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A COMPARISON OF ISOKINETIC KNEE STRENGTH AND POWER OUTPUT RATIOS BETWEEN FEMALE BASKETBALL AND VOLLEYBALL PLAYERS

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ABSTRACT
Purpose. Tests such as the counter movement jump (CMJ) and squat jump (SJ) allow for determining the ratio of maximal power output generated during SJ to CMJ (S/C). The isokinetic peak torque ratio of the hamstrings contracting eccentrically to the quadriceps contracting concentrically (H/Q) is defined as functional H/Q. The purpose of this study was to compare the S/C and functional H/Q between female basketball and volleyball players.
Methods. The total of 14 female basketball players (age, 19.8 ± 1.4 years) and 12 female volleyball players (age, 22.3 ± 4.2 years) participated in the study. A piezoelectric force platform was used for the CMJ and SJ. Moreover, isokinetic tests of the hamstrings and quadriceps muscle torque during eccentric and concentric contraction were performed.
Results. The results of the S/C and functional H/Q at 90 deg $\cdot$ s^{-1}/60 deg $\cdot$ s^{-1} velocities were higher in basketball players (87.3 ± 9.1% and 91.4 ± 9.3%, respectively) than in volleyball players (83.1 ± 9.8% and 83.6 ± 16.5%, respectively). No significant differences in S/C or functional H/Q values between the two groups were found ($p > 0.05$).
Conclusions. Decreasing the S/C may result from an improvement in the power output during CMJ and a better utilization of the stretch-shortening cycle effect. Balancing the functional H/Q through increasing the eccentric hamstrings strength can provide dynamic knee joint stabilization.
Key words: muscle strength, power output, vertical jumps, basketball, volleyball

Introduction

The counter movement jump (CMJ) and squat jump (SJ) are popular vertical jumps [1–3]. During the CMJ, a downward movement from an upright standing position is performed first, and then an immediate take-off is accomplished, thereby muscles are activated in the stretch-shortening cycle (S-SC) [3, 4]. In turn, the SJ is defined as a vertical jump from the squat position without arm swinging and counter movement [2, 3]. The CMJ and SJ performed on a force platform are commonly used to assess the mechanical power output and jump height in athletes. On the other hand, training programmes often incorporate different vertical jumps, also SJs and CMJs.

The magnitude of force and velocity during the take-off in a vertical jump indicates the capabilities of a player to develop power and jumping ability [2, 5, 6]. Increasing the muscle strength and power in specialized training, incorporating e.g. plyometric exercises as well as proper jumping technique, can help to improve the vertical jump height [7–11]. Undoubtedly, these potential force-velocity capabilities play a significant role in basketball and volleyball [12]. Apart from the CMJ, efficient use of elastic energy in the S-SC can also provide greater power output and jump height during basketball and volleyball jumping [1, 7, 13].

The hamstrings to quadriceps torque ratio (H/Q) is an important parameter for both training and rehabilitation [14–20]. In isokinetic tests, the H/Q depends on the velocity and position [21]. The correct H/Q indicates the muscle strength balance between the hamstrings and quadriceps [15, 17, 19, 20, 22]. The H/Q results can be determined by sport-specific demands that are associated with the movement patterns including running or jumping [15, 18, 20, 23]. Furthermore, the imbalance in the H/Q may reflect predisposition to injury within the knee joint [15].

The conventional H/Q represents peak torque of concentric hamstring strength divided by peak torque

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of concentric quadriceps strength [17]. Another proposed muscle strength ratio is functional H/Q, which is calculated by dividing the hamstrings peak torque during eccentric contraction by the quadriceps peak torque during concentric contraction at a specified angular velocity [14, 16, 17, 24]. This dynamic control ratio is considered more useful in determining injury risk than conventional H/Q [16, 25]. Furthermore, the functional H/Q may better reflect the flexors and extensors co-activation pattern and the injury mechanism of the knee ligamentous structures [14, 19].

The eccentric-concentric sequence of muscle actions often occurs during volleyball and basketball jumping. Movement patterns related to jumping, such as a blocks and spikes, are typical of volleyball. In turn, basketball demands other jumping techniques, involving jump shots and rebounds. Moreover, basketball athletes apply pivoting and rapid position changes during running. Therefore, the purpose of this study was to compare the maximal power output ratio and isokinetic peak torque ratio between female basketball and volleyball players.

Material and methods

Participants

The total of 14 female basketball players and 12 female volleyball players participated in the laboratory tests. The age and basic somatic characteristics of the athletes are presented in Table 1. All the athletes provided their written informed consent to participate in the study. The research received ethical approval from the Bioethical Committee of Poznan University of Medical Sciences.

Experimental procedures

The tests were conducted upon completion of the preparatory phases of both teams' training before the league. Prior to the testing, each participant performed a 10-minute run on a treadmill as a warm-up, followed by dynamic exercises for the hamstrings and quadriceps. The measurements were performed in a 4-day period for the basketball players and in a 3-day period for the volleyball players.

SJ and CMJ tests

A piezoelectric force platform Kistler 9261A 1000 Hz (Winterthur, Switzerland) and Multi Vertical Jump 1.0 software were used for the CMJ test and SJ test. After a few trials, each athlete performed three independent successful CMJs and SJs. Half-minute rest periods were assumed between the jumps in both tests. Each participant carried out the CMJs from an upright standing position with their arms swinging and with a self-selected depth. During SJs (i.e., starting position of the squat without any counter movement), the athletes held their hands behind their back, thus avoiding any arm swing. The values of the maximal power output (P_{MAX}) obtained in the best trials were subjected to analysis. The P_{MAX} results were normalized to the athlete's body mass (BM) (P_{MAX}/BM [W · kg^{-1}]). The SJ to CMJ maximal power output ratio (S/C) was calculated.

Isokinetic tests

The isokinetic tests of the hamstrings and quadriceps muscle strength were performed with the use of the Biodex System 3 (Biodex Medical Systems, Inc., Shirley, NY, USA). The following isokinetic knee bilateral measurement protocol was applied:

– concentric contraction (CON) at 240 deg · s^{-1} (7 trial reps) and 60 deg · s^{-1} (3 reps) velocities during extension / eccentric contraction (ECC) at 30 deg · s^{-1} (7 trial reps) and 90 deg · s^{-1} (3 reps) velocities during flexion – CON/ECC, respectively;

– ECC at 30 deg · s^{-1} (7 trial reps) and 90 deg · s^{-1} (3 reps) velocities during extension / CON at 240 deg · s^{-1} (7 trial reps) and 60 deg · s^{-1} (3 reps) velocities during flexion – ECC/CON, respectively.

The peak torque (PT) results during ECC at 90 deg · s^{-1} and CON at 60 deg · s^{-1} were retained for analysis. The PT values were normalized to the female athlete's BM and 100% (PT_{ECC}/BM and PT_{CON}/BM [Nm · kg^{-1} · 100%]). The isokinetic peak torque ratio of the hamstrings contracting eccentrically to the quadriceps contracting concentrically (functional H/Q) was evaluated.

During the test, the participant sat on an optimally positioned Biodex chair with stabilization straps at the trunk, hips, and thigh, while holding their arms across their chest. The knee joint rotation axis coincided with the rotation axis of the dynamometer. The gravitational torque of the lower leg for incomplete knee extension was measured to correct the source data of strength. The females performed maximal knee extension and flexion of their left and right lower extremities, respectively, in the angular range of motion from 90 deg (flexion) to 0 deg (extension). Between the series, a rest break of 60 seconds was established. Dynamometer calibra-

Table 1. Characteristics of the female athletes (mean ± *SD*)

Subjects	Age (years)	Height (m)	Body mass (kg)	BMI (kg · m^{-2})
Basketball (*n* = 14)	19.8 ± 1.4	1.78 ± 0.08	67.6 ± 9.3	21.8 ± 2.1
Volleyball (*n* = 12)	22.3 ± 4.2	1.83 ± 0.09	74.4 ± 10.9	22.1 ± 1.8

SD – standard deviation, BMI – body mass index tion was performed before each session and in accordance with the manufacturer's instructions. The isokinetic tests were carried out after the CMJs and SJs.

Statistical analysis

Statistical analysis was performed with the Statistica 12.0 software (StatSoft, Inc., Tulsa, USA). The descriptive statistics of the data are presented as mean ± *SD*. Normal distribution of the data was confirmed by the Shapiro-Wilk test. The Mann-Whitney U test was used to compare the variables between the two groups. The level of statistical significance was set at $p < 0.05$.

Results

In female volleyball players, we found not significantly lower P_{MAX}/BM and PT_{ECC}/BM values, and higher PT_{CON}/BM values than in female basketball players (Mann-Whitney U test, $p > 0.05$) (Table 2).

The mean results of the S/C and functional H/Q equalled 87.3 ± 9.1% and 91.4 ± 9.3% in basketball players, and 83.1 ± 9.8% and 83.6 ± 16.5% in volleyball players, respectively (Figures 1 and 2).

The female athletes generated greater maximal power in CMJ compared with SJ: by about 12.7% for basketball players and by about 16.9% for volleyball players. In the case of functional H/Q at 60 deg · s^{-1}, the quadriceps concentric strength was higher than hamstrings eccentric strength by about 8.6% in basketball athletes and by about 16.4% in volleyball athletes. No significant differences in S/C and functional H/Q values between the two groups were found (Mann-Whitney U test, $p > 0.05$).

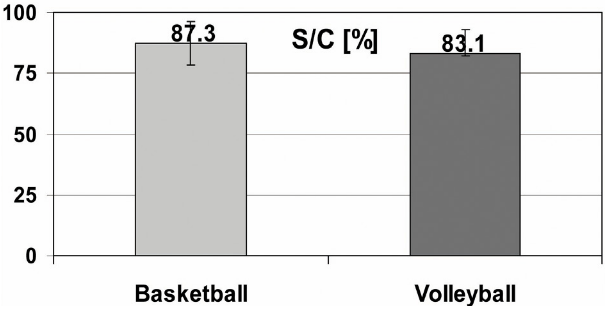

Figure 1. The results of the squat jump (SJ) to counter movement jump (CMJ) maximal power output ratio (S/C) in the female athletes

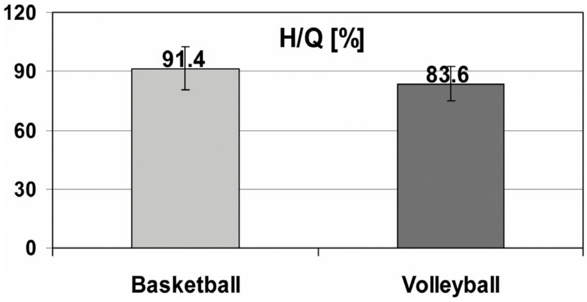

Figure 2. The results of the isokinetic peak torque ratio of the hamstrings contracting eccentrically to the quadriceps contracting concentrically (functional H/Q) in the female athletes

Discussion

In this study, power output in female athletes was evaluated with the SJ and CMJ tests on a force platform. The findings demonstrated no significant differences in S/C values between the basketball and volleyball players, which is partly related to the repetitive S-SC during jumps performed in both sports. However, lower values of this ratio were observed in volleyball players. Smaller S/C indicates better S-SC effect utilization. Furthermore, decreased S/C can result from greater quadriceps concentric strength in volleyball athletes.

A skilled use of the S-SC effect during jumps allows for an increase in the rate of force development, power, and the jumping ability as compared with exclusively concentric contractions of the muscles, without prestretch. In basketball and volleyball jumps, the S-SC applied in the run-up phase can improve the take-off dynamics of a player. An increase in mechanical power output during the take-off phase and the jumping ability of volleyball players result in the successful performance during an offensive action (by gaining sufficient height to hit over the block of the opponent) and during a defensive action (by obtaining a higher blocking position). In basketball, in turn, a significant improve-

Table 2. The values of P_{MAX}/BM, PT_{CON}/BM, and PT_{ECC}/BM (mean ± *SD*)

Subjects	P_{MAX}/BM (W · kg^{-1})		PT_{CON}/BM (Nm · kg^{-1} · 100%)		PT_{ECC}/BM (Nm · kg^{-1} · 100%)	
	SJ	CMJ	left	right	left	right
Basketball (*n* = 14)	24.6 ± 4.9	28.3 ± 5.0	160.0 ± 34.8	159.5 ± 33.4	146.2 ± 28.0	142.7 ± 28.5
Volleyball (*n* = 12)	23.2 ± 4.9	28.0 ± 5.3	165.1 ± 31.2	163.4 ± 29.3	140.9 ± 29.3	134.1 ± 30.5

BM – body mass, *SD* – standard deviation, SJ – squat jump, CMJ – counter movement jump, P_{MAX} – maximal power output, PT_{CON} – hamstrings and quadriceps peak torque during concentric contraction, PT_{ECC} – hamstrings and quadriceps peak torque during eccentric contraction, no significant differences in the P_{MAX}/BM, PT_{CON}/BM and PT_{ECC}/BM values between the two groups (Mann-Whitney U test, $p > 0.05$)

ment in the power and jump height may increase the effectiveness of jump shots, blocks, and rebounds.

The force-velocity capabilities of a player are often enhanced through sport-specific training (e.g., plyometrics). Popular plyometric exercises may increase the rate of force development, power, as well as the jumping ability of an athlete [7, 10, 11]. For example, Sheppard et al. [26] reported that the accentuated eccentric load condition in a vertical jump promoted significant gains in lower-body power, peak velocity, and jump height. Additionally, Hewett et al. [12] suggested that the use of dynamic stabilization exercises in plyometric training could contribute to a reduction in high external loads during landing from a jump when the quadriceps was eccentrically contracting to resist flexion.

The evaluation of the isokinetic strength of the hamstrings contracting eccentrically to the quadriceps contracting concentrically may provide the agonist-antagonist strength relationship for the knee joint. This study demonstrated comparable functional H/Q values between the female basketball and volleyball players, partly related to the eccentric-concentric sequence of muscle actions in jumps. Although the differences in H/Q values were not significant between the groups, higher H/Q results were observed in basketball athletes, which indicates greater eccentric strength of the hamstrings relative to the concentric strength of the quadriceps, as compared with volleyball players. During jumping, as well as running, eccentric hamstring action occurs simultaneously with concentric quadriceps action, and strong hamstrings (increased functional H/Q) are essential to fully brake the action of the concentrically contracting quadriceps.

In both groups, the functional H/Q did not exceed 100% and the deficit of this indicator was equal to approximately 9% for basketball players and 14% for volleyball players. However, these studies evaluated the functional H/Q for higher velocity (90 deg $\cdot$ s^{-1}) during eccentric contraction (more torque) and lower velocity (60 deg $\cdot$ s^{-1}) during concentric contraction (more torque). Previous investigations determined the eccentric peak torque for hamstrings to concentric quadriceps during fast knee extension. Aagaard et al. [14, 21] reported that functional H/Q increased above 100% with rising velocity and more extended knee joint positions. Similarly, Gerodimos et al. [27] demonstrated that this functional ratio increased with the growth of angular velocity. Furthermore, Schiltz et al. [28] revealed the results of functional H/Q at 30 deg $\cdot$ s^{-1}/240 deg $\cdot$ s^{-1} velocities to be approximately 131% (dominant limb) and approximately 126% (non-dominant limb) in professional players. Thus, the functional H/Q > 100% during fast knee extension indicated the ability of eccentrically acting hamstrings to produce a braking joint flexor moment greater than the joint extensor moment exerted by the quadriceps [14, 16, 21].

The functional H/Q ratio may dictate dynamic joint stabilization [25], which potentially protects the knee during sports-related tasks. For example, Aagaard et al. [14, 21] demonstrated the potential 1:1 hamstring to quadriceps strength relationship for fast knee extension, reflecting a significant functional capacity of the hamstring muscles for providing muscular stability at the knee joint. In contrast, too low values of the functional H/Q indicate an imbalance in muscle strength between the agonist and the antagonist, and may contribute to a greater risk of anterior cruciate ligament (ACL) injury. A predisposition to ACL injury may also result from decreased antagonist hamstring co-activation during extension loads, as well as knee ligamentous structures bearing most of the imposed load [15, 29, 30]. In particular, non-contact situations may potentially occur near the foot strike when the quadriceps are eccentrically contracting to resist flexion [31, 32]. Therefore, some authors have indicated the physical training of eccentric strength as an effective strategy for preventing injuries related to landing from a jump [12, 33, 34]. Furthermore, Corrigan et al. [35] reported that posterior stabilization of the knee joint through hamstrings strengthening potentially caused a reduction in anterolateral translation and decreased the incidence of ACL injury. Strong hamstrings may protect ACL from excessive strain in athletes [12, 32, 33].

Conclusions

The presented findings revealed no significant differences in S/C or functional H/Q values between the female basketball and volleyball athletes. However, lower S/C values were found in volleyball players, which could be caused by greater concentric quadriceps strength and a better utilization of the S-SC effect as compared with the basketball players. Furthermore, a decrease in the S/C is also associated with an improvement in the power output during CMJ. The study showed functional H/Q < 100%, indicating a decreased eccentric hamstrings strength relative to the concentric quadriceps strength. Therefore, strengthening the hamstrings in specific training, incorporating eccentric exercises, can effectively prevent ACL injuries, often related to an excessive ACL strain during landing and pivoting. Balance in the functional H/Q should provide dynamic knee joint stabilization.

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