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Changes in Countermovement Vertical Jump Force-Time Metrics Across Different Competitive Levels in Women's Volleyball

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ABSTRACT

As one of the most fundamental skills in volleyball, the countermovement vertical jump (CVJ) has been commonly implemented as a non-invasive and time-efficient method for the assessment of lower-body neuromuscular function. The purpose of the present study was to examine differences in CVJ performance between three different competitive levels in female volleyball players (i.e., national team [n=20], professional league [n=16], collegiate [n=16]). While standing on a uni-axial force plate system sampling at 1000 Hz, athletes performed three maximal-effort CVJs with no arm swing (i.e., hands on the hips during the entire movement). Each jump was separated by a 10-15 second rest interval to minimize the possible influence of fatigue. Significantly greater eccentric braking impulse, peak velocity, peak force, mean and peak power, vertical jump height, reactive strength index-modified, countermovement depth, and shorter braking phase, eccentric duration, and contraction times were observed for the national team and professional players when compared to collegiate athletes. Also, national team players demonstrated significantly greater eccentric braking impulse, peak velocity, mean and peak power, reactive strength index-modified, and countermovement depth than professional volleyball players. However, during the concentric phase of the CVJ, the only significant differences observed were between national team players and collegiate athletes, where national team players exhibited significantly greater peak velocity, impulse, and mean and peak power. Thus, it can be concluded that higher-level players may be more capable of effectively utilizing the eccentric phase of the CVJ and executing the stretch-shortening action more rapidly, which contributes to better CVJ height.

Keywords: coaching; monitoring; biomechanics; female; testing; eccentric; concentric; sport

INTRODUCTION

Volleyball is one of the most popular international team sports [1,2]. It is a complex game that combines explosive movements and sudden changes of direction with short periods of rest in which players are required to possess adequate physical (e.g., height, body mass) and physiological characteristics (e.g., speed, agility, strength) [3-10].

One of the most fundamental skills in volleyball is the vertical jump, which is essential for executing both offensive (i.e., attacking, serving) and defensive (i.e., blocking) actions of the game [3,5,7,11]. Previous research has indicated that during a 12-second rally, frontcourt players performed at least four block jumps and three attack jumps, along with a considerable number of lateral movements [7,12]. However, the number of jumps completed by the players varied significantly across different positions. Setters on average exhibited the highest jump loads during both training sessions and games (121 and 136 jumps respectively), followed by middle hitters (92 and 97 jumps respectively), opposite hitters (75 and 88 jumps respectively), and outside hitters (62 and 65 jumps respectively) [13,14]. These findings further emphasize the importance of good jumping skills that volleyball players need to possess in order to achieve the desired game outcome.

Considering the importance of jump performance in volleyball, the countermovement vertical jump (CVJ) has been commonly implemented as a non-invasive and time-efficient method for the evaluation of lower-body neuromuscular function [9,15-19]. The CVJ performance is often assessed via force plates, considered a "gold standard" or criterion measure, and has been widely adopted by strength and conditioning specialists and sports scientists in practical settings [17,18]. This technology allows practitioners to gain a better understanding of the movement strategies and forces generated throughout different phases of CVJ (i.e., eccentric and concentric phases) and assess key outcome metrics such as vertical jump height and reactive strength index-modified (RSI-modified) [20,21]. The obtained results can help coaches identify areas for improvement and establish levels of resiliency to fatigue, as well as allow for the development of effective training regimens to optimize athletes' on-court performance [21].

A couple of previously published scientific reports have focused on examining differences in physical performance capabilities (e.g., CVJ, aerobic and anaerobic capacity) among different competitive levels in team sports such as basketball, handball, and volleyball. For example, Ferioli et al. [22] assessed changes in the physical capacities of basketball athletes playing at three different levels of competition and found that Division-I players had significantly greater absolute peak force during the CVJ than Division-III players (19.5±6.7%). In addition, Moss et al. [23] indicated that top-elite female handball athletes (i.e., European Championship and World Championship holders) outperformed both elite (i.e., players who competed at either the highest or second-highest European League) and non-elite players (i.e., players who did not qualify to compete at the championship) in all performance assessments (i.e., 20 m sprint, CVJ, throwing velocity, repeated shuttle sprint and jump ability, and Yo-Yo intermittent recovery test). Specifically, top-elite players had ~4-5 cm higher CVJ heights and generated more power when compared to the elite and non-elite players [23]. Similar findings were observed among volleyball players. Smith et al. [24] found that male national volleyball players demonstrated 7-9% greater attack and block jump heights when compared to university players, while Fleck et al. [25] revealed that female national team players had ~15% higher jump heights than university players. Moreover, a recently published study conducted on a large cohort of elite collegiate female volleyball players found significant relationships between strength and conditioning measures and game success [26]. For example, setters' game statistics were positively associated with hang clean, T-drill, and broad jump performance, and defensive specialists' stats with squat and total strength measures [26]. However, the aforementioned research reports were solely focused on the assessment of the outcome metrics (i.e., vertical jump height) and did not encompass a comprehensive analysis of CVJ neuromuscular performance that entails a plethora of force-time metrics during both eccentric and concentric phases of the jumping motion, especially within the female athlete population that still remains under-researched in the scientific literature.

Therefore, to bridge a gap in the scientific literature, the present study aimed to examine differences in CVJ force-time metrics during both eccentric and concentric phases of the jumping motion across three different competitive levels in female volleyball players (i.e., national team, professional league, collegiate). It is hypothesized that national players as highly elite athletes would possess superior jumping capabilities and outperform both professional and collegiate players and that professional players will demonstrate better CVJ performances than collegiate players.

METHODS

Participants

The present study involved a diverse cohort of female volleyball athletes, consisting of 20 national team players (x̄±SD; age= 22.9±4.5 years; height= 184.5±8.1 cm; body mass= 72.4±9.2 kg), 16 professional players (age= 21.8±3.1 years; height= 179.8±5.5 cm; body mass= 73.8±5.8 kg) competing in one of the top European leagues (i.e., SuperLeague), and 16 collegiate players (age=

20.4±1.2 years; height= 176.4±7.2 cm; body mass= 72.4±11.6 kg) competing at the National Association of Intercollegiate Athletics (NAIA) Division-I level. All athletes were free of musculoskeletal injuries and were previously cleared by their respective sports medicine staff to participate in team activities. The testing procedures were approved by the University's Institutional Review Board and all athletes signed the informed consent document.

Testing Protocol

Prior to the beginning of the testing protocol, all athletes performed a 15-minute standardized warm-up routine consisting of dynamic stretching exercises (e.g., lateral lunges, high-knees, A-skips, butt kicks) administered by a Certified Strength and Conditioning Specialist. Upon completion of the warm-up, each athlete completed a total of three maximal-effort CVJs with no arm swing (i.e., hand on the hips throughout the entire movement) while standing on a uni-axial force plate system (ForceDecks Max, VALD Performance, Brisbane, Australia) sampling at 1000 Hz. The force plate system was zeroed (i.e., recalibrated) prior to each participant. In addition, a rest interval of 10-15 seconds was incorporated between the consecutive CVJs to minimize the possible influence of fatigue [4,7,27-30]. All athletes were verbally encouraged to give their maximum effort during each CVJ and to focus on pushing against the ground as explosively as possible [31].

Variables

In order to obtain a deeper understanding of the neuromuscular performance changes in volleyball players, both the eccentric and concentric phases of the CVJ were analyzed [4,27,30,32-34]. The beginning of the CVJ was determined as a point where the athlete's system mass was reduced by 20 N, while the take-off was marked when the vertical force decreased below the 20 N threshold [4,27,30, 32-34]. The eccentric phase was defined as the phase containing negative velocity and was further subdivided into the braking phase, starting from the minimum force until the end of the eccentric phase [4,30]. Lastly, the concentric phase was initiated after the eccentric movement and estimated from the time point when the athlete's velocity reached zero until the moment of take-off [30].

Based on previous scientific literature [4,20,21,27-30] the following variables were examined during the eccentric phase: braking phase duration (s), braking impulse (Ns), eccentric duration (s), peak velocity (m/s), mean and peak force (N), and mean and peak power (W). The following variables were examined during the concentric phase of the CVJ: concentric duration (s), impulse (Ns), peak velocity (m/s), mean and peak force (N), and mean and peak power (W). In addition, contraction time (s), vertical jump height (i.e., impulse-momentum relationship) (cm), countermovement depth (cm), and RSI-modified (m/s) were analyzed. A detailed description of the CVJ force-time variables can be found in the previous research reports [4,20,21,27-30].

Statistical Analysis

Descriptive statistics, means (standard deviations) or median (interquartile range), were calculated for each dependent variable examined in the present study. Before data were analyzed, the homogeneity of variance was checked using Levene's test, and Shapiro-Wilk's test was used to examine if the assumption of normality was violated for each dependent variable. For variables that violated the assumption of normality (i.e., braking phase duration, eccentric duration, eccentric mean force, and eccentric mean power) the Kruskal-Wallis test with Dunn correction was selected to examine the differences across three different levels of volleyball competition (i.e., national, professional, and collegiate). For the remaining force-time metrics that did not violate the assumption of normality, the one-way analysis of variance (ANOVA) with Bonferroni adjustments was used. Effect sizes were calculated using the eta-squared (η^2) [35,36]. Based on suggestions provided by Richardson [36], η^2= 0.01 was considered a small effect size, η^2= 0.06 was a medium effect size, and η^2= 0.14 was a large effect size. Lastly, statistical significance was set a priori to p<0.05 and all statistical analyses were performed in the RStudio Software (Version 1.4.1106).

RESULTS

Statistically significant differences across three competitive levels (i.e., national, professional, and collegiate) were found to exist for braking phase duration (H[2]= 11.681, p= 0.003, η^2= 0.157), eccentric braking impulse (F[2,49]= 17.443, p< 0.001, η^2= 0.416), eccentric duration (H[2]= 19.200, p< 0.001, η^2= 0.310), eccentric peak velocity (F[2,49] = 27.840, p< 0.001, η^2= 0.531), eccentric peak force (F[2,49]= 6.559, p= 0.003, η^2= 0.211), eccentric peak power (H[2]= 26.672, p< 0.001, η^2= 0.463), eccentric mean power (F[2,49]= 24.987,

$p< 0.001$, $\eta^2= 0.505$), concentric impulse ($F[2,49]= 5.345$, $p= 0.008$, $\eta^2= 0.179$), concentric peak velocity ($F[2,49]= 8.098$, $p< 0.001$, $\eta^2= 0.248$), concentric peak power ($F[2,49]= 4.720$, $p= 0.013$, $\eta^2= 0.162$), concentric mean power ($F[2,49]= 6.669$, $p= 0.003$, $\eta^2= 0.214$), contraction time ($F[2,49]= 10.040$, $p< 0.001$, $\eta^2= 0.291$), vertical jump height ($F[2,49]= 8.671$, $p< 0.001$, $\eta^2= 0.261$), RSI-modified ($F[2,49]= 23.375$, $p < 0.001$, $\eta^2= 0.487$), and countermovement depth ($F[2,49]= 4.829$, $p= 0.012$, $\eta^2= 0.164$). However, eccentric mean force ($H[2]= 2.318$, $p= 0.314$), concentric duration ($F[2,49]= 1.707$, $p= 0.192$), concentric peak force ($F[2,49]= 2.242$, $p= 0.117$), and concentric mean force ($F[2,49]= 2.588$, $p= 0.085$) did not significantly differ between the aforementioned competitive levels.

Post-hoc analyses showed that national team players had significantly greater eccentric braking impulse ($p< 0.001$), peak velocity ($p< 0.001$), mean and peak power ($p< 0.001$), and peak force ($p= 0.003$) when compared to collegiate players, as well as greater concentric impulse ($p= 0.006$), peak velocity ($p< 0.001$), mean and peak power ($p= 0.002$ and $p= 0.012$), RSI-modified ($p< 0.001$), countermovement depth ($p= 0.031$), and vertical jump height ($p< 0.001$). In addition, they demonstrated significantly lower contraction time ($p< 0.001$), braking phase duration ($p< 0.001$), and eccentric duration ($p< 0.001$) than collegiate players. Similar findings were observed between the national team and professional players. More specifically, national team players had significantly greater eccentric braking impulse ($p= 0.009$), peak velocity ($p= 0.001$), mean and peak power ($p< 0.001$ and $p= 0.023$), RSI-modified ($p= 0.008$), and countermovement depth ($p= 0.036$) than professional athletes. Additionally, professional players demonstrated greater eccentric braking impulse ($p= 0.037$), peak velocity ($p= 0.004$), peak force ($p= 0.024$), mean and peak power ($p= 0.026$ and $p= 0.006$), RSI-modified ($p= 0.003$), and vertical jump height ($p= 0.037$) than collegiate players. However, they had lower contraction times ($p= 0.018$), braking phase duration ($p= 0.017$), and eccentric duration ($p= 0.012$) when compared to college-level volleyball players. See Figures 1-3 for a visual comparison of all variables of interest between the aforementioned levels of competition.

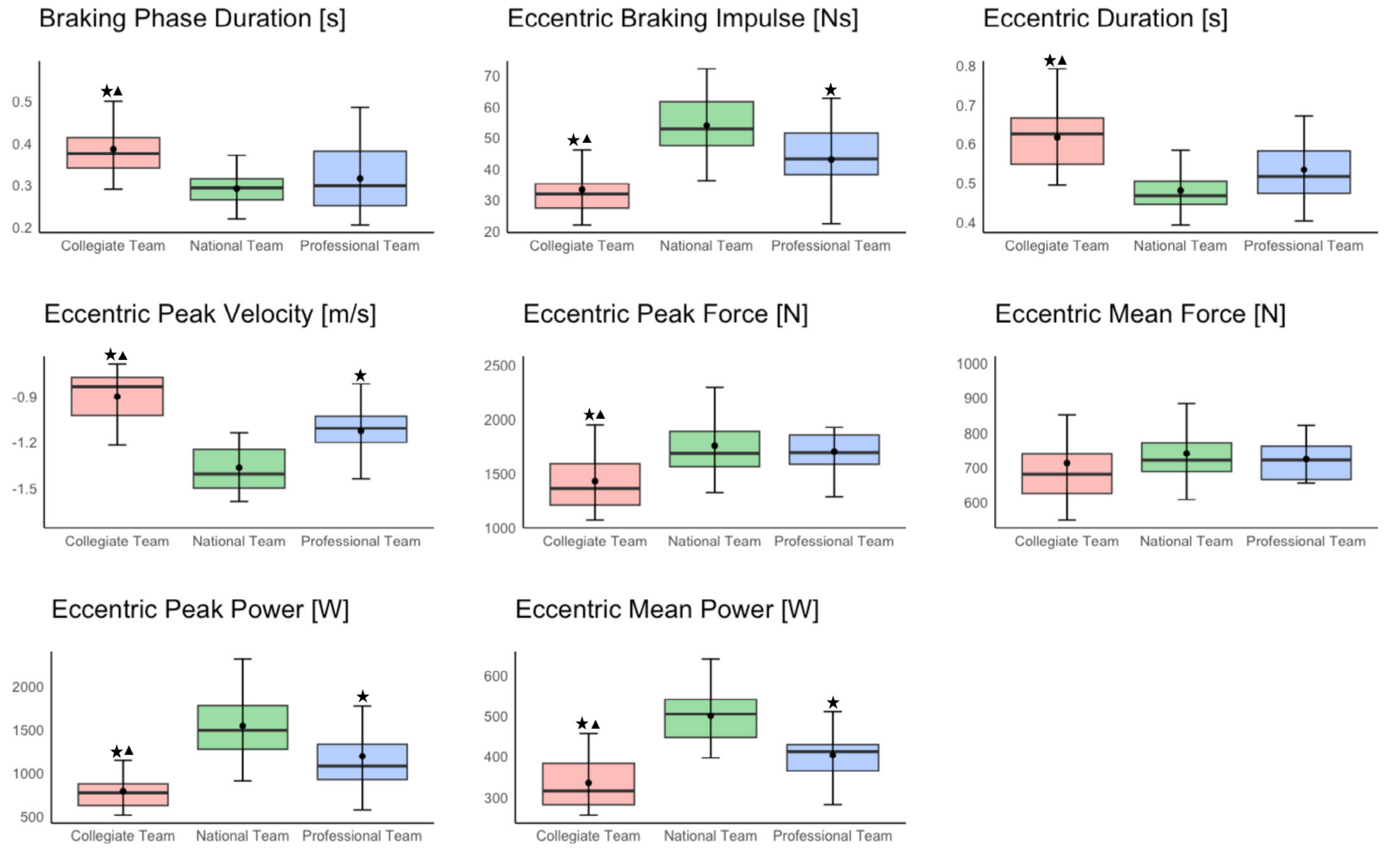

Figure 1. Boxplots comparing the eccentric countermovement vertical jump variables between national team, professional, and collegiate female volleyball players. ★ - significantly different when compared to the national team players; ▲ - significantly different when compared to the professional players.

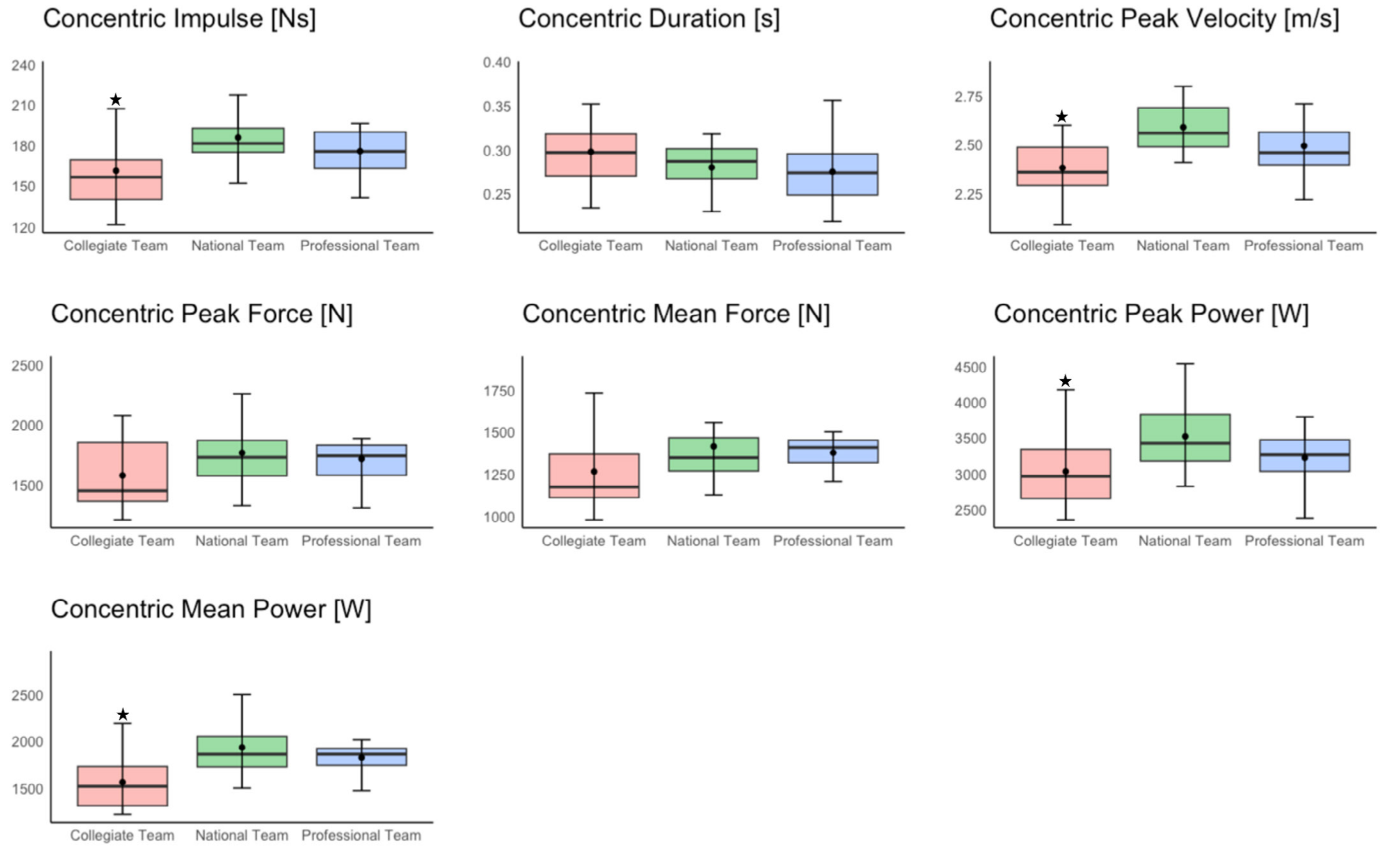

Figure 2. Boxplots comparing the concentric countermovement vertical jump variables between national team, professional, and collegiate female volleyball players. ★ - significantly different when compared to the national team players.

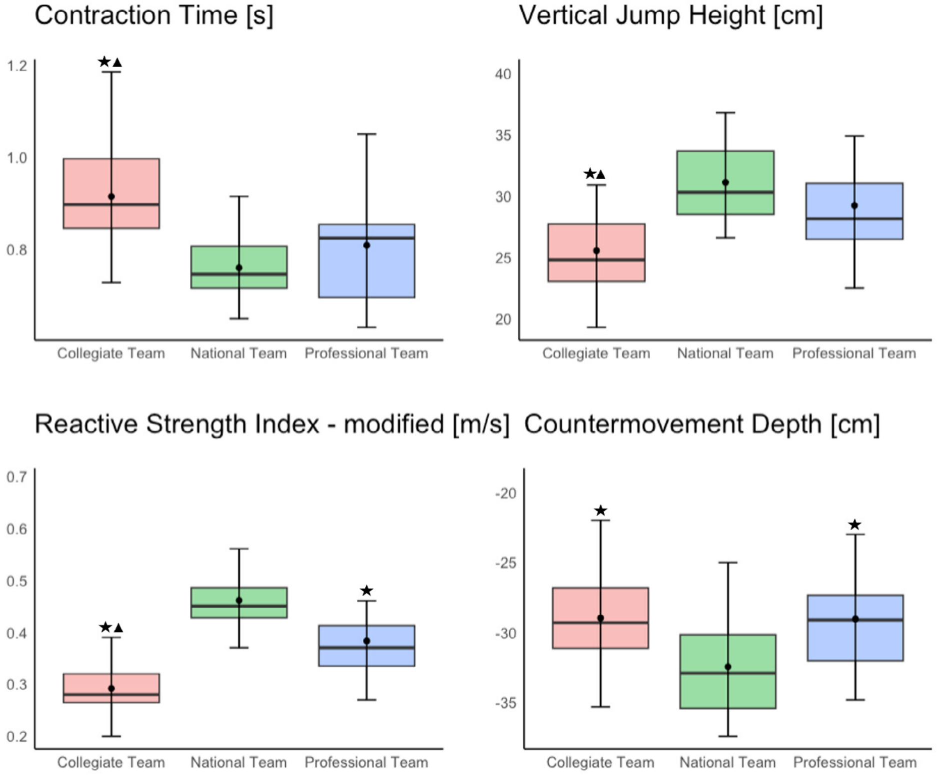

Figure 3. Boxplots comparing the contraction time, vertical jump height, reactive strength index-modified and countermovement depth between national team, professional and collegiate female volleyball players. ▲ - significantly different when compared to the national team players; ★ - significantly different when compared to the professional players.

DISCUSSION

The purpose of the present investigation was to examine differences in CVJ force-time metrics during eccentric and concentric phases of the jumping motion across three competitive levels in female volleyball players (i.e., national team, professional league, collegiate). As hypothesized, national team and professional players had significantly greater eccentric braking impulse, peak velocity, peak force, mean and peak power, vertical jump height, RSI-modified, and countermovement depth when compared to collegiate players, as well as lower braking phase and eccentric duration and contraction time. In addition, national team players demonstrated significantly greater eccentric braking impulse, peak velocity, mean and peak power, RSI-modified, and countermovement depth than professional volleyball players. However, during the concentric phase of the CVJ, no significant differences were observed between professional and collegiate players. In contrast, national team players had considerably greater impulse, peak velocity, and mean and peak power when compared to the players competing at the collegiate level.

Previous research has indicated that athletes who had deeper and faster countermovement and applied greater forces during the eccentric phase of the jumping motion achieved a more effective utilization of the stretch-shortening cycle, which led to improved force-generating capabilities during the concentric phase and ultimately resulted in the better CVJ performance [37]. The aforementioned findings may offer an explanation for why female national team volleyball players in the present investigation, who had greater countermovement depth, higher eccentric peak force, and shorter contraction times, demonstrated better jumping capabilities when compared to the professional and collegiate players. Additionally, our findings reveal that national team players had significantly greater eccentric peak velocity than the other two groups of athletes, which is in direct agreement with results obtained by Floira et al. [37], where a higher-scoring group (i.e., greater vertical jump height) of rugby players had 19.3% greater eccentric peak velocity when compared to the lower-scoring group. Therefore, based on the previously mentioned results we can conclude that athletes playing at higher competitive levels (i.e., national team and professional players) were capable of utilizing the eccentric phase of CVJ more efficiently than college-level players, which resulted in enhanced CVJ performance [38]. Another possible explanation for the observed discrepancies between different levels of competition can be attributed to the fact that national team and professional players have more training experience and access to top-tier strength and conditioning coaching staff as well as performance monitoring equipment (e.g., force plates, motion capture systems) that allows them to maximize their performance to be able to perform at an elite level, unlike collegiate athletes who may have fewer resources and less training experiences.

When examining the outcome metrics, our results revealed that national team players had notably greater vertical jump heights and RSI-modified when compared to both professional and collegiate players. Moreover, professional players outperformed collegiate athletes in the same performance metrics. Similar findings were observed by Forthomme et al. [39] who focused on examining differences in physical features and on-court performances (i.e., spike velocity) between male volleyball players competing at the first and second Belgian national divisions. The authors found that the higher-level players (i.e., first division) had superior vertical jump performance (i.e., flight time and jump height) when compared to the second-division players [39]. Also, Smith et al. [24] implied that Canadian male national team players had significantly higher block (3.27 vs. 3.21 m) and spike (3.43 vs. 3.39 m) jump heights when compared to the university/college team players, which is in agreement with findings obtained by Fleck et al. [25] who found that USA female national team players had 15% greater vertical jump heights than the collegiate athletes. As previously indicated, the key difference between volleyball athletes playing at a higher competitive level (e.g., national team and professional league) and collegiate players is located within the preparatory phase of the CVJ. Highly skilled athletes capitalize during the initial phase of the CVJ (i.e., eccentric phase), executing the stretch-shortening action more rapidly, which results in higher jump heights and greater RSI-modified [38,40]. Therefore, these findings suggest that strength and conditioning professionals and sports scientists should not overlook the eccentric phase of the CVJ as it plays an important role in successful jump execution and can translate directly to the on-court playing performance.

While providing valuable information regarding the differences in CVJ across three different levels of competitive volleyball play within the female athlete population, this study is not without limitations. The present investigation did not account for the weekly training or competitive workload exposure.

Also, nutritional intake, recovery, and sleep were not included in this study. Moreover, although all three groups of athletes examined in the present investigation were similar in age, athletes' maturation status and playing experience are additional factors that need to be considered as they are likely to contribute to a wide range of performance parameters [41]. Thus, future research should include the aforementioned factors which may help strength and conditioning practitioners, sports scientists, and volleyball coaches obtain an even deeper insight into the factors that may affect CVJ performance.

CONCLUSION

In conclusion, the findings of the present investigation suggest that national team players had superior CVJ performance in comparison to both professional and collegiate players. Also, the professional players outperformed collegiate players in eccentric and outcome force-time metrics, while no significant differences were observed between the groups during the concentric phase. Therefore, it can be implied that higher-level players (e.g., national team and professional players) are capable of effectively utilizing the eccentric phase of the CVJ and executing the stretch-shortening action more rapidly, which results in better CVJ performance (i.e., higher jump heights and greater RSI-modified). These findings can help strength and conditioning professionals and sport-specific coaches obtain a deeper insight into the different strategies that volleyball players at different levels use during the jumping motion, which may ultimately aid in developing adequate training regimens targeted toward optimizing on-court performance.

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