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RESEARCH

The Association Between Isokinetic Strength and Strength Asymmetry and Jump Performance in Female Volleyball Players

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Abstract

Purpose Since the use of normalized isokinetic strength was recently proposed to analyze sportive performance, it was aimed to examine relative isokinetic muscle strength as well as absolute strength in jump performance. Secondly, the investigation of the relationship between extremity-based and inter-extremity strength asymmetry and selected jump tasks was aimed.

Methods Thirty female professional volleyball players (23.70 ± 5.27 years) who has at least four training sessions per week participated to study during the pre-season period Peak torque (PT) of knee flexors and extensors at the speed of 60°/s and 180°/s were evaluated using isokinetic dynamometer. Jump height (cm) and relative power (W/kg) of vertical countermovement jump (CMJ) and squat jump (SJ) were tested by optojump photoelectric system.

Results A positive moderate correlation between PT and relative PT(rPT) at both speeds with jump height was detected ($r = 0.365$–0.594). It was found that jump power had a positive moderate to good correlation with PT($r = 0.557$–0.731) and low to moderate correlation with rPT ($r = 0.314$–0.601). No significant correlation was found between hamstring/quadriceps ratio and bilateral muscle asymmetry with jump parameters ($p > 0.05$).

Conclusions Due to the relatively low level of relationship between normalized strength and performance, we suggest carrying out further studies examining the effects of normalized parameters on performance. Considering the findings based on strength asymmetry, the coordinated action of the relevant muscles may come to the forefront during the performance, rather than muscle strength.

Keywords Sports performance · Muscle strength · Lower extremity · Vertical jump

Introduction

In the sport of volleyball, muscle strength and jumping performance appear to be the most essential parameters that provide an advantage during competition besides technical and tactical skills [1]. The performance of professional volleyball players is related to especially their jumping ability during the game [2] and it is clearly detected that better jump performance improves attack efficiency [3]. In the vertical jump performance, appropriate mechanical energy transfers between the lower limb joints could be acquired through coordinated muscle movements and results in skilled movement and higher displacement [4]. Jump height is one of the most frequently used parameters in terms of evaluating jump performance in volleyball players and other athletes [5–9]. Vertical countermovement jump (CMJ) and squat jump (SJ) are frequently used tests to measure jumping performance in volleyball [10]. CMJ is used for measuring lower body reactive strength/power, while SJ is used for assessing lower body concentric strength/power [11].

Muscle strength constitutes an important parameter for power development of jumping, and in parallel the strength training characteristics are recently considered as important factors influencing the match performance in elite volleyball [12]. Especially, the increase in knee flexor and extensor muscular strength has been shown associated with the improvement of jumping performance [13, 14]. In this direction, isokinetic strength testing and training of muscles around the knee joint in team sports such as volleyball is of a decisive importance for training purposes

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and rehabilitation [15].The generated torque capacity of the muscles during specific joint movements is used to assess dynamic muscle function and performance by using isokinetic muscle dynamometers. This method especially allows getting more detailed information to identify the strength imbalances between oppositional muscles or strength asymmetries between the lower extremities which may possibly affect the quality of sports performance [16]. Contradictory results on association of the knee extensor and flexor strength at various levels of speed and jumping performance in different sports have been reported [17–21]. Absolute muscle strength was mostly defined as "directly measured exerted force or torque as a measure of strength" [22]. Athletic or functional movement performance assessed by testing muscle strength could frequently not be interpreted correctly due to the effect of body size [23]. Thus, because of the relation between absolute muscle strength and indices of body dimensions, normalized or, relative in other words, muscle strength has been recently using to assess athlete's strength as a physical ability independent of body dimensions [23]. Peak torque (PT) which is also labelled as isokinetic muscle strength has been widely studied, whereas there are a limited number of studies researching the relative peak torque (rPT) which is a normalized form of the absolute muscle strength with the body mass, in various team sports, such as soccer or handball, except of volleyball [5, 7, 24]. Gonzalez-Rave et al. determined a positive association between jump height and relative muscle strength of muscles controlling knee joint in the handball players [7]. Similar findings were also reported for the soccer players in two different research [24].

In addition to isokinetic strength, the relationship between muscle asymmetry defined as Hamstring/Quadriceps (H/Q) ratio" (by dividing concentric strength of the oppositional muscles around the knee) [16] and bilateral asymmetry (the strength ratio of PT on dominant side to PT on non-dominant side) [4] and jump performance has been recently investigated [2, 9]. Schons et al. reported that the higher H/Q ratio between knee extensors in relation to the flexors was associated with greater mechanical power in CMJ for male volleyball players [2]. Strength balance around the knee rather than isolated strength of a muscle or muscle groups is a parameter to examine the functional ability and joint stability during velocity-dependent sportive movements [25]. In addition, side-to-side strength imbalance has been considered as a possible risk factor for sports injuries [26]. In this perspective, the strength imbalance of opposite knee joint muscles and strength asymmetry between extremities have been analyzed in limited number of studies including especially soccer players [2, 9]. To the best of our knowledge, any research regarding the relationship between extremity-based and inter-extremity strength asymmetry and SJ task used frequently by volleyball players has yet to be reported.

As stated above, since the analysis of relative muscle strength in different jump performances in volleyball players was recently proposed to analyze for sportive performance, and has not been adequately investigated in the literature, the primary aim of the study was to examine the association between absolute and relative muscle strength on jump performance in volleyball players. We secondly hypothesized that extremity-based and inter-extremity kneeflexor and extensor strength imbalances are related to diminished vertical jump performance. Therefore, the research questions of the present study were whether PT and rPT of muscles controlling the knee movements at lower (60°/s) and higher (180°/s) speed levels and extremity-based and inter-extremity strength asymmetry which are currently being investigated in terms of sport-related performance, are associated to vertical jump performance such as tasks of CMJ and SJ.

Materials and methods

Study design

A cross-sectional and correlational design was carried out to analyze the association between knee muscular strength (PT and rPT) and muscular symmetry (extremity-based and inter-extremity) tested by isokinetic dynamometer, and the jump performance assessed by vertical jumping tests in professional female volleyball players.

Participants

Thirty female professional volleyball players competing in the national volleyball league who were in the preseason period participated in the study. The mean and standard deviation of age, body weight and height of the participants were 23.70 ± 5.27 years old, 68.14 ± 6.92 kg, and 178.67 ± 7.16 cm, respectively. Elite female volleyball players who train four or more days a week and play volleyball for a minimum 4 of years were included in the study. Athletes who had to cease training due to any type of lower extremity injury in the last 6 months were excluded from the study.

Procedure

The tests were conducted over 2 consecutive days. The tests were performed at an athletic health and performance center. Demographic features were recorded, and isokinetic muscle strength test was performed on consecutive days.

Isokinetic muscle strength test

The participants were instructed to warm up for approximately 5 min which includes 2 min of jogging and approximately 3 min of dynamic stretching exercises including major lower extremity muscles before the isokinetic muscle strength test. Each exercise was performed for two sets and maintained for 10 s.

A Cybex isokinetic dynamometer (CSMI Humac Norm, Massachusetts, USA) was used to assess isokinetic muscle strength. After the warm-up period, the participants were positioned in a sitting position with the 90° hip flexion and the knee angle was permitted from 90 degree flexion and 0 degree extension on the Cybex's chair [27]. The widest part of the chest and femoral distal $^{1}/_{3}$ area of the participants were strapped with belts to achieve stabilization and avoid any undesirable movements [5]. The alignment between the lateral femoral condyle of the tested limb and the center of the dynamometer was ensured. The limb weight was corrected at 0 degree to eliminate the gravity effect [18].

The isokinetic strength test was performed at two different angular speeds, 60°/s and 180°/s, and concentric muscle strength was measured on both sides [20]. The muscle strength of quadriceps femoris and the hamstrings were defined as the knee extensor strength, and the knee flexor muscle strength, respectively [16]. Furthermore, the peak torque (PT) values were defined as the maximum torque values of both knee flexor and extensor muscle contraction. The participants were asked to rest for 30 s for achieving recovery after the warm-up period and performed three repetitions of submaximal trials for familiarisation before each test. Considering the test procedures of related similar studies, maximum values of 8 repetitions at 60°/s and 12 repetitions at 180°/s with 45-s intervals between each speed of execution were recorded [2, 16, 28]. In addition, participants were encouraged verbally to perform the test with the maximum possible force and speed during the test (Fig. 1).

Relative peak torque (RPT) was calculated by dividing concentric PT of knee flexors or extensors to body mass in order to normalize the muscle strength [9].

After PT of knee extensors and knee flexors muscles were obtained by an isokinetic dynamometer at two angular speeds (60°/s and 180°/s), H/Q (Hamstring/ Quadriceps) ratio and bilateral asymmetry were calculated by the recorded PT values.

H/Q ratio was calculated by dividing concentric PT of knee flexors to concentric PT of knee extensors of the same leg and multiply the ratio with 100, as shown it formally: H/Q ratio" (%) = (PT of Hamstring Muscle/PT of Quadriceps Muscle) × 100 [2].

Bilateral asymmetry was defined the ratio of muscle PT in dominant extremity to muscle PT in non-dominant extremity. The bilateral asymmetry for knee flexors and knee extensors were calculated separately by using that calculation method [2].

Fig. 1 Isokinetic testing procedure

Vertical jump tests

The relative power and height in the CMJ and SJ were calculated by the ground reaction force curves reported by an optojump photoelectric system. (Microgate, Bolzano, Italy) which has almost perfect reliability and has been found good correlation with force platforms for the flight time evaluation [29]**.** The area where the participants perform their usual training was chosen to set up the jumping platform.

The participants were instructed to warm up for approximately 5 min before the testing procedure. The warm-up protocol was exactly the same as we used in isokinetic muscle strength testing. Subsequent to the warm-up period, the participants were placed in the center of optojump bars and asked to perform the test in two different jumping types, CMJ and SJ [6]. After familiarisation trials, each participant performed three attempts in both tests. Thirty seconds intervals were given between each repetition. The optojump bars connected to the computer and data were recorded in a virtual platform with Microgate Software version 3.01. The highest jump height was recorded for both tasks [30].

For CMJ testing, the participant was asked to stand on the platform with hands on the hips. The auditory cue was given, and the participant performed a quick hip and knee flexion (approximately 90 degree) and instantly extended these joints in order to achieve the highest jump possible [31]. For SJ testing, participant was asked to squat with 90 degree knee flexion with hands on the hips [6]. The auditory cue was given and the participant was requested to jump

as much as possible while extending the knee joints fully [5]. The flight time started after the participant jumped and stopped when stepped onto the platform. CMJ and SJ tests are detected as reliable tests to determine vertical jump performance (Intraclass correlation > 0.95, coefficient of variation < 1%) [31].

Statistical analysis

The data of this study were analyzed by using the IBM SPSS Statistics for Windows, Version 21 (IBM Corp., Armonk, NY, USA). Descriptive statistics were reported as mean, standard deviation, minimum and maximum values. The data presented normality according to the Shapiro–Wilk test. The Pearson correlation coefficient was used to determine the relationship between the H/Q ratio, bilateral asymmetry, RPT and CMJ and SJ values. Alpha level was chosen as 0.01 for statistical significance. As the absolute value of the correlation coefficient, $r = 0$ was considered null, between 0 and 0.3 low, 0.3 and 0.6 moderate, 0.6 and 0.9 good, 0.9 and 1 excellent [32].

Results

PT and relative PT values of knee flexor and extensor muscles at the speeds of at 60°/s and 180°/s obtained by isokinetic dynamometry test were shown by separating dominant and non-dominant sides in Table 1.

The H/Q ratio and bilateral muscle asymmetry parameters of extremity-based and between extremities calculated for angular speeds of 60°/s and 180°/s are presented in Table 2.

Table 3 shows the values referring to the correlation analyses between knee muscles' PT and rPT at 60°/s and 180°/s angular speeds and jump height and relative power of CMJ and SJ tasks. It was determined a positive moderate correlation between the knee flexor and extensor muscle's PT and rPT at both speeds of 60°/s and 180 °/s with CMJ and SJ height ($r = 0.365$–0.594). When analyzing the correlation between jump power and muscle strength, it was found that jump power had a positive moderate to good correlation with PT ($r = 0.557$–0.731) and low to moderate correlation with rPT ($r = 0.314$–0.601, Table 3).

No significant correlations were found between H/Q ratio and bilateral asymmetry values with CMJ and SJ height and relative power ($p > 0.05$, Table 4).

Discussion

In the present study, it was investigated whether there is any association between absolute and relative muscle strength controlling knee joint and the vertical jump performance. In addition, it was aimed to analyse the association between extremity-based and inter-extremity muscle strength asymmetry and vertical jump performance in elite female volleyball players. A positive moderate correlation was detected between the knee flexor and extensor muscle's absolute and

Table 1 Peak torque of flexor and extensor muscle' at 60°/s and 180°/s angular speeds

	Dominant Side		Non-dominant Side	
	Mean ± SD	Min–Max	Mean ± SD	Min–Max
Peak torque (N.m)				
Extensor 60°/s	183.90 ± 28.96	120–236	182.13 ± 27.17	123–225
Flexor 60°/s	94.40 ± 17.91	63–133	95.47 ± 16.17	64–129
Extensor 180°/s	133.43 ± 21.50	82–175	130.90 ± 21.40	90–175
Flexor 180°/s	75.86 ± 15.65	43–117	78.43 ± 14.12	54–103
Relative peak torque (N.m/kg)				
Extensor 60°/s	2.71 ± 0.36	2.1–3.5	2.68 ± 0.37	1.9–3.5
Flexor 60°/s	1.39 ± 0.20	1.0–1.8	1.39 ± 0.17	1.0–1.7
Extensor 180°/s	1.95 ± 0.28	1.3–2.5	1.92 ± 0.28	1.5–2.6
Flexor 180°/s	1.10 ± 0.18	0.7–1.5	1.15 ± 0.13	0.9–1.4

Table 2 Extremity-based and inter-extremity strength and jump task parameters

	Mean ± SD	Minimum–Maximum
H/Q ratio (%)		
D 60°/s	51.38 ± 5.67	41.0–61.6
ND 60°/s	52.57 ± 5.72	40.6–67.2
D 180°/s	56.81 ± 6.62	42.2–72.2
ND 180°/s	60.68 ± 7.54	44.4–73.7
Bilateral asymmetry		
Extensor 60°/s	6.45 ± 4.65	0–18.7
Flexor 60°/s	6.50 ± 5.39	0–22.6
Extensor 180°/s	6.31 ± 4.22	0–17.1
Flexor 180°/s	9.08 ± 6.53	0–24.7
Jump height (cm)		
CMJ	27.86 ± 2.97	22.1–34.2
SJ	27.34 ± 2.95	22.4–32.9
Relative power (W/kg)		
CMJ	40.57 ± 2.46	45.5–36.8
SJ	40.14 ± 2.61	44.6–34.3

H Hamstring, *Q* Quadriceps, *D* Dominant, *ND* Nondominant, *CMJ* Countermovement Jump, *SJ* Squat Jump

Table 3 Correlation analyses between peak torque and jump task parameters

	CMJ height (cm)	SJ height (cm)	CMJ power (W/kg)	SJ power (W/kg)
Peak torque (N.m)				
Extensor D 60°/s	0.452*	0.594*	0.623*	0.731*
Extensor ND 60°/s	0.494*	0.586*	0.639*	0.692*
Flexor D 60°/s	0.402	0.529*	0.616*	0.702*
Flexor ND 60°/s	0.434	0.505*	0.667*	0.697*
Extensor D 180°/s	0.429*	0.542*	0.574*	0.653*
Extensor ND 180°/s	0.545*	0.585*	0.671*	0.680*
Flexor D 180°/s	0.374	0.421	0.557*	0.574*
Flexor ND 180°/s	0.365	0.440	0.592*	0.638*
Relative peak torque (N.m/kg)				
Extensor D 60°/s	0.484*	0.552*	0.389	0.445
Extensor ND 60°/s	0.511*	0.492*	0.381	0.347
Flexor D 60°/s	0.427	0.444	0.314	0.321
Flexor ND 60°/s	0.541*	0.516*	0.403	0.369
Extensor D 180°/s	0.497*	0.580*	0.525*	0.577*
Extensor ND 180°/s	0.577*	0.559*	0.601*	0.550
Flexor D 180°/s	0.447	0.387	0.457	0.385
Flexor ND 180°/s	0.412	0.435	0.453	0.456

CMJ Countermovement Jump, *SJ* Squat Jump, *D* Dominant, *ND* Nondominant

**Correlation is significant at the 0.01 level*

Table 4 Correlation analyses between extremity-based and inter-extremity strength and jump task parameters

	CMJ height (cm)	SJ height (cm)	CMJ power (W/kg)	SJ power (W/kg)
H/Q ratio (%)				
D 60°/s	0.071	0.068	0.175	0.151
ND 60°/s	0.017	− 0.005	0.178	0.147
D 180°/s	0.089	0.004	0.209	0.116
ND 180°/s	− 0.204	− 0.148	− 0.058	< .001
Bilateral asymmetry				
Extensor 60°/s	0.112	− 0.038	0.025	− 0.127
Flexor 60°/s	0.173	0.013	0.125	− 0.033
Extensor 180°/s	− 0.246	− 0.253	− 0.244	− 0.209
Flexor 180°/s	0.049	− 0.029	.054	0.001

H Hamstring, *Q* Quadriceps, *D* Dominant, *ND* Nondominant, *CMJ* Countermovement Jump, *SJ* Squat Jump

relative muscle strength at both speeds of 60°/s and 180°/s with CMJ and SJ height. When examining the association between isokinetic muscle strength and jump power, it was found that absolute strength had a positive moderate to good correlation with jump power at both speeds, while relative strength generally had a positive low-to-moderate correlation with jump power. In addition, there was no statistically association between extremity-based and inter-extremity muscle strength balance at the related speeds and vertical jump performance parameters.

The correlation between isokinetic absolute muscle strength and jump height in athletes has been previously researched and a positive relationship has been detected [5, 8]. In recent years, the normalized form of absolute strength has been used in research procedures, because muscle strength is often positively correlated with various body size indices, such as body mass [33]. It has been recommended that muscle strength analyses made in this framework can provide more reliable and detailed information about the association between strength-specific properties and performance [23, 34]. Unlike previous studies, our study, which examined rPT beside PT, showed that both muscle strength parameters in two different speed levels had a similar level of positive association with performance height of volleyball

players. Although some studies shown that relative muscle strength related to jump task performance in basketball, soccer and handball players [7, 24, 35], to our knowledge, this study is the first study researched in volleyball players. Similar to our study, a positive association between CMJ height and relative muscle strength of muscles controlling knee joint in athletes from other sports [7, 24]. Lehance et al. showed similar findings for the SJ task in soccer players [5].

Considering the jump power and isokinetic muscle strength, absolute and relative muscle strength at the speed of 60º/s and 180º/s were found to be correlated with CMJ and SJ relative power by different correlation levels in both sides. Frequently, PT was examined in terms of jump power and conflicting results were reported [2, 7, 21, 27]. In some studies, an association was determined between knee extensors absolute muscle strength and CMJ relative power at the speed of 180^0/s, particularly [2, 21]. Pääsuke et al. reported a higher level of correlation between knee extension absolute strength measured at 60^0/s and 180º/s and jumping performance [27]. Oppositely, Ganzolez et al. did not find any correlation between absolute isokinetic strength at the speed of 60º/s and 180º/s and CMJ power for handball players [7]. In addition to the literature, when comparing the effects of absolute and relative strength on jump performance at fast and slow angular speed, it was remarkable that relative strength has a lower level of correlation with jump power, compared to the correlation level between absolute strength and jump power. This result reminds us that when the effect of body parts is eliminated, the association between strength and jump performance may be relatively less, and muscle coordination may be the priority. While the findings in the case where the body demission effect is removed are thought-provoking in terms of jumping power, there is no such difference in terms of jumping height.

Our second hypothesis was that whether the muscle strength asymmetry around the knee joint and between extremities are related with vertical jump performance or not. In this study, there was no association found between extremity-based (Hamstring / Quadriceps femoris) and two different jump tasks (CMJ and SJ). Similar to our findings, Schons et al. found no significant association between the knee muscles strength imbalance at 60º/s and 180º/s angular speeds and CMJ power of 11 elite male volleyball players [2]. However, it was also reported a moderate correlation between the extremity-based knee muscle strength asymmetry at 300°/s angular speed and the vertical jump performance in the same study [2]. Recently, extremity-based strength asymmetry around knee at 60º/s and 180º/s angular speed were shown positively related to CMJ height and CMJ power in the volleyball and soccer players, opposite to our findings [8, 9]. Although the number of studies is limited, the fact that the available findings were reported differently may be due to the fact that athletes from different sports branches were evaluated. Considering the research specific to volleyball players, since the jumping activity is a fast and frequently used task in volleyball, the strength asymmetry at high speeds would be further investigated to clarify this gap in the literature.

Strength imbalances in the lower extremities can negatively affect the jumping ability and performance of the volleyball players because of the importance of muscle strength for the power generation in the related task [2]. In addition to isokinetic testing of isolated knee muscle groups of each limb, inter-extremity strength asymmetry (Dominant/Non-dominant), a parameter that has been researched in sportive activities recently, was detected not associated with jump performance of volleyball players. Similarly, bilateral asymmetry was evaluated with the same jump tests in physically active individuals and volleyball players and it was concluded that no association between those parameters previously [8, 36]. Cengizel et al. investigated the association between inter-extremity balance asymmetry and isokinetic strength in volleyball players [28]. Although it was hypothesized that the strength asymmetry may have a negative effect on jump performance in the present study, interpreting the findings with a limited number of studies have shown that the coordinated action of the relevant muscles comes to the forefront during the performance [11], rather than the strength differences between the extremities. However, the small number of similar studies makes it difficult to interpret and draw conclusions. We suggest examining and comparing the effects of similar parameters on performance in different sports branches in further studies.

This study has a number of limitations that should be acknowledged. One of the limitations was that the isokinetic muscle strength at higher angular speeds was not investigated in more detail in order to examine the factors affecting the jumping activity that occurs rapidly in volleyball. The second limitation is that due to the limited number of subjects, the evaluated volleyball players could not be analyzed by separating them according to the position they play which may have affected the finding of research. In addition, the period in which players are evaluated may also constitute another limitation since the possibility of impacting performance of the player.

Conclusions

The results of the present study have shown that relative muscle strength besides absolute strength had a similar level of positive association with jumping height of volleyball players. Secondly, relative power of jump performance was associated to absolute (moderate to good) and relative (low to moderate) PT of muscles controlling the knee (for the angular speeds of 60º/s and 180º/s) for female volleyball

players. Due to the relatively low level of association between relative strength and performance, we suggest carrying out further studies examining the effects of normalized parameters on performance in volleyball players. Additionally, it was detected that extremity-based and inter-extremity strength asymmetry for both higher and lower angular speed were not associated with vertical jump height and power of athletes playing volleyball. Although it was hypothesized that extremity-based and inter-extremity strength asymmetry would affect the jump performance, the findings showed that strength differences has not reflected to jump tasks, possibly due to the coordinated action of the relevant muscles during the performance, which may be considered in sports medicine and rehabilitation.

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Author contributions B.A. collected the data prepared for the statistical analysis.B.Ö. analyzed the data.B.A. and B.Ö. prepared tables.B.A., B.A. and B.Ö. wrote the main manuscript textM.G.P. supervised the research team during all steps.All authors edited and reviewed the manuscript.

Data availability Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Human and animal rights Ethical approval was obtained from the Ethical Committee of Marmara University Health Science Faculty (protocol number: 24.09.2020/56).

Informed consent Informed consent was obtained from all individual participants included in the study.

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