



Article

Isometric Strength in Volleyball Players of Different Age: A Multidimensional Model

Nikola Majstorović ^{1,*}, Milivoj Dopsaj ^{1,2} , Vladimir Grbić ¹, Zoran Savić ³,
Aleksandar Vićentijević ¹, Zdravko Aničić ¹, Marko Zadražnik ⁴, Lazar Toskić ³  and
Goran Nešić ¹

¹ Faculty of Sport and Physical Education, University of Belgrade, 11221 Belgrade, Serbia; milivoj@eunet.rs (M.D.); zver70@gmail.com (V.G.); aleksandarvicentijevic91@gmail.com (A.V.); zdravko.anicic@yahoo.com (Z.A.); goran_nesic@yahoo.com (G.N.)

² Institute of Sport, Tourism and Service, South Ural State University, Chelyabinsk 454080, Russia

³ Faculty of Sport and Physical Education, University of Priština – Kosovska Mitrovica, 38218 Leposavić, Serbia; zoran.savic@pr.ac.rs (Z.S.); lazar.toskic@pr.ac.rs (L.T.)

⁴ Faculty of Sport, University of Ljubljana, 1501 Ljubljana, Slovenia; marko.zadraznik@fsp.uni-lj.si

* Correspondence: nikolamajstorovic@hotmail.com; Tel.: +38-169-270-8920

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Abstract: Physical abilities modelling has a profound connection with long-term athlete development and talent identification. There is not enough data to support evidence about age-related changes in volleyball players' isometric strength. This study aimed to define the age-related model of volleyball players multidimensional muscles' contractile characteristics. The participants were divided according to gender (male $n = 112$, female $n = 371$) and according to age into four groups: under 15 (U15), under 17 (U17), under 19 (U19), and under 21 (U21) years old. Participants performed three isometric strength tests: handgrip, lumbar extensors, and ankle extensors. Maximal force and rate of force development results from all three tests were transformed into a single Score value as a representation of contractile potentials using principal component analysis. The main findings were that Score values of both genders showed significant differences between age groups (male: $F = 53.17$, $p < 0.001$; Female: $F = 41.61$, $p < 0.001$). Trends of those yearly changes were slightly more balanced for female subjects (3.9%) compared to male subjects (6.3%). These findings could help in strength training adjustments when working with volleyball players of a certain age, and enable coaches to detect ones that stand out positively, considering them as strong in regard to their age.

Keywords: isometric strength; abilities; profile; muscle forces prediction; training; rehabilitation

1. Introduction

Physical abilities monitoring has always been an important part in better understanding of each sports' characteristics [1]. Moreover, such results offer a representation of the physical abilities level necessary in each step of athletic development [2]. Physical abilities modelling has a profound connection with long term athlete development and talent identification [3,4], because it can help with the detection of those athletes who are better than the majority of their peers in a particular sport [5]. Moreover, shortcomings in physical abilities, detected early enough, could help in injury prevention. Abilities selected for modelling should be the ones correlated with the actual game performance, and the testing should have high reliability when performed on different types of subjects. With all of the aforementioned conditions met, obtained models can offer improved and more specific selection procedures.

Volleyball is an intermittent sport that requires players to participate in frequent short bouts of high-intensity exercise, followed by periods of low-intensity activity [6,7]. It is considered as a sport dominated by power and strength characteristics, demonstrated through jumps and the ability to spike the ball with great speed. This kind of game structure emphasises muscle development for strong and fast actions and moves away from the endurance training and performance [8]. Present volleyball topics in the scientific literature are mostly focused on jumping and agility as a dominantly manifested part of the game, with few authors investigating the muscle functions that enable the athletes to actually perform jumps, changes of direction, or any other movement. Contractile potentials modelling is somewhat more present in research directed towards other sports [9,10], with strength assessment methods ranging from dynamic [11] and isokinetic [12], to isometric [13]. Isometric strength is believed to have a strong relationship with volleyball-related abilities [14], which is well documented for handgrip strength and its connections with jumping ability ($r = 0.55\text{--}0.65$) [15] and upper body strength ($r = 0.65$) [16], as well as the features of some volleyball techniques, such as spike and serve speed [17]. In contrast to studies focusing on upper body strength, lower body strength of volleyball players is dominantly investigated with the use of a leg press dynamometry [15,18,19] and its correlations with the jumping ability ($r = 0.52\text{--}0.74$). Leg strength is an important part of a volleyball player's ability profile, because it is proven to be a characteristic that can be used as a selection criterion [18]. Age-related isometric strength differences have also been observed [20] by previous researchers who reported no significant difference in knee strength, but a significant difference in elbow flexor strength of 9–18 years old volleyball players. Moreover, a previous study [21] highlighted the importance of isometric strength, especially the rate of force development (RFD) as a dominant factor of volleyball players' explosiveness. With all aforementioned research focusing on volleyball players strength, there is still a considerable gap in the literature regarding the relevance of isometric strength testing in volleyball, and dynamic sports activities [22] in general, but high reliability and number of information about contractile potentials obtained from this type of testing favour it, compared to other strength assessment procedures [23,24].

Given its relationship with different volleyball-specific abilities, as well as game performance, isometric strength has been previously suggested as a selection criterion in volleyball [16,18]. A simple, field-based procedure could provide a useful and effective diagnostical tool for routine monitoring, further improving the selection process. We selected handgrip, lumbar and ankle extensor isometric strength tests, hoping to thoroughly investigate the separate contributions involved in the force production of arms, body and legs. These muscle groups are included in the majority of movements during a volleyball game or training, making them suitable for gathering normative data for selection and talent identification purposes. More muscle groups provide more individual pieces of information, which are consequently summed into a multidimensional integrated score value as a general predictor of body movement and motoric potential in volleyball. Normative data of contractile potentials across the span of volleyball players development would make the selection process, in terms of strength required for certain category of competition, much more comprehensible. Procedures suggested for this type of monitoring should be field-based, so they can be performed outside of the laboratory, making them more efficient for frequent use.

Long-term athlete development modelling usually includes several abilities, or in this context, several muscle groups, so it can offer a more comprehensive and diverse depiction of athlete's capabilities. Previous researchers who investigated volleyball players' isometric strength mainly investigated it in a single muscle group [25], with age [17] and playing position [26] as criteria for comparison. Moreover, there is no evidence in the literature regarding the contractile potentials of volleyball players throughout all youth categories, which would provide useful guidelines regarding general muscle contractile dimensions as a particularly important part in a system of talent identification. Considering the aforementioned lack of evidence in the literature about volleyball players' isometric strength in general, this study aimed to define the age-related model of volleyball players' multidimensional muscle contractile characteristics.

2. Materials and Methods

The participants were divided according to gender (male $n = 112$, female $n = 371$) and according to age into four groups: under 15 years old (U15), under 17 years old (U17), under 19 years old (U19), and under 21 years old (U21). Descriptive statistics of the selected subject samples are shown in Table 1. In order to be part of the study, all subjects had to be national-level competitors with at least three years of five times per week volleyball workout. Subjects had no previous injuries that could influence the results of the study. Upon obtaining consent and written approval from their parents (or them) and their clubs' managements, all subjects voluntarily agreed and signed up to participate in this research. The study was conducted in accordance with the requirements of the Helsinki declaration and recommendations guiding physicians in biomedical research involving human subjects [27]. The research was approved by the Ethics Commission of the Faculty of Sport and Physical Education, University of Belgrade (Number 484-2).

Table 1. Descriptive statistics of subject samples.

| Variable | U15 (Mean \pm SD) | | U17 (Mean \pm SD) | | U19 (Mean \pm SD) | | U21 (Mean \pm SD) | |
|----------|------------------------|-----------------|------------------------|----------------|------------------------|-----------------|------------------------|-----------------|
| | Male | Female | Male | Female | Male | Female | Male | Female |
| Age | 14.2 \pm 0.6 | 14.2 \pm 0.6 | 16.2 \pm 0.4 | 15.9 \pm 0.5 | 17.7 \pm 0.5 | 17.9 \pm 0.6 | 19.8 \pm 0.8 | 19.9 \pm 0.6 |
| BH | 176.6 \pm 7.4 | 173.6 \pm 1.1 | 183.8 \pm 7.9 | 175.8 \pm 7 | 186.2 \pm 6.8 | 177.2 \pm 7.5 | 193.4 \pm 5.7 | 180.5 \pm 6.1 |
| BW | 65.2 \pm 7.5 | 62.7 \pm 9.6 | 72.2 \pm 9.6 | 65.7 \pm 8.1 | 78.7 \pm 10.1 | 68.2 \pm 7.9 | 90.4 \pm 6.9 | 70.9 \pm 8.8 |
| <i>n</i> | 22 | 129 | 43 | 118 | 25 | 63 | 22 | 61 |

Legend: U15—under 15 years; U17—under 17 years; U19—under 19 years; U21—under 21 years. SD—standard deviation; BH—body height; BW—body weight; *n*—number of subjects.

2.1. Testing Procedure

Testing was carried out from May 18, 2019 until May 25, 2019, two weeks after the end of competitive volleyball season in Serbia. Testing was conducted by the authors of the study. Each subject performed a single testing session, with anthropometric measurements taken first, and three isometric strength tests afterwards. Subjects reported no fatiguing activity that could affect the results of the study 24 h prior to the testing session.

Body height was assessed with a standard anthropometer (GPM, Swiss Made) with an accuracy of 0.01 cm and body mass with a digital scale (FitScan UM-028F, Tanita, Tokyo, Japan) measured to the nearest 0.1 kg. Variables obtained from all isometric strength tests were maximal force (F_{\max}) expressed as Newtons (*n*) of force, and maximal rate of force development (RFD_{\max}) results expressed as Newtons per second (*n/s*). In that manner, each subject's force and explosiveness muscle potentials of all three body segments (arms, body and legs) were obtained. All of the measurements were performed by specially designed constructions with a fixed force transducer (Hottinger, Type S9, Darmstadt, Germany; tensile/compressive sensitivity 2 mV/*n*). Specially designed software-hardware system (Isometrics Lite, ver. 3.1.1) was used for data collection and processing. The force–time signal was sampled at 500 Hz and low-pass filtered (10 Hz), using a fourth-order (zero-phase lag) Butterworth filter [28]. Gravity correction was provided with baseline force in rest subtracted from all force recordings during an active phase. The onset of the contraction was defined as the point in time where the first derivative of force–time curve exceeded the baseline by 3% of its maximum value.

Testing sessions began with a 5 min general warm-up composed of 3 min jogging and dynamic stretching of lower and upper body, followed by a specific 3 min specific warm-up prior to each test that consisted of dynamic exercises focusing on the muscle group to be measured afterwards. Testing protocols were explained in detail to the subjects, and they had three submaximal familiarisation attempts prior to each test. Subjects performed three trials, and the best result was taken for further analysis. The order of tests was the same for every subject, with 10 min rest between tests, while the rest time between trials was 2 min.

2.1.1. Isometric Handgrip Strength (HG)

The testing was conducted in accordance with the procedures described by previous authors [29,30], showing its validity and reliability (ICC = 0.91–0.98; cV% = 16.8%–29.8%). Each subject was tested while sitting upright, gripping the measuring device with the hand tested, while the arm was extended in the natural posture alongside the body. The hand gripping the device was approximately 5 to 10 cm away from the body. The examinees were not allowed to move from the initial position during the test trial, nor could they lean the hand or the device against the thigh or any other part of the body. The power grip, for which all the fingers are flexed around the device, was chosen as it could produce a higher level of force than the other grips (the precision grip, the manipulative grip, or various tool and pinch grips). The subjects' handgrip strength was measured unilaterally, to obtain the results for left (HGL) and right (HGR) hand.

2.1.2. Isometric Lumbar Extensors Strength (LB)

The test for isometric hip and back extensor muscles strength was carried out using a standardised procedure (ICC = 0.89–0.99; cV% = 13.8%–17%) and a dynamometric probe with structure specially designed for this purpose [31,32]. Subjects were standing on a platform with feet a hip-width apart, facing a barbell rack. The barbell was firmly attached to a strain gauge force transducer. At its bottom, the probe was connected to the platform. The subjects were grasping the barbell, in position with arms and legs extended at the elbow and knee joints, while the body was in a half-forward bent position, with the chest protruded. After having assumed a proper body position, subjects were instructed to perform a maximum contraction of the lumbar muscles in an attempt to make the extension movement. The examiner instructed them to lift as fast and as hard as possible for at least 2 s.

2.1.3. Isometric Ankle Extensors Strength (AE)

Test was conducted using a standardised procedure, shown to be reliable (ICC = 0.90–0.95) by previous authors [33,34]. After testing procedure explanation, subjects performed two familiarisation attempts separated by 1 min rest and three trials of measuring the maximal ankle extensor muscle force with 2 min rest between trials. In order to evaluate isometric strength of the AE, participants were seated on the chair with knees and ankles bent, so that the thighs were parallel to the ground, and knees were in line with toes, thereby ensuring that the leg position is similar to the squatting and prejumping positions (Figure 1). The subject's thighs were firmly strapped to the chair, preventing them from performing any knee or hip joint movement. Subjects were instructed to sit on the front 2/3 of the chair, with back straight and legs a hip-width apart. The strain gauge position was exactly between the feet for two points of pressure during the isometric force production of ankle joint extensors. The strain gauge was firmly fixed to the plate, which was under the subject's feet, and connected by a thin metal rod to the plate on the subject's upper leg, so that the force of upward plantar flexion push would be directly transferred and recorded by the strain gauge force transducer. The position of the plate on subject's upper leg ensured that there would not be any unpleasant or painful sensations during testing that could affect the results. For the purpose of measurement, the participants were instructed to push as hard and fast as possible against the footplate by plantar flexing their ankle as if they were pushing on a gas pedal.

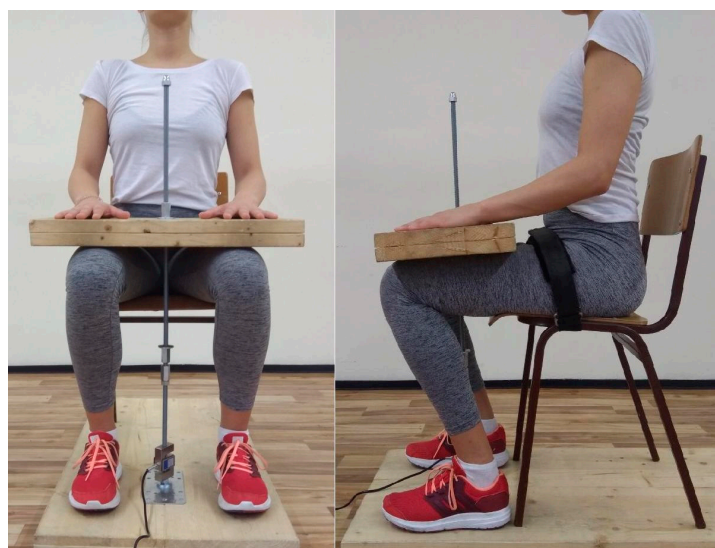


Figure 1. Isometric ankle extensors strength measurement procedure.

2.2. Statistical Analysis

All the raw data were initially analyzed by applying the basic descriptive statistical methods in order to calculate the mean value (Mean), and the standard deviation (SD).

Data were evaluated using Keiser–Meyer–Olkin (KMO) and Bartlett’s test, to confirm sphericity of the data for both male and female subjects’ samples and its adequacy. The principal component analysis (PCA) with explorative model was used to determine the factor underlining contractile potential, as well as each component’s contribution to the factor variability. PCA (Bartlett method) was also used for multidimensional transformation of F_{max} and RFD_{max} values from each subject to calculate a single Score value as a representation of subjects’ contractile potentials [29,35]. Score values, as a measure of dispersion, were calculated from Z values and represented on a 0–100 scale for easier interpretation and understanding.

ANOVA with Bonferroni post hoc analysis was used to compare contractile potentials (Scores) between different subject groups. Linear Regression analysis was used to define the trend of Score changes as a function of age groups and to obtain Best Fit Line equation for multidimensional Score prediction.

All the statistical analyses were calculated using the SPSS 22.0 software, while statistical significance was defined as $p < 0.05$.

3. Results

Tables 2 and 3 show descriptive statistics of all the variables obtained from the performed tests for both male and female age groups, respectively.

Table 2. Descriptive statistics of male subjects’ isometric strength.

| Variable | U15 (Mean ± SD) | U17 (Mean ± SD) | U19 (Mean ± SD) | U21 (Mean ± SD) |
|-----------------------|------------------|------------------|------------------|------------------|
| HGR F_{max} (n) | 321.1 ± 78.1 | 432.4 ± 78.5 | 437.3 ± 83.6 | 572.2 ± 82.7 |
| HGR RFD_{max} (n/s) | 2299.4 ± 538.9 | 3018.0 ± 559.1 | 3196.4 ± 622.3 | 3976.9 ± 423.8 |
| HGL F_{max} (n) | 303.7 ± 78.4 | 402.6 ± 86.7 | 417.4 ± 78.2 | 521.0 ± 82.4 |
| HGL RFD_{max} (n/s) | 2161.3 ± 605.8 | 2798.7 ± 600.5 | 2979.3 ± 562.5 | 3605.2 ± 571.6 |
| LB F_{max} (n) | 814.7 ± 234.9 | 1157.2 ± 199.4 | 1249.1 ± 167.4 | 1568.5 ± 222.9 |
| LB RFD_{max} (n/s) | 5328.5 ± 1958.5 | 8251.7 ± 2407.6 | 9736.2 ± 1920.7 | 12538.3 ± 2784.7 |
| AE F_{max} (n) | 2736.3 ± 788.1 | 3506.8 ± 602.2 | 3540.2 ± 634.8 | 4616.5 ± 354.1 |
| AE RFD_{max} (n/s) | 12650.5 ± 3679.7 | 16458.7 ± 2857.6 | 17409.7 ± 2785.3 | 21384.7 ± 3810.3 |

Legend: HGR— isometric handgrip right; HGL— isometric handgrip left; LB— isometric lumbar extensors; AE— isometric ankle extensors; F_{max} — maximal force; RFD_{max} — maximal rate of force development.

Table 3. Descriptive statistics of female subjects’ isometric strength.

| Variable | U15 (Mean ± SD) | U17 (Mean ± SD) | U19 (Mean ± SD) | U21 (Mean ± SD) |
|------------------------------|------------------|-------------------|------------------|------------------|
| HGR F _{max} (n) | 272.9 ± 50.9 | 290.1 ± 47.6 | 302.0 ± 51.4 | 347.4 ± 55.2 |
| HGR RFD _{max} (n/s) | 1819.1 ± 438.6 | 1946.77 ± 365.3 | 2072.1 ± 385.4 | 2344.8 ± 431.9 |
| HGL F _{max} (n) | 260.4 ± 48.7 | 273.49 ± 46.4 | 288.2 ± 51.1 | 331.3 ± 53.5 |
| HGL RFD _{max} (n/s) | 1700.5 ± 427.9 | 1827.34 ± 389.6 | 1914.2 ± 409.4 | 2241.6 ± 436.6 |
| LB F _{max} (n) | 766.8 ± 133.1 | 845.18 ± 143.3 | 865.4 ± 144.5 | 978.9 ± 167.2 |
| LB RFD _{max} (n/s) | 4713.2 ± 1699.6 | 5836.19 ± 1781.2 | 6054.8 ± 1917.2 | 6769.5 ± 1873.6 |
| AE F _{max} (n) | 2558.1 ± 582.8 | 2825.24 ± 582.1 | 2981.4 ± 547.0 | 3337.9 ± 647.6 |
| AE RFD _{max} (n/s) | 12196.7 ± 3169.6 | 13776.27 ± 2810.4 | 14514.9 ± 2658.2 | 15824.6 ± 3214.1 |

Legend: HGR—isometric handgrip right; HGL—isometric handgrip left; LB—isometric lumbar extensors; AE—isometric ankle extensors; F_{max}—maximal force; RFD_{max}—maximal rate of force development.

PCA results are presented in Table 4. Initial KMO analysis showed sufficient sampling adequacy (0.857 and 0.817 for male and female samples, respectively), indicating that the PCA was justified. Bartlett method indicator was statistically significant (Sig. < 0.001) for both male and female subject samples, confirming the sphericity of data for further analysis. Table 3 shows the component matrix results of both samples with a cumulative percentage of variability explanation. All components have had high participation (0.688–0.940) in the main factor extracted with PCA. Cumulative variance explained by the extracted factors was moderate to high (Table 3).

Table 4. Principal component analysis structure matrix.

| Variable | Male | Female |
|------------------------|---------------|---------------|
| HGR RFD _{max} | 0.940 | 0.869 |
| HGR F _{max} | 0.939 | 0.877 |
| HGL F _{max} | 0.925 | 0.897 |
| HGL RFD _{max} | 0.916 | 0.884 |
| LB F _{max} | 0.913 | 0.818 |
| AE F _{max} | 0.879 | 0.736 |
| LB RFD max | 0.798 | 0.688 |
| AE RFD _{max} | 0.784 | 0.767 |
| Cumulative % | 78.984 | 67.284 |

Table 5 shows descriptive statistics of Score values for every age group, calculated with PCA multidimensional transformation. The table also shows ANOVA F values for both samples with statistical significance of differences (*p* value).

Table 5. Descriptive statistics of all subject groups’ Scores with F values (ANOVA).

| Sample | Male (Mean ± SD) | Female (Mean ± SD) |
|--------------|---------------------------------|---------------------------------|
| U15 | 30.46 ± 12.30 | 41.50 ± 15.09 |
| U17 | 48.10 ± 10.99 | 49.11 ± 13.57 |
| U19 | 51.94 ± 10.17 | 53.37 ± 14.06 |
| U21 | 71.03 ± 11.03 | 66.18 ± 15.11 |
| ANOVA | F = 53.17 (p < 0.001) | F = 41.61 (p < 0.001) |

Figure 2 depicts post hoc differences in Score values between age groups of male and female samples. Regression analysis results are shown with trend lines, which were significant predictors for both male (F = 36.897, R² = 0.947, *p* = 0.026), and female subjects’ (F = 44.297, R² = 0.957, *p* < 0.022) age-related changes of Score values.

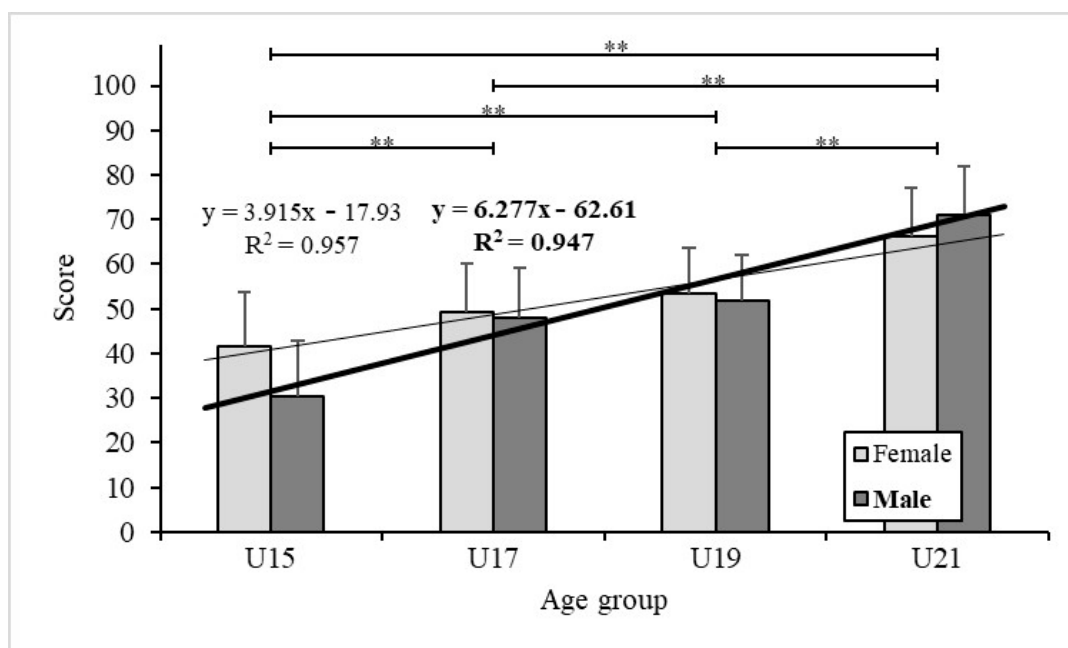


Figure 2. Both genders' Scores as a function of age group. Significant differences (** $p < 0.001$) between age groups were the same for both gender samples, so they are illustrated together.

4. Discussion

This study aimed to define the age-related model of volleyball players muscles' contractile characteristics. The main findings of this research indicate that the youngest (U15) and the oldest (U21) groups differ from each other, as well as from middle two groups significantly ($p < 0.001$), and that there were no significant differences between the two middle groups (U17 and U19).

Volleyball players' isometric handgrip results obtained in this study (Tables 2 and 3) are nearly identical to previous studies observing similar groups of subjects [15,17,36], with authors reporting the F_{\max} results of U17 male subjects in the range of 400–425 N, and female in the range of 277–285 N. Other authors reported slightly stronger isometric handgrip $F_{\max} = 338$ N for U17 female volleyball players [17], and similar F_{\max} results in the range of 407–434 N for under 18 years old male and female subjects grouped together [36]. Particular studies were conducted with somewhat different procedures, including the handgrip force measurements in standing position [15], or the 90° flexed elbow [36], but differences compared to our results were still small to nonexistent. There is not much evidence in the literature regarding ankle extensor isometric strength in bilateral conditions, given that most of the researchers investigated unilateral force [37] and torque [38,39]. Ankle extensor isometric force procedures comparable to this study were performed on recreational subjects with bilateral extended [40] and flexed knees [41], reporting results (male subjects 3910 N \pm 1106 N) similar to our study. Isometric lumbar strength, although present in the literature, have not been observed on volleyball player samples, but usually on recreational physically active adult subjects, or athletes from other sports [42], with similar F_{\max} results to our study. Depicted F_{\max} and RFD_{\max} results (Tables 2 and 3) of three important muscle groups, included in almost all of the activities in a volleyball game, represent normative values of age-related maximal force and maximal explosiveness potentials. Both male and female participants become stronger with age in all muscle groups investigated, with male subjects having slightly better results compared to females. Handgrip results are unilateral, explaining the lesser forces as opposed to the other two tests, where the force was exerted in bilateral conditions. AE F_{\max} and AE RFD_{\max} results are significantly greater compared to LB results, given that this muscle group is mainly responsible for human bipedal stance, and every other type of locomotion in an upright position (walking, running, jumping, etc.).

Strength modelling has been previously suggested by authors for volleyball players of different levels of competition [18,43,44], or positions in a volleyball team [45]. Isometric strength results from many muscle groups have been shown as sensitive for differentiating volleyball players of various age [46], making this procedure a useful tool in the identification of individuals that are ahead of their peers and considered as talents. Moreover, modelling procedures were tested regarding various training interventions [47–49] and provided evidence of sensitivity and great benefits in terms of long-term athlete development monitoring. Knowledge of contractile characteristics through models also provides a useful aid in injury prevention [50,51].

Dimension reduction has been previously suggested [52] as helpful for better understanding of the relationships between different groups of abilities [44], or different muscle groups as in the present study. This procedure makes it possible to unite a greater number of muscle groups and to calculate their F_{\max} and RFD_{\max} results into a single Score using PCA multidimensional transformation. The Score result summarises the effects of all three isometric strength tests on a scale of 0–100, thus describing the upper body, back, and lower body characteristics together, and making it possible to model the whole-body contractile potentials of different age groups. PCA distinguished a single factor underlining both F_{\max} and RFD_{\max} from all of the isometric strength tests, with statistically significant components participations. Previous authors used the PCA for a reduction of the multidimensional structure in handball [53] to obtain three variables describing body massiveness, strength, and the length and height aspect of the body. Those variables proved to be significant predictors of playing position and level of handball players. Furthermore, PCA proved to be a useful method for eliminating the large number of highly interrelated variables to a fewer number of independent factors that would better reflect the characteristics of observed abilities [54]. A previous study suggested PCA in quantitative evaluation of an athlete's jumping performance while combining useful information from some of the most critical mechanical variables that have been proposed as potential predictors in the literature [55]. Dimension reduction has even been used for recognition and decomposition of actions in volleyball, as it can help understand the different, but connected components in abundant data [56].

The calculated Score values in our study, which represent the contractile potentials of every participant relative to the whole sample, are presented as descriptive statistics of age groups (Table 5). Demonstrated mean values for all age groups indicate the appropriate fit for an average volleyball player regarding his strength, both in terms of maximal and explosive muscle contractions.

The results of ANOVA showed statistically significant differences between the youngest and the oldest age groups compared to all other groups. For male subjects, those differences were at the level of 24.8% between U15 group and U17 group, and 26.9% between the U19 group and U21 group, in favour of the older groups. In contrast, the U17 and U19 age groups had only 5.4% difference between them. A slightly more balanced trend, demonstrated by the slope in the best fit line equation ($a = 6.277$ and $a = 3.915$ for male and female subjects, respectively), was observed for female subjects, with 11.5% difference between U15 and U17, and 19.3% between U19 and U21, but still only 6.4% difference between U17 and U19. Moreover, based on a regression model of Score changes as an integral measure of muscle potential development in the function of age groups, the average yearly F_{\max} and RFD_{\max} rise of selected male subjects was 6.3%, while for female subjects the rise was somewhat more moderate at 3.9% (Figure 2). Changes in strength are not uniform throughout development. For boys, the window for increased trainability starts somewhere around the ages of 14–16, and for girls a little bit earlier [3], which could explain the differences observed for the U15 group. Previous studies also showed age-related differences in strength of volleyball players, but mostly while observing a single muscle group [17], or measuring the strength in dynamic conditions [44]. We speculate that characteristics of volleyball training in that younger age could not yet affect innate strength ability, which was different for every participant, thus also explaining the higher variability in the youngest group. Moreover, even though the participants had to have at least three years of training experience to meet the study inclusion condition, usually a big part of that initial period of volleyball development is dedicated to acquiring basic volleyball skills. As opposed to that, in the U17 and U19 groups, volleyball workout,

sport selection, and the window of increased trainability of strength [3] tends to rectify the differences in contractile potentials, as demonstrated by our study. Consequently, in senior squads and with maturation finished for most participants, coaches usually shift the focus from technique to physical abilities, mostly strength, and court training is usually accompanied by fitness workouts with lifting weights. The U21 group showed significantly higher Score values compared to the other three groups ($p < 0.001$), which could be explained by the aforementioned volleyball players training characteristics during that age. Previous authors [48] demonstrated that the changes in volleyball players' strength could increase by 44% with focused training adaptations. Other authors suggested that even during a single annual training macrocycle, a senior volleyball player can experience significant changes ($p < 0.05$) in isometric strength of the lower limbs. Conversely, no significant changes were observed for the upper limbs during the same period [57]. The slightly higher variability observed for the U21 group could be explained by diverse strength training conducted with participants from different clubs, with some being more effective than others. As stated previously, in this stage of development, external factors dominate contractile potential improvement, and thus further differentiate this age group from the others. Slightly different trends of contractile potential change between genders could be explained by the most commonly used volleyball training techniques, where coaches who train girls do not tend to use as much strength and power drills as those who work with boys. We speculate that these training techniques shape the volleyball game itself, in the direction of powerful and fast, attack-oriented male volleyball and slightly less quick, but with longer rallies, defence-oriented female volleyball [58].

All tests suggested by this study are field-based, making the monitoring more efficient and easier to perform during any period of the season, as well as being convenient for rehabilitation, because there is no need to visit a laboratory or any other facilities. The limitations of the present study include unequal subject samples, which was the consequence of more female volleyball players being able to participate in the study. Another limitation could be the absence of an additional day for isometric strength testing familiarisation, where subjects could have performed the procedure a day before the actual testing and learn it even better. The reason for this assumption lies in the fact that the majority of subjects had no experience with isometric strength procedures.

5. Conclusions

The selected tests and procedures offer important information about conjoint F_{\max} and RFD_{\max} results of three important muscle groups in volleyball performance, making it possible to account for weaknesses in one of those, even if the others are well developed. Modelling volleyball players' contractile potentials is important for monitoring the effects of training in long-term athlete development. It can be concluded that, even though strength develops with age, U15 volleyball players are significantly weaker than older groups, and that U21 volleyball players are significantly stronger. In between, U17 and U19 groups have relatively similar contractile potentials. Trends in contractile potential change over time are slightly more balanced for female subjects compared to male subjects, meaning that the F_{\max} and RFD_{\max} do not have as much of dramatic improvement for female subjects as they do for male subjects. This was well illustrated by the average yearly rise of Score values for male subjects at 6.3%, compared to 3.9% for female subjects. These findings could help in strength training adjustments when working with volleyball players of a certain age. Practical application of the present findings is in the normative values of isometric strength potentials offered by these models, which enable practitioners to detect those who stand out compared to their age groups. Coaches might find these normative values useful to detect athletes that stand out as strong in regard to their age, and clinicians could notice the deficient athletes as being at risk of becoming injury prone.

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