Loaded and unloaded jump performance of top-level volleyball players from different age categories

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ABSTRACT: The aim of this study was to investigate the differences in loaded and unloaded jump performances between different age categories of top-level volleyball players from the same club. Forty-three volleyball players were divided into four age groups: under-17, under-19, under-21 and professional. Vertical jumping height for squat jump (SJ), countermovement jump (CMJ) and CMJ with arm swing (CMJa) and mean propulsive velocity (MPV) in the loaded jump squat exercise with 40% of the athlete's body mass were compared among the different age categories, considering body mass as a covariate. SJ and CMJ jump height values were higher for professional and under-21 players than under-17 players ($p<0.05$). CMJa height was higher for under-21 players than under-19 and under-17 players ($p<0.05$). MPV in the loaded jump squat was higher for under-21 players than under-17 players ($p<0.05$). From a general perspective, these results suggest that aging per se is not capable of substantially improving loaded and unloaded vertical jump performances across different age categories of top-level volleyball players. Therefore, to increase the vertical jumping ability of these team sport athletes throughout their long-term development, coaches and strength and conditioning professionals are encouraged to implement consistent neuromuscular training strategies, in accordance with the specific needs and physiological characteristics of each age group.

CITATION: Kitamura K, Pereira LA, Kobal R et al. Loaded and unloaded jump performance of top-level volleyball players from different age categories.Biol Sport. 2017;34(3):273–278.

Received: 2016-11-03; Reviewed: 2016-12-31; Re-submitted: 2017-02-05; Accepted: 2017-03-21; Published: 2017-04-06.

Key words:
Team sports
Muscle power
Jump squat
Plyometrics
Young athletes

INTRODUCTION

The capacity of the neuromuscular system to produce power using the lower limbs is critical for performance in numerous volleyball game actions that involve jumping activities, such as serving, attacking, blocking, and setting [1]. Since physical and technical demands tend to increase during the long-term development of the athlete (related to athletes' specialization) [2], it is also expected that the power-related capacities (e.g., vertical jump ability) will simultaneously increase throughout the maturational and players' preparation processes [3-5].

In fact, a previous study in which volleyball players regularly performed strength training for two consecutive years indicated that the athletes who demonstrated greater improvements in neuromuscular capacities were more prone to successfully transition from junior to senior categories [6]. Another investigation involving senior volleyball athletes engaged in a long-term strength-training programme (a 2-year programme) indicated that increases in lower limb muscle power might be closely related to improvements in vertical jumping height, which is recognized as a determinant factor in elite volleyball performance [7]. Although these studies highlight the importance of developing muscle power in top-level volleyball players, based solely on these data, it is not possible to assert whether these physical changes occur due to the strength-training adaptations or to the aging process.

Another important concern that emerges from these previous investigations is that they were executed using exclusively junior and senior athletes, which may hamper extrapolation of their outcomes to younger populations. For instance, in a study performed with top-level soccer players from different age categories (from under-17 to professional) it was observed that professional players performed better in vertical jumps than their younger counterparts [8]. On the other hand, the performance in squat and countermovement jumps did not differ between under-17 and under-20 players. Additionally, a comparison of the vertical jump ability involving 4 distinct age categories (under-15, under-17, under-19 and professional) and a national team of rugby players revealed that the younger athletes (under-15) presented the worst performance among all the investigated groups [5]. Furthermore, it was observed that the vertical jump height increased progressively throughout the aging process, except during the transition from the under-19 to the professional category. Conversely, the national team players jumped higher than all other players (even professionals), indicating that vertical jumping performance can also be used to differentiate between competitive levels of team athletes.

In addition to the traditional unloaded jumps, training based on the "optimum power loads" (i.e., using loads capable of maximizing the muscle power) has been shown to be very effective in the improvement of neuromuscular performance in volleyball players [9], and has been strongly associated with specific motor tasks in numerous sports disciplines [10-12]. Furthermore, when comparing athletes from distinct age categories, the "jump squat" outputs seem to be a sensible and meaningful indicator of functional performance [4,13]. For instance, it was previously demonstrated that under-20 futsal and under-20 soccer players performed better than their older counterparts in loaded jump squats [4, 13]. In this context, it would also be interesting to investigate whether this "counterintuitive phenomenon" also occurs throughout the development of top-level volleyball players.

Considering that jump ability is crucial for volleyball performance, it is important to investigate whether this capacity varies among volleyball players from different age categories. Additionally, by analysing volleyball players from the same club (who follow a controlled and integrated training programme) it should be possible to examine the influence of age and accumulated training exposure on the neuromuscular changes which occur in these athletes during their development. Therefore, the purpose of this study was to investigate the differences in loaded and unloaded jump performance among four distinct age categories of players (i.e., from under-17 to professional) from the same volleyball club. Due to their higher level of specialization and increased professional training and competitive routine, we hypothesized that the professional volleyball players would present superior performance in loaded and unloaded jump ability.

MATERIALS AND METHODS

Study design

This cross-sectional study was designed to compare loaded and unloaded vertical jump performances of volleyball players from four different age categories from the same professional club. The tests were performed on different days for each category and all athletes were already well familiarized with the test procedures. After a standardized warm-up protocol (including self-selected moderated running for 5 min, active stretching, and sub-maximal vertical jumps), the vertical jumping performance was assessed during squat (SJ), countermovement (CMJ) and CMJ with arm swing (CMJa) and a loaded

TABLE 1. Characteristics of volleyball players (mean ± standard deviation*)* for under-17 (U17), under-19 (U19), under-21 (U21), and professional (PRO) age categories.

	U17 (n=16)	U19 (n=11)	U21 (n=7)	PRO (n=9)
Age (years)	15.2 ± 0.8	17.1 ± 0.5	19.0 ± 0.6	28.1 ± 4.7
Body mass (kg)	79.4 ± 14.8*	80.0 ± 7.7	88.5 ± 13.8	90.2 ± 12.4
Height (cm)	186.4 ± 10.1	191.5 ± 10.4	197.0 ± 7.3	194.9 ± 11.0

*different from PRO, $p<0.05$.

TABLE 2. Typical weekly training schedule of volleyball players, for under-17 (U17), under-19 (U19), under-21 (U21), and professional (PRO) age categories.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
U17	Strength/Power 60'# Tec/Tac 90'	Tec/Tac 120'	Strength/Power 60' Tec/Tac 90'	Tec/Tac 120'	Strength/Power 60' Tec/Tac 90'	Rest
U19	Strength/Power 60' Tec/Tac 120'	Strength/Power 60' Tec/Tac 120'	Tec/Tac 120'	Strength/Power 60' Tec/Tac 120'	Strength/Power 60' Tec/Tac 120'	Rest
U21	Strength/Power 60' *Tec/Tac 120'	Strength/Power 60' Tec/Tac 120'	Tec/Tac 120'	Strength/Power 60' Tec/Tac 120'	Strength/Power 60' Tec/Tac 120'	Tec/Tac 90'
PRO	Strength/Power 60' *Tec/Tac 150'	Strength/Power 60' Tec/Tac 120'	Strength/Power 60' Tec/Tac 150'	Strength/Power 60' Tec/Tac 120'	Strength/Power 60' Tec/Tac 150'	Tec/Tac 120'

Note: Tec/Tac: technical and tactical training; *for U21 and PRO age categories Tec/Tac training sessions were divided into two periods; #time in minutes.

jump squat exercise with 40% of the athlete's body mass (BM). a 30-minute recovery was allowed between unloaded vertical jumps and the loaded jump squat. All age categories were assessed in the same period of the day 24 h apart. All players were starting the transition period (i.e., off-season), so no matches occurred close to the assessments.

Participants

Forty-three volleyball players from the same volleyball club participated in this study. The subjects were divided into four different groups according to their age categories as follows: under-17 (U17), under-19 (U19), under-21 (U21), and professionals (PRO) (Table 1). The U17, U19 and U21 groups competed in the most qualified state championship (regional level) and the PRO participated in the first division of the Brazilian National Championship, achieving second place in the previous season and including one player who was an Olympic champion at Rio 2016, attesting to their higher level of competitiveness. Volleyball players' experience ranged from 4 to 14 years of practice. A typical weekly training schedule involves technical-tactical and strength-power training sessions (Table 2). Technical training comprises sessions aimed at improving the specific technical actions of the game (e.g., serving, passing, and spiking). Tactical training comprises game-based training simulating specific match situations (i.e., from serving to spiking and counterattack situations). For U17 and U19 the strength-power training includes light plyometric exercises (e.g., countermovement jumps) and half squats with light loads (<50% of body mass); for U21 and PRO the strength-power training includes drop jumps and loaded jump squats with light to moderate loads (from 30 to 60% of body mass). All participants and their respective parents or legal guardians (<18 years old) signed an informed consent form prior to participating in the study. This study was approved by the local ethics committee.

Vertical jump tests

The unloaded vertical jump height was assessed using SJ, CMJ, and CMJa. During SJ, subjects started from a semi-squat position and jumped without any preparatory movement, while during CMJ the athletes started from a standing position and executed a downward movement followed by complete extension of the legs, freely determining the amplitude of the countermovement. For the SJ and CMJ the athletes jumped keeping their hands on their hips. The CMJa was executed in the same way as the CMJ, but with an arm swing while jumping. The vertical jump tests were performed on a force platform (AccuPower, AMTI, USA), which sampled at a rate of 400 Hz. Vertical jump height was determined using the velocity of the take-off during a given attempt as follows: jump height = $V^2/2g$, where V is the velocity of the take-off and g is the gravitational acceleration [14]. Five attempts at each jump test were allowed for each participant interspersed by 15-s intervals. The best attempt of each jump was considered for analysis.

Mean propulsive velocity in jump squat exercise

Mean propulsive velocity (MPV) in the loaded jump squat exercise was assessed with 40% of the athlete's BM on Smith machine equipment (Hammer Strength, Rosemont, USA). The athletes executed a knee flexion until the thigh was parallel to the ground and, after a command, jumped as high as possible, without their shoulder losing contact with the bar. To determine MPV, a linear transducer (T-Force, Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) was attached to the Smith machine bar. The bar position data were sampled at 1,000 Hz using a computer and the finite differentiation technique was used to calculate bar velocity and acceleration. We selected the highest velocity obtained in the jump squat attempts using a load corresponding to 40% of BM for analysis. This range of load (i.e., 40% of BM) was used due to its close relationship with specific sports performance and jumping ability [10,15].

Statistical analyses

Normality of data was assessed through visual inspection and the Shapiro-Wilk test. When a non-normal distribution was detected, data were transformed into natural logarithms for the analysis and then back-transformed to facilitate presentation and interpretation. An one-way ANOVA was used to test the differences for the BM among age-group categories. Dependent variables were compared using an ANCOVA, assuming the age categories as fixed factors and BM as a covariate. The significance level was set at $p<0.05$. Whenever significant differences were found, effect sizes (ES) were also reported [16]. Intraclass correlation coefficients (ICCs) were similar across all groups, and were used to indicate the relationship within vertical jumps (i.e., unloaded and loaded conditions) for height and mean propulsive velocity. The ICC was 0.95 for the SJ, 0.94 for the CMJ, and 0.92 for the loaded jump squats. All data were analysed using SPSS software.

RESULTS

The BM was significantly higher in PRO when compared to U17 age category ($p<0.05$) (Table 1). The following comparisons for the BM among the different age categories were not statistically significant. The comparisons of the unloaded vertical jump height among the different age categories are presented in Figure 1. For the unloaded vertical jumping height, SJ height was higher for PRO than U17 (ES: 0.96; $p<0.05$), and the CMJ in PRO and U21 categories was higher when compared to U17 (ES: 0.66 and 0.78, respectively; $p<0.05$). For the CMJa, jumping height was higher for U21 than U19 (ES: 1.34; $p<0.05$) and U17 (ES: 0.81; $p<0.05$). No differences were observed when comparing the PRO group with the younger age categories for the CMJa. Figure 2 depicts the MPV in the loaded jump squat for the different age categories. The MPV was statistically significantly higher for U21 when compared to U17 (ES: 0.92; $p<0.05$). No differences were observed when comparing the PRO group with the younger age categories for the MPV in the jump squat exercise.

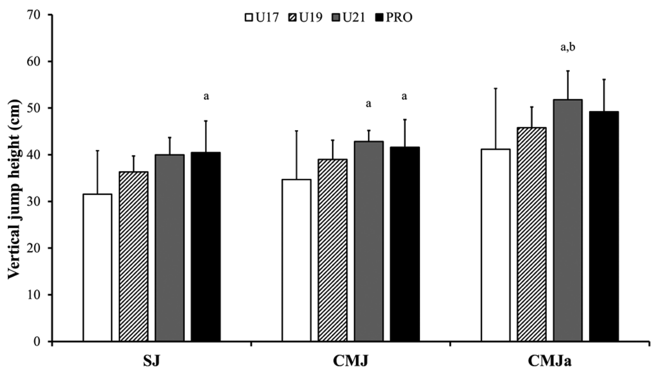

FIG 1. Comparison of vertical jump performance among under-17 (U17), under-19 (U19), under-21 (U21), and professional (PRO) age categories. [a]significantly different from U17 ($p<0.05$); [b]significantly different from U19 ($p<0.05$).

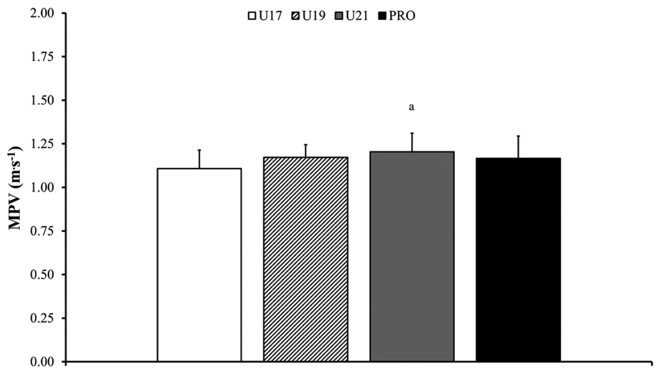

FIG 2. Comparison of mean propulsive velocity (MPV) in the jump squat exercise using 40% of the athlete's body mass among under-17 (U17), under-19 (U19), under-21 (U21) and professional (PRO) age categories. [a]significantly different from U17 ($p<0.05$).

DISCUSSION

The aim of this study was to investigate the differences in loaded and unloaded vertical jump performances between distinct age categories of volleyball players from the same club. The main findings reported herein were that: 1) PRO players were only better than the U17 group in the SJ and CMJ; 2) U21 presented superior performances in comparison to U17 in the CMJ, CMJa and MPV in the jump squat, and jumped higher than U19 in the CMJa. Therefore, our results did not confirm our initial hypothesis that the professional volleyball players would present superior performance in loaded and unloaded jumps. Importantly, in spite of the absence of significant differences between PRO and U21, the U21 players jumped higher than the PRO players in both the CMJ and CMJa (3% and 6%, on average, respectively).

The gradual but non-significant increases observed throughout the age categories revealed that the natural development of volleyball players was not able to significantly enhance their unloaded vertical jump performance. In fact, the SJ height showed a significant difference only between the older (PRO) and younger category (U17). Similarly, Stanganelli et al. [17] have already reported that, after a macrocycle of preparation for the World Volleyball Championship, players in this age range (i.e., U19) achieved significant enhancements only in "specific volleyball jumping ability" (i.e., jumps executed during specific attack or block actions), without exhibiting any significant change in SJ or CMJ performance. These results suggest that these "specialized improvements" might be directly related to the neuromechanical adaptations provoked by sport specific actions that are repetitively performed during training and matches. Finally, since vertical jump performance plays an essential role in elite volleyball, it is rational to assume that athletes able to jump higher may be "naturally selected" over the younger categories, which could limit the progressive development of this ability throughout the age categories [4,5].

Despite the absence of significant differences in CMJ performance between PRO and U21, U21 players jumped 3% higher than PRO players. The superior performance of U21 players in CMJs (in relation to PRO) is also highlighted when analysing the results of the CMJa tests. Curiously, even in these jumping measurements – which better mimic the specific volleyball jumps – PRO players jumped 6.3% less than U21. Accordingly, Nikolaidis et al. [18] have already reported no significant differences between volleyball players from U14, 14-18 and over-18 age groups in CMJ performance. Partially, it can be inferred from previous research that the "lack of improvement" in CMJ from U21 to PRO categories is related to the interference phenomenon which usually occurs between concurrent aerobic and strength training [13,19-21]. Although volleyball is an intermittent sport, optimum aerobic capacity is still important [22-24], as volleyball matches can last up to 90 minutes and players may also require high levels of aerobic fitness to aid recovery after high-intensity bouts of activity. In fact, substantial enhancements in estimated maximal aerobic power with concomitant increases in competitive levels have already been reported in the literature [25,26]. Hence, intensification of training loads during pre-competitive phases in adult volleyball is a common practice, which relies more on volume than intensity of the activities [27].

The velocity that a given subject attains with a load corresponding to 40% of his/her individual BM and the power output produced during a jump squat attempt have been shown to be capable of differentiating between distinct levels of athletic performance [10,15] and age categories [4]. In this regard, Loturco et al. [4] recently reported that U20 soccer players present greater levels of relative muscle power in the jump squat exercise than their older counterparts (i.e., senior athletes). Similarly, our results evidenced no differences in jump squat MPV between PRO and their younger counterparts. Apart from the aforementioned concurrent effects [13,19-21], the lack of significant (and appropriate) improvements in neuromechanical capacities across the long-term development of these athletes may be related to the ineffectiveness of the strength-power training methods used in each distinct age category [22,28]. Of note, the same phenomenon has already been observed in other disciplines [4,5,13], suggesting that the neuromuscular programmes adopted in older categories are partially ineffective to couple with the increased demand of professional team sports. In this context, some studies have reported positive adaptations in jump and power performances of elite volleyball players with the addition of multiple ballistic (i.e., loaded jump squats and overhead medicine ball throw) and plyometric exercises to traditional strength-training routines [9,29]. Furthermore, Sheppard et al. [30] demonstrated that, throughout a 12-month period, the increases in vertical jumping capacity of international volleyball athletes were significantly related to increases in relative power, peak force, and peak velocity in the loaded jump squat and improved depth-jumping ability. Consequently, besides the implementation of plyometric training strategies [31], volleyball coaches should be aware of the importance of using loaded jumps even in young players, always in accordance with the physiological characteristics of each particular age category.

We recognize that a longitudinal investigation tracking the changes of unloaded and loaded vertical jump abilities would be ideal to characterize the development of these sport-specific physical components determining the performance of volleyball players. However, our sample is composed of players from the same club subjected to the same "training philosophy", thus minimizing possible bias related to distinct training routines adopted by each age category. Lastly, another important limitation of the present study is the lack of assessment of individuals' genetic endowment, which is recognized as a determinant factor in the development of physical and physiological capacities throughout the maturation process of top-level athletes.

CONCLUSIONS

The importance of vertical jump performance for match proficiency in volleyball is widely recognized by coaches and sport scientists. Our results suggest that "aging per se" is not capable of substantially improving loaded and unloaded jump performances of top-level volleyball players across different age categories. Therefore, the adoption of more complex, efficient and consistent training strategies intended to improve the lower limb power production is strongly recommended, and could be crucial to properly develop the vertical jumping ability in this group of team sport athletes. It is important to note that the training content (e.g., volume, intensity, frequency and types of exercises) needs to be designed and prescribed in accordance with the developmental stages of the players.

Conflict of interests: the authors declared no conflict of interests regarding the publication of this manuscript.

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