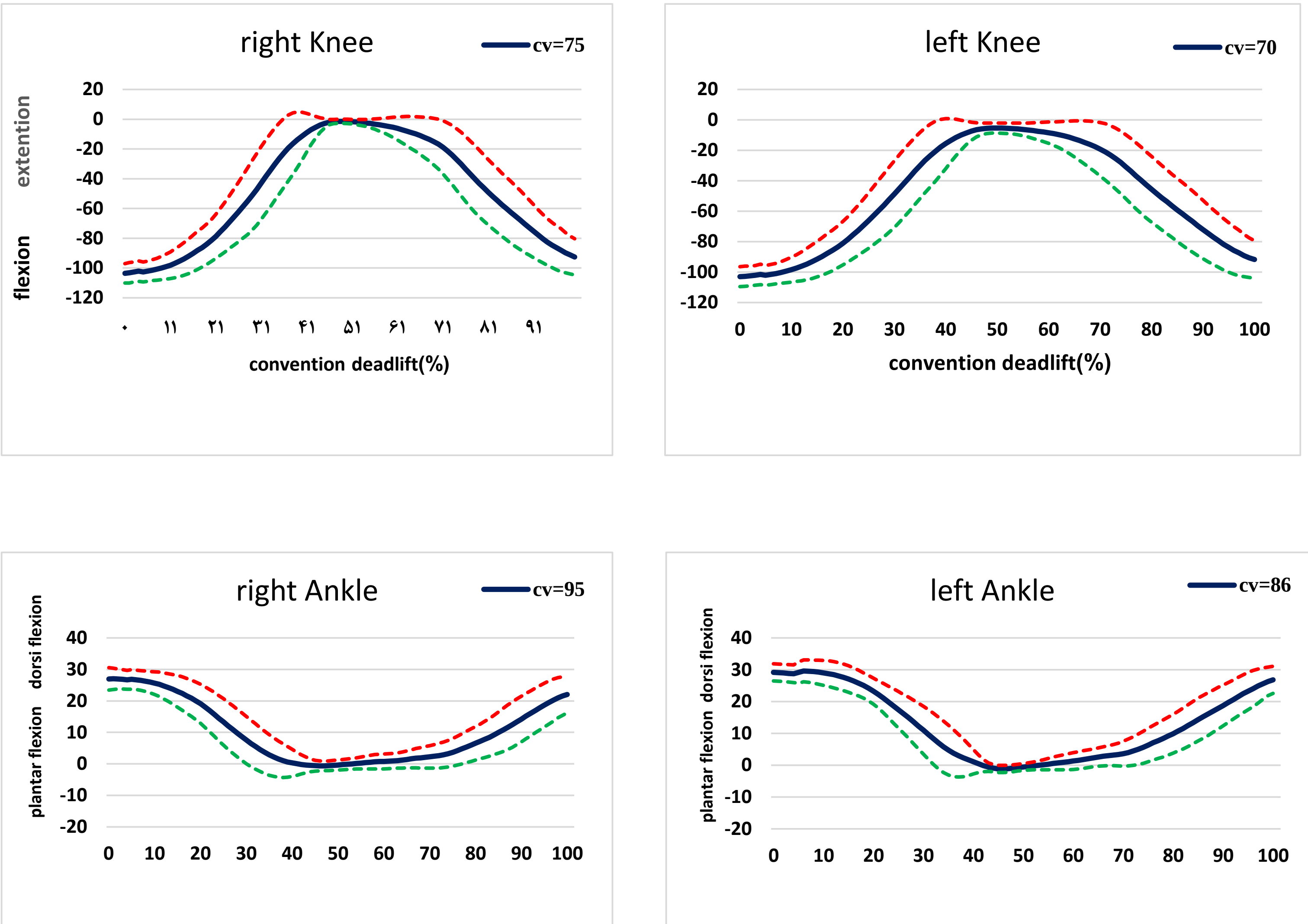


Figure 5. Mean and standard deviation of the knee and ankle angles for the conventional deadlift technique of elite athletes across the movement cycle (%)

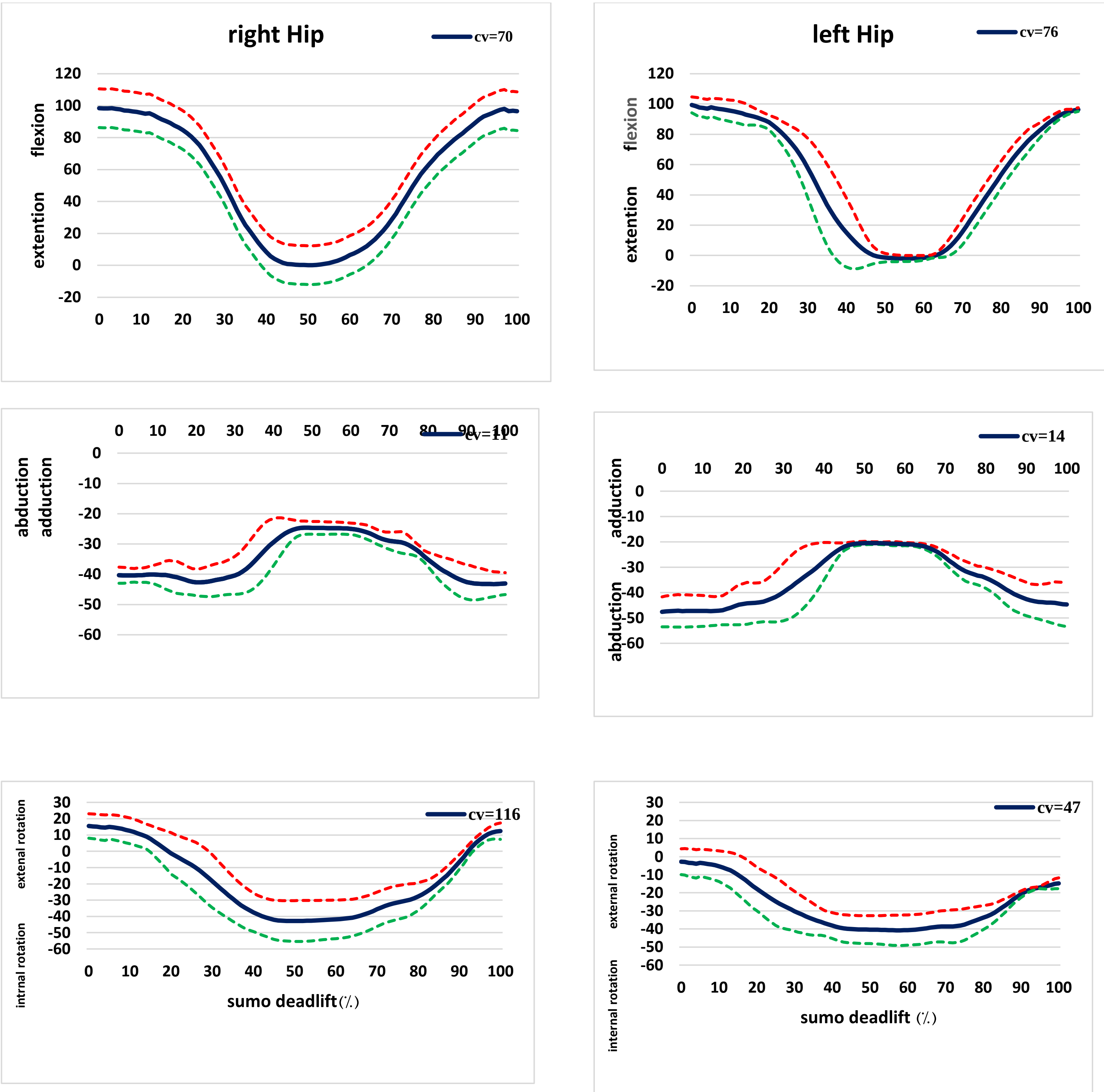


Figure 6. Mean and standard deviation of hip angles in three planes of motion for the sumo deadlift technique of elite athletes across the movement cycle(%)

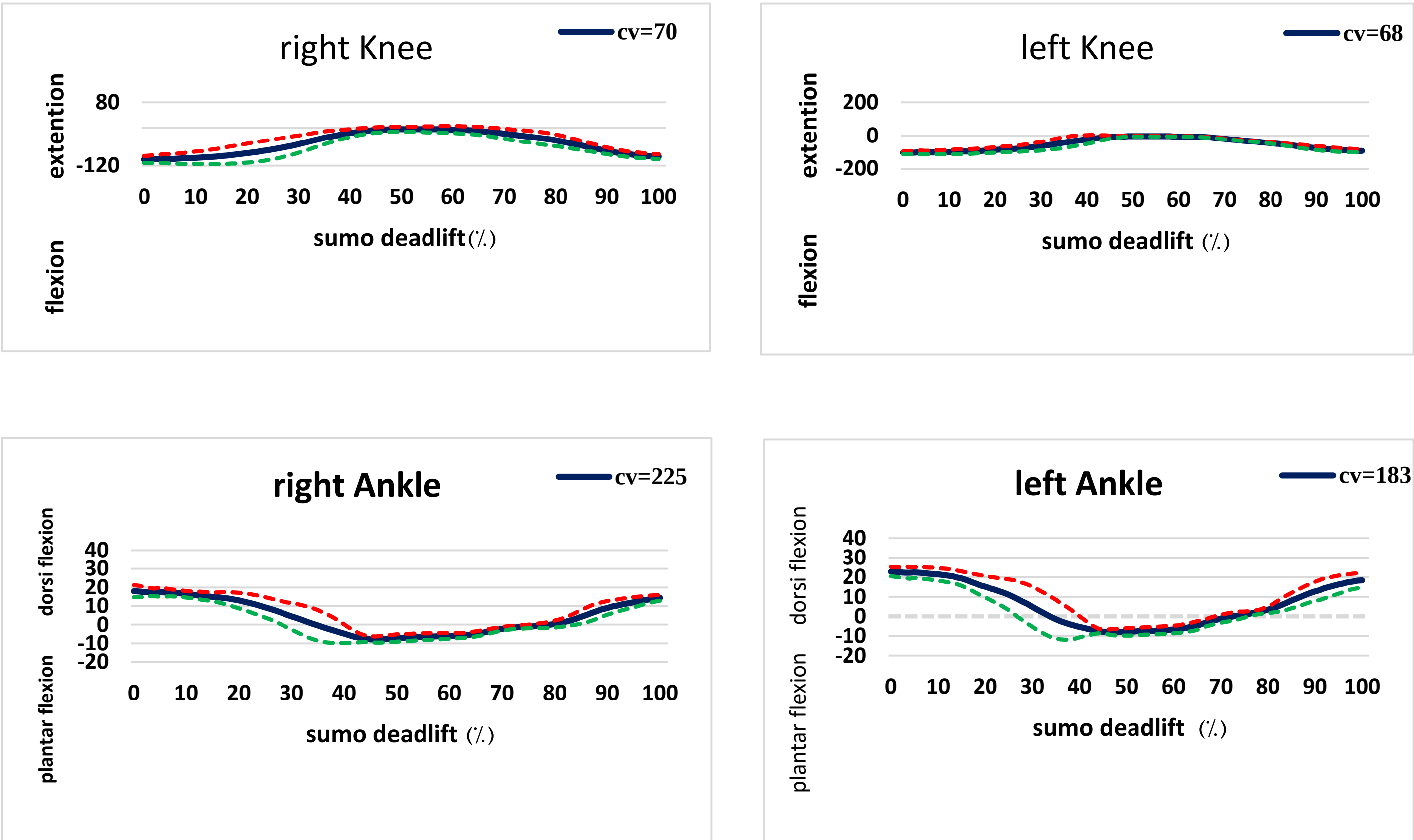


Figure 7. Mean and standard deviation of the knee and ankle angles for the sumo deadlift technique of elite athletes across the movement cycle (%)

Hip Flexion to Left Knee Flexion :According to Figure 8(a), the continuous relative phase (CRP) during hip flexion to left knee flexion shows consistency in both the conventional and sumo deadlift techniques during the first and sixth phases. In the sumo movement, the positive slope from the first to the third phases indicates that the knee moves faster than the hip. In contrast, in the conventional deadlift, a negative slope from the second to the fourth phase shows that the hip moves faster than the knee. From the fourth to the seventh phase, both techniques exhibit a negative slope. The statistical analysis revealed a significant difference in CRP during the first to third and fifth to eighth phases.

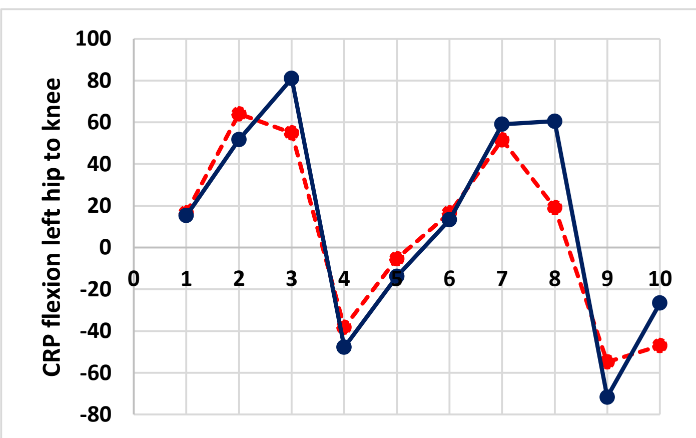
Hip Flexion to Right Knee Flexion :As shown in Figure 8(b), both techniques are consistent during the first, fourth, and tenth phases. The positive slope from the first to third, fourth to seventh, and ninth to tenth phases suggests faster movement of the knee joint compared to the hip in both techniques, indicating that these two joints are nearly in phase with each other. The dependent t-test showed significant differences in CRP during the second and fifth to tenth phases.

Hip Abduction to Left Knee Flexion :In Figure 8(c), the CRP for hip abduction to left knee flexion in both techniques is consistent in the first and eighth phases. The statistical test revealed significant differences in CRP during the first to third, fifth, and seventh phases.

Hip Abduction to Right Knee Flexion :In the first, fifth, and ninth phases, the CRP for hip abduction to right knee flexion (Figure 8d) shows a consistent pattern in both techniques. The statistical analysis revealed significant differences during the second, fourth, sixth, and tenth phases. The positive slope from the first to third and fourth to seventh phases indicates that the hip moves faster than the knee. During the seventh to eighth phase in the conventional deadlift, the negative slope indicates faster movement of the knee than the hip. In contrast, during the sumo deadlift, the opposite occurs.

Knee Flexion to Left Ankle Dorsiflexion :As shown in Figure 8(e), the CRP for knee flexion to left ankle dorsiflexion is the same for both techniques in the first, fourth, and sixth phases. However, the statistical test revealed significant differences in the second, fifth, seventh, and tenth phases.

Knee Flexion to Right Ankle Dorsiflexion :According to Figure 8(f), the CRP for knee flexion to right ankle dorsiflexion is consistent in the first, fifth, sixth, and eighth phases. The dependent t-test showed significant differences in the second to fourth, seventh, and tenth phases. The slope of the graph is negative from the first to second and fourth to seventh phases, indicating faster movement of the knee joint compared to the ankle. From the second to fourth and eighth to tenth phases, the slope is positive, indicating faster movement of the ankle joint compared to the knee in both the conventional and sumo deadlift techniques.



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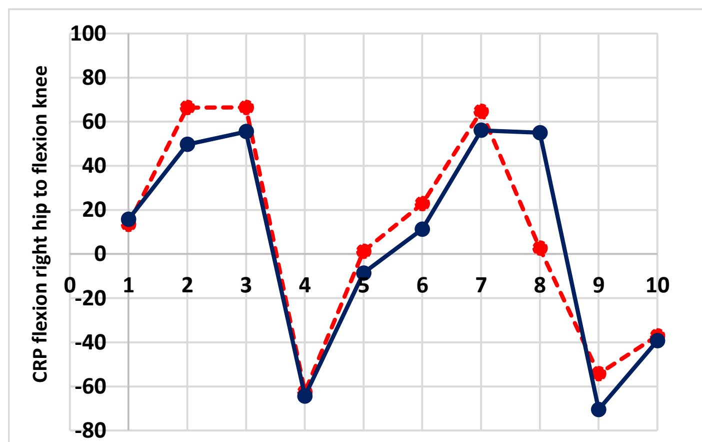

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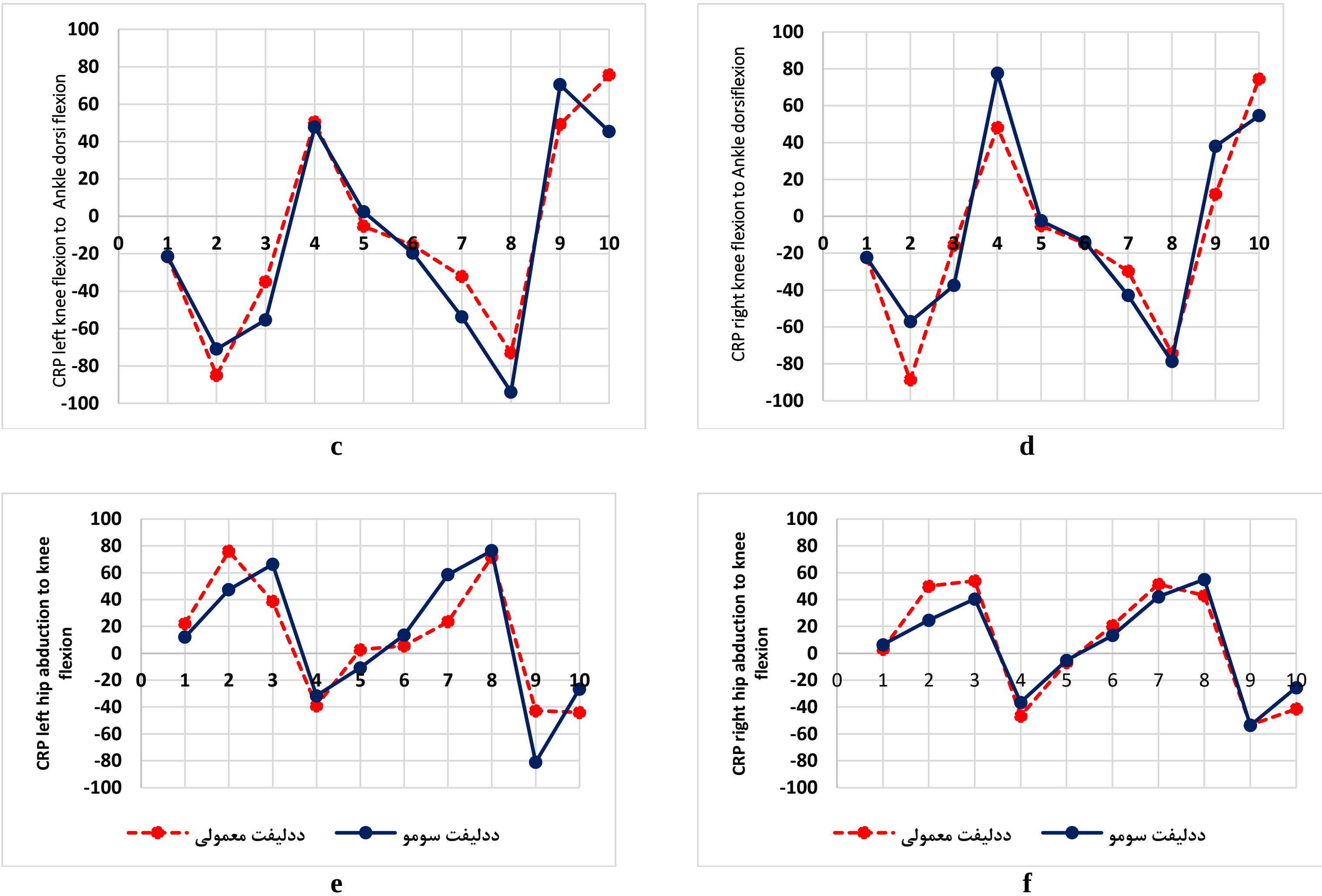

Figure 8. Coordination Pattern of Lower Limb Joints Across Ten Phases in Conventional and Sumo Deadlift Techniques

Discussion and Conclusion

The aim of this study was to compare two deadlift techniques, the conventional deadlift and the sumo deadlift, with respect to lower limb joint angles and continuous relative phase (CRP) changes of the hip, knee, and ankle across a full movement cycle among elite male athletes.

The results revealed significant differences in lower limb joint angles between the two techniques, with the exception of right thigh rotation ($p=0.146$) and right knee flexion ($p=0.964$). Significant differences were observed in the angles of the right thigh in the sagittal and transverse planes, the left thigh angles in all three planes, left knee flexion, and both ankle angles in the sagittal plane.

Due to the fact that previous studies have typically assessed the deadlift at specific moments rather than evaluating the entire movement cycle, a direct comparison of this study's results with other research was challenging. The significant differences observed between the lower limb joint angles in the sumo and conventional techniques can likely be attributed to the distinct mechanics of the two techniques. Regarding limb coordination, greater coordination was observed in the early phase (phase 1) of both techniques compared to the final phase (phase 10).

In both techniques, the positive slope of the hip-to-knee flexion coordination diagram during phases 1–3 (sumo) and phases 4–7 (conventional) indicates a higher knee speed relative to the hip. Similarly, the positive slope of the knee-to-ankle dorsiflexion coordination diagram during phases 2–4 in both techniques suggests that the ankle moves faster than the knee, while the negative slope during phases 4–8 indicates that the knee moves faster than the ankle. From these results, it can be concluded that knee movement is faster than both hip and ankle movements during the middle phases (phases 4–7) of both the sumo and conventional techniques.

Chiu and Chan (2013) reported a significant difference (p=0.001) between the hip flexion angles in the sagittal plane for both the conventional and sumo techniques. The maximum hip flexion angle in their study was 100° for the sumo technique [18]. Schellenberg et al. (2013) found the maximum hip angle during the deadlift to be 101°[29]. In studies by Escamilla et al. (2000, 2001), the maximum hip angles were reported as 108° and 124°, respectively [1,30]. McGuigan et al. (1996) reported a maximum hip angle of 113°[31], while Brown et al. (1985) calculated 110°[8].

In the present study, the mean coefficient of variation (CV) for hip flexion in the sagittal plane ranged between 70% and 80% for both techniques. The maximum hip angle in this plane was 85 ± 5° and 83 ± 8° for the left and right legs, respectively, in the conventional technique, and 99 ± 5° and 98 ± 10° in the sumo technique. The initial hip flexion in the conventional technique was less than in the sumo technique, likely due to the wider stance in the sumo technique or greater involvement of upper limb muscles in the conventional technique.

In the transverse plane (abduction-adduction), there was a significant difference (p=0.001) between the two techniques. The CV of hip angles in this plane ranged from 11% to 18% for both techniques. The maximum hip angle in the transverse plane was 30 ± 5° (left) and 29 ± 3° (right) in the conventional technique, and 47 ± 6° (left) and 43 ± 4° (right) in the sumo technique. The greater abduction in the sumo technique is likely due to the nature of the stance and the muscles involved, which may also contribute to greater balance and confidence among athletes in this technique.

For internal-external rotation of the thigh (horizontal plane), no significant difference was observed in right thigh rotation between the two techniques (p=0.146), but there was a significant difference in left thigh rotation (p=0.001). The CV of thigh angles in the horizontal plane ranged from 16% to 116%, with the highest and lowest variation recorded in the right leg for the sumo and conventional techniques, respectively. The maximum thigh angle in this plane was 22 ± 2° (left) and 21 ± 3.5° (right) in the conventional technique, and 41 ± 8° (left) and 43 ± 13° (right) in the sumo technique.

Regarding knee flexion in the sagittal plane, Jagodnik et al. (2016) reported a maximum knee angle of 101° at the start of the movement for both techniques [10]. Schellenberg et al. (2013) found the maximum knee angle in the deadlift to be 107 ± 22°[29].

The maximum ankle angle in the sagittal plane was 29.5 ± 3.5° (right leg) and 27.5 ± 3.5° (left leg) in the conventional technique, and 23 ± 3.5° (right leg) and 18 ± 3° (left leg) in the sumo technique. Given the variation in ankle angles, athletes with ankle injuries or those seeking to use the deadlift for rehabilitation may benefit from using the sumo technique due to its greater variability in ankle movement.The findings also suggest that since the mean coefficient of variation for joint angles in the conventional technique is lower than that of the sumo technique, it may be advisable for novice athletes to start their training with the conventional technique.

One limitation of this study was the restriction to a weight of 70% of the subjects' one-repetition maximum to avoid damage to the laboratory environment. Additionally, due to the unavailability of standard markers, custom-designed markers using a 3D printer were employed, and 24 markers were used in conjunction with OpenSim software to capture data. Another limitation was the exclusion of electromyography (EMG) data to record muscle activity, as subjects were reluctant to use the device due to the COVID-19 pandemic. It is recommended that future studies include a biomechanical analysis of the upper limbs in both deadlift techniques.

Based on the findings, the use of the continuous relative phase model and the calculated joint angles can be recommended for bridging the gap between the techniques used by amateur powerlifters and elite athletes, helping amateurs achieve better coordination and technique.Given the observed differences in lower body joint angles between the conventional and sumo deadlift techniques, it is suggested that professional athletes and coaches incorporate both techniques into their training programs and competition preparation. The results also indicate that the hip joint undergoes more abduction in the sumo technique than in the conventional deadlift, providing greater support and balance. Lastly, since the sumo technique shows a higher mean coefficient of variation, especially in the ankle joint, it is recommended that amateur athletes, particularly those with ankle injuries or those using deadlifts for rehabilitation, prioritize the conventional technique over the sumo technique in their training regimen**.**

Ethical Considerations:

Compliance with ethical guidelines

This work consistently adheres to ethical guidelines, ensuring integrity, transparency, and respect in all my actions and decisions

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Authors state no funding involved.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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مقایسه هماهنگی و زوایای مفاصل اندام تحتانی مردان ورزشکار نخبه در تکنیک ددلیفت معمولی و سومو

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چکیده

مقدمه و هدف: ددلیفت به عنوان یکی از پایه‌ای‌ترین حرکات بدن‌سازی و یکی از اجزاء اصلی در رقابت های پاورلیفتینگ است. هدف پژوهش حاضر، مقایسه هماهنگی و تغییرپذیری مفاصل اندام تحتانی ورزشکاران مرد نخبه در اجراء ددلیفت معمولی و سومو بود.

روش شناسی: ۱۴ مرد ورزشکار نخبه شرکت کننده در این پژوهش، با۷۰٪یک تکرار بیشینه حرکت، شش بار دو تکنیک ددلیفت را انجام دادند. جمع آوری داده های کینماتیکی با استفاده از هفت دوربین سرعت بالا، و با بهره گیری از نرم‌افزار اپن‌سیم تحلیل شد .

نتایج: الگوی هماهنگی بین مفاصل اندام تحتانی به ده فاز تقسیم شد. از آزمون آماری تی وابسته جهت مقایسه میانگین فاز نسبی پیوسته در ۱۰ فاز برای هر دو تکنیک استفاده شد. اختلاف معنادار در هماهنگی مفاصل ران، زانو و مچ پا در فازهای اولیه ، میانی و انتهایی در هر دو تکنیک ددلیفت معمولی و سومو مشاهده شد.

نتیجه گیری: بر اساس یافته‌های این پژوهش، توصیه می‌شود که ورزشکاران و مربیان از هر دو تکنیک در تمرینات و مسابقات استفاده نمایند و برای ورزشکاران مبتدی و کسانی که مستعد آسیب هستند، تکنیک ددلیفت معمولی ممکن است برای شروع تمرینات ددلیفت مناسب تر باشد.

واژه‌های کلیدی: ددلیفت، تغییرات زاویه‌ای، هماهنگی، تغییرپذیری