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Handball research: State of the art

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Muscle Strength Variations of Knee Joint Muscles in Elite Female Handball Players after Pre-Season Conditioning

by
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Monitoring seasonal variations in strength performance and the relative risk of injury indicators related to strength of hamstring (H) and quadriceps (Q) in female elite athletes is beneficial for the training process. The aim of this study was to examine and compare the level of muscle strength, the conventional ratio (HCONC/QCONC) as well as two functional and strength ratios reflecting the movement of knee extension (HECC/QCONC) and flexion (HCONC/QECC), and the bilateral percentage strength deficit (BSD) in elite female handball players. The concentric and eccentric isokinetic peak torque was measured at an angular velocity of 60°/s on three occasions (in-season cessation, 4 weeks of rest followed by 4 weeks of individual conditioning and 6 weeks of group conditioning) in eleven female handball players (age: 23.1 ± 3.5 years, body height: 1.73 ± 0.6 m). According to ANOVA results, the BSD of H muscles in the concentric mode decreased between the in-season cessation and the end of the pre-season, and HCONC/QCONC increased at the beginning of the pre-season and at the end of the pre-season in comparison with in-season cessation measurement. The effect size analyses showed that the off-season rest followed by 10 weeks of the conditioning programme increased Q and H strength in comparison with the previous season with a large effect. Coaches should include progressive conditioning in the pre-season phase to decrease the bilateral strength deficit and to support further conditioning development.

Key words: *H/Q ratios, bilateral strength deficit, torque, annual training cycle.*

Introduction

Team handball belongs to high-speed sports in which muscle strength is an important variable of handball-specific physical fitness (McHugh, 2004). Strength of the lower extremities is an important predisposition for individual and team execution of various handball skills and actions during a game (McHugh, 2004). Moreover, strength of the knee flexors and extensors and their ratios have also been considered important in prevention of stress factors and risk of injury of the knee and hamstrings (Hughes and Watkins, 2006). The highest incidence of non-contact hamstring and anterior cruciate ligament (ACL) injuries was observed at the age between 15 and 25 years (Bahr and Krosshaug, 2005). A higher prevalence (by 5 %) of ACL injuries was found in females than in males (Myklebust et al., 2003). Despite the low predictability of ACL injury by muscle strength itself (Steffen et al., 2016), muscle strength changes during the season play an important role in the ACL injury factorial model (Bahr and Krosshaug, 2005; De Ste Croix, 2012; Hughes and Watkins, 2006). Insufficient muscle strength of the hamstring (H) and quadriceps (Q) muscles (Jönhagen et al., 1994), bilateral strength deficits, insufficient ipsilateral concentric H to Q ratio (HCONC/QCONC) and eccentric H to concentric Q ratio (HECC/QCONC) during the knee extension movement (Dauty et al., 2003) have been reported as relative H and ACL injury related factors. However, ACL injuries mostly occur in two particular types of movement: single-leg landing, especially after a jump shot and a

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rapid change of direction initiated on one leg (De Ste Croix, 2012). In these situations, Q muscles actually work eccentrically and H muscles must stabilize the knee joint dynamically during the knee flexion movement (HCONC/QECC). For this reason it was proposed to introduce another functional concentric H to eccentric Q ratio (HCONC/QECC) to evaluate knee joint function (Aagaard et al., 1998). Nevertheless, use of the HCONC/QECC in elite athletes has been rare so far.

It has been reported that muscle strength and power of the lower extremities alter during the annual training cycle in team sports with regard to a particular training phase and intended neuromuscular adaptations (Lehnert et al., 2014b). The training programmes throughout the annual training cycle may result in muscle imbalances caused by inappropriate adaptation leading to a higher risk of injury of the knee joint (Mujika and Padilla, 2000; Ratamess, 2008). Therefore, decrease in training volume followed by progressive conditioning might be beneficial for eliciting the desired muscle strength development (Siff, 2003).

Taking into account the above mentioned knowledge, monitoring muscle strength of the lower extremities seems to be beneficial especially for training adjustments with respect to recognized muscle deficiencies (McHugh, 2004) and risk of injury (Dauty et al., 2003). However, there are only few studies focusing on changes of muscle strength in male players throughout the different phases of the annual training cycle in team sports (Lehnert et al., 2014a, b). Yet there is a great number of studies focused on the evaluation of isokinetic strength of the lower extremities in female team sports, such as soccer (Brophy et al., 2010), basketball (Cook et al., 2004) and team-handball (Andrade et al., 2012; Lund-Hanssen et al., 1996; Xaverova et al., 2015). The mentioned studies, however, were of a cross sectional design regardless of the different phases of the annual training cycle, mostly without taking into account the importance of eccentric strength and ipsilateral ratios. To our knowledge, there is a lack of studies determining the effects of off-season and pre-season conditioning on the fitness level in handball players.

Only a limited number of studies focused on thigh muscle strength in female handball players and the effect of off-season and pre-season training exists. Based on muscle strength measurements, peak torque during maximal isokinetic contraction has been considered a representative indicator of muscle strength of the hamstring and quadriceps muscles (Kannus, 1994). Therefore, the aim of the present study was to examine and compare the level of muscle strength, the conventional and two functional H/Q strength ratios, and the bilateral percentage strength deficit (BSD) in elite female handball players during and after off-season and pre-season conditioning.

Methods

Participants

The study group consisted of 11 elite female handball players (age: 23.1 ± 3.5 years, body height: 1.73 ± 0.06 m, body mass measurement 1: 76.1 ± 13.2 kg, body mass measurement 2: 75.4 ± 13.5 kg, body mass measurement 3: 76.2 ± 11.7 kg, training experience: 14.3 ± 4.6 years) competing in the International Czech-Slovak Inter League. All participants had previous experience with isokinetic testing. The exclusion criteria were self-reported health problems concerning pain during the testing procedure and previous knee injury. The players stated their preferred leg for kicking a ball as their dominant leg (DL), and at the same time stated their contralateral leg that was the take-off leg for a jump shot as non-dominant (NL). The day before testing, the participants were not exposed to intensive training. The participants provided written informed consent. The study was approved by the ethics committee of the Faculty of Physical Culture, Palacky University in Olomouc in accordance with the ethical standards of the Declaration of Helsinki (1983).

Procedures

Three repeated measurements of isokinetic strength were performed at the following seasonal periods: the first measurement was completed one week after the in-season cessation, the second measurement after the off-season comprising 4 weeks of rest with subsequent 4 weeks of individual conditioning, and the third measurement after another 6 weeks of conditioning at the end of the pre-season (Figure 1).

Bilateral isokinetic strength of knee

flexors and extensors was assessed using the IsoMed 2000 isokinetic dynamometer (D. & R. Ferstl GmbH, Hemau, Germany) in a seated position as described earlier by Xaverova et al. (2015). The reliability of measurement had been confirmed by Dirnberger et al. (2012). A non-specific warm-up was performed on a stationary Kettler ergometer (Heinz Kettler GmbH and Co. KG, Ense-Parsit, Germany) for 6 minutes at a submaximal intensity of 1.5 W/kgBW and a pedal rate of 70–80 rpm, and was followed by 10 minutes of dynamic stretching that targeted the main muscle groups involved in testing, and 8 full squats. The warm-up routine was completed under the researcher's supervision.

Testing of the knee extensors and flexors was carried out at an angular velocity of 60°/s in the mode of concentric/concentric and eccentric/eccentric reciprocal actions. Between the modes there was a rest period of 2 min, and the rest time between the measurements of the lower limbs was 3 minutes. The starting leg was specified randomly to minimize the effects of learning bias. Prior to each test, the participants performed 4–5 submaximal practice trials as a specific warm-up to become familiar with the test. Thereafter, the participants were instructed to extend/flex the knee as hard and fast as possible throughout the entire range of motion in each of the subsequent testing repetitions. The actual testing in each mode consisted of a set of 4 reciprocal repetitions. The players were notified by a verbal countdown as well as provided with verbal encouragement and visual online feedback to ensure maximum effort. The monitored variable included the normalized peak torque (PT) per body weight. The highest PT was used to determine the conventional ratio H_{CONC}/Q_{CONC}, as well as the functional ratios H_{ECC}/Q_{CONC} and H_{CONC}/Q_{ECC}. Moreover, BSD was determined using the formula (stronger leg – weaker leg)/stronger leg *100, which had been previously reported (Newton et al., 2006).

Training program

The players had a 4-week rest after the in-season cessation; this period was dedicated to mental and physical rest, with non-specific physical activity of moderate intensity. Thereafter, the training program consisted of individual and group conditioning in the pre-season phase as presented in Table 1. Players completed an individual training program for 4 weeks followed by final 6 weeks of group pre-season conditioning. Group training included one or two training sessions daily. The training program was recorded by the head coach.

Statistical Analysis

The resulting variables did not show a normal distribution according to the Shapiro-Wilk test; therefore, non-parametric tests were implemented for further analysis. The Friedman's analysis of variance (ANOVA) and Kendall's coefficient of concordance were computed for the assessment of the main effect. A post-hoc analysis was performed by means of the Wilcoxon signed-rank test, and effect size was estimated using the Wilcoxon's Z score by $r = Z/\sqrt{N}$, where N was the number of samples (N = 11). According to Cohen's guidelines, the effect for r was established as follows: large effect ≥ 0.5, moderate effect < 0.5 and ≥ 0.3, and small effect < 0.3 and ≥ 0.1 (Fritz et al., 2012; Maszczyk et al., 2014, 2016). All statistical analyses were performed using the Statistica programme (v. 12, StatSoft, Inc., Tulsa, OK, USA) and Microsoft Excel 2010 (Microsoft Corp., Redmond, Washington, USA). The level of significance was originally set at $\alpha = 0.05$, a Bonferroni correction for multiple comparisons (3 comparisons) was applied resulting in the final significance level of $\alpha = 0.017$.

Results

The ANOVA results showed differences in the H_{CONC}/Q_{CONC} in the DL ($p < 0.01$) and in the concentric H bilateral strength deficit ($p = 0.02$) (Table 3). The H_{CONC}/Q_{CONC} in the DL was greater after individual and group conditioning in comparison with the in-season cessation testing with a large effect size. The concentric H bilateral strength deficit decreased after the rest period followed by individual and group conditioning in comparison with the in-season cessation testing with a large effect size.

Despite the significance of the "*p*" value, the effect size showed that the off-season rest followed by individual conditioning did not result in decreased H strength (Table 2), with the exception of lower eccentric H strength of the NL (Table 2) with a large effect. The concentric Q strength in the DL decreased after the period of rest followed by individual conditioning with a large effect. The H_{CONC} in the DL, as well as Q_{ECC}

in the DL and NL were greater after group conditioning than after the in-season cessation with a large effect. The H_{CONC} in the DL, H_{ECC} in the DL, H_{ECC} in the NL, Q_{CONC} in the DL, Q_{CONC} in the NL and Q_{ECC} in the NL were greater after group conditioning compared to after the off-season rest followed by individual training with a large effect.

Except for a significant decrease in H_{CONC}/Q_{CONC} in the DL, other ipsilateral ratios did not show a large effect between the measurements (Table 3). Besides significance in the concentric H bilateral strength deficit, the bilateral strength deficit decreased after individual and group conditioning in comparison with the in-season cessation with a large effect.

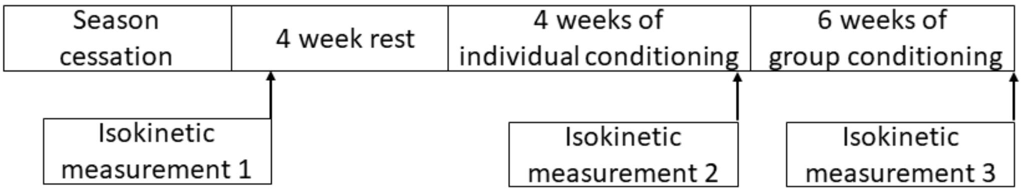

Figure 1

The measurement and season phase chart.

Table 1

Indicators of training loads during individual (4 weeks) and group (6 weeks) conditioning

Type of training	Individual conditioning (min)	Group conditioning (min)
	4 weeks	6 weeks
Physical fitness training		
Warm-up	500	780
Strength and power training	450*	735**
Speed and agility training	300	465
Endurance training	330	525
Non-specific additional sport	200	210
Skill-oriented training		
Technical-tactical training	0	2430
Game-like training	0	720
Matches	0	660
Regeneration	250	1100
TOTAL	2010	7625

** Core training, free-weights 12-15 repetition maximum, machines (twice a week, whole body every time).*
*** Core training, free-weights at 80% of repetition maximum, machines, plyometric training, additional loads (from twice to three times a week, whole body every time).*

Table 2

Descriptive statistics and Friedman's ANOVA for peak torque of hamstring and quadriceps muscle.

	Mean ± SD (95% CI)			Friedman´s ANOVA			Effect size r		
Variable	Session 1	Session 2	Session 3	X^2	p	W	S_1 - S_2	S_1 - S_3	S_2 - S_3
H_{CONC} DL	1.20 ± 0.22 (1.05-1.35)	1.21 ± 0.22 (1.07-1.36)	1.29 ± 0.20 (1.16-1.42)	5.09	0.078	0.23	0.03	0.67	0.54
H_{ECC} DL	1.45 ± 0.32 (1.24-1.66)	1.44 ± 0.29 (1.24-1.63)	1.53 ± 0.26 (1.35-1.70)	5.09	0.078	0.23	0.05	0.43	0.54
H_{CONC} NL	1.22 ± 0.25 (1.05-1.39)	1.20 ± 0.24 (1.04-1.36)	1.25 ± 0.21 (1.11-1.39)	2.36	0.307	0.11	0.27	0.19	0.29
H_{ECC} NL	1.46 ± 0.32 (1.25-1.68)	1.35 ± 0.33 (1.13-1.57)	1.49 ± 0.21 (1.35-1.63)	3.82	0.148	0.17	0.48	0.21	0.56
Q_{CONC} DL	2.27 ± 0.36 (2.03-2.51)	2.14 ± 0.36 (1.90-2.38)	2.31 ± 0.31 (2.10-2.51)	5.09	0.078	0.23	0.51	0.05	0.62
Q_{ECC} DL	2.53 ± 0.67 (2.08-2.98)	2.70 ± 0.63 (2.27-3.12)	2.89 ± 0.67 (2.44-3.34)	1.27	0.529	0.06	0.27	0.54	0.43
Q_{CONC} NL	2.19 ± 0.32 (1.98-2.40)	2.14 ± 0.37 (1.89-2.39)	2.32 ± 0.31 (2.11-2.52)	4.55	0.103	0.21	0.32	0.48	0.54
Q_{ECC} NL	2.59 ± 0.69 (2.13-3.06)	2.65 ± 0.84 (2.08-3.21)	3.00 ± 0.53 (2.64-3.35)	2.91	0.234	0.13	0.11	0.62	0.59

H – hamstring muscles, Q – quadriceps muscles, CONC – concentric mode, ECC – eccentric mode, DL – dominant leg, NL – non-dominant leg, Session 1 – after in-season cessation, Session 2 –beginning of the pre-season, Session 3 –end of the pre-season, SD - standard deviation, CI – confidence interval, X^2 – chi-squared, W – Kendall coefficient of concordance, Effect size r: r ≥ 0.5 is large effect, r < 0.5 and ≥ 0.3 is moderate effect, r < 0.3 and ≥ 0.1 is small effect.

Table 3

Descriptive statistics and Friedman's ANOVA for ipsilateral ratios and bilateral strength deficits

	Mean ± SD (95% CI)			Friedman's ANOVA			Effect size r		
Variable	Session 1	Session 2	Session 3	X^2	p	W	$S_1 - S_2$	$S_1 - S_3$	$S_2 - S_3$
Ipsilateral H/Q ratios									
H_{CONC}/Q_{CONC} DL	0.53 ± 0.04 (0.50-0.55)	0.57 ± 0.06 (0.53-0.61)	0.56 ± 0.04 (0.53-0.59)	10.36	0.006*	0.47	0.72	0.67	0.46
H_{CONC}/Q_{CONC} NL	0.56 ± 0.11 (0.49-0.63)	0.57 ± 0.10 (0.50-0.63)	0.54 ± 0.07 (0.49-0.59)	1.27	0.529	0.06	0.11	0.27	0.35
H_{ECC}/Q_{CONC} DL	0.64 ± 0.13 (0.56-0.73)	0.68 ± 0.11 (0.60-0.75)	0.66 ± 0.09 (0.61-0.72)	1.64	0.441	0.07	0.38	0.35	0.05
H_{ECC}/Q_{CONC} NL	0.67 ± 0.12 (0.59-0.75)	0.63 ± 0.12 (0.55-0.72)	0.65 ± 0.09 (0.59-0.71)	2.36	0.307	0.11	0.40	0.32	0.11
H_{CONC}/Q_{ECC} DL	0.49 ± 0.12 (0.41-0.57)	0.46 ± 0.05 (0.42-0.49)	0.46 ± 0.07 (0.41-0.51)	2.36	0.307	0.11	0.35	0.32	0.05
H_{CONC}/Q_{ECC}NL	0.49 ± 0.14 (0.40-0.59)	0.48 ± 0.14 (0.39-0.58)	0.42 ± 0.07 (0.38-0.47)	1.27	0.529	0.06	0.19	0.40	0.51
Bilateral strength deficit									
H_{CONC}	13.6 ± 9.3 (7.4-19.9)	8.9 ± 5.5 (5.2-12.6)	6.7 ± 4.1 (3.9-9.5)	7.82	0.020*	0.04	0.46	0.78	0.56
H_{ECC}	9.1 ± 5.0 (5.8-12.5)	10.2 ± 9.0 (4.2-16.3)	11.6 ± 9.5 (5.2-18.0)	0.18	0.913	0.01	0.03	0.11	0.00
Q_{CONC}	9.5 ± 6.8 (4.9-14.0)	4.9 ± 5.8 (1.0-8.8)	6.2 ± 3.5 (3.9-8.6)	4.55	0.103	0.21	0.67	0.54	0.32
Q_{ECC}	15.3 ± 9.2 (9.2-21.5)	11.9 ± 9.3 (5.7-18.2)	10.0 ± 9.4 (3.7-16.3)	1.27	0.529	0.06	0.16	0.40	0.32

*H – hamstring muscles, Q – quadriceps muscles, CONC – concentric mode, ECC – eccentric mode, DL – dominant leg, NL – non-dominant leg, Session 1 – after in-season cessation, Session 2 –beginning of the pre-season, Session 3 –end of the pre-season, SD – standard deviation, CI – confidence interval, X^2 – chi-squared, W – Kendall coefficient of concordance, Effect size r: r ≥ 0.5 is large effect, r < 0.5 and ≥ 0.3 is moderate effect, r < 0.3 and ≥ 0.1 is small effect, * significant difference.*

Discussion

The main finding of the present study is that muscle strength did not significantly decrease after 4 weeks of rest followed by 4 weeks of individual training, and that muscle strength increased after a 6-week group conditioning in comparison with the strength level in the previous season. This finding is in agreement with the recommendation to use a rest period followed by a progressive conditioning block (Siff, 2003). Furthermore, muscle imbalances represented by BSD of H muscles and H_{CONC}/Q_{CONC} were reduced at the end of the pre-season in comparison with in-season cessation measurement, which is one of the desired goals of this part of the annual training cycle. Although the presented conditioning programme did not include specific exercises for muscle imbalance reduction, the off-season rest followed by individual conditioning had a positive effect on muscle strength and muscle imbalances in the following conditioning programme.

Muscle strength level of hamstring and quadriceps

The effect size analyses showed an increase in H and Q strength during pre-season conditioning in concentric and eccentric strength of H muscles and concentric strength of Q muscles in both lower limbs with large effect sizes ($r > 0.5$). On the other hand, there was a non-significant progressive increasing trend in Q eccentric strength over the observed periods with medium-to-large effect sizes in both lower limbs ($r = 0.43–0.59$). In fact, general muscle strength development reflected in the measurement results should be implemented during the off-season, and maximal strength development followed by its conversion to handball-specific and explosive strength should be planned in the pre-season (Ratamess, 2008), which was included in the group conditioning phase of the program described in this paper.

With regard to the annual training cycle, a previously reported study (Xaverova et al., 2015) focusing on concentric PT in H and Q muscles at an angular velocity of 60°/s presented the results of female handball players with national (DL and NL: H = 1.2 and Q = 2.2 Nm/kg) and junior national team experience (DL: H = 1.4 and Q = 2.3 Nm/kg; NL: H = 1.3 and Q = 2.4 Nm/kg). The stated values were similar to the corresponding findings of the present study. Comparable results concerning identical periods can also be observed in female volleyball players as an average of DL and NL (H = 1.21 and Q = 2.38 Nm/kg) (Fry et al., 1991), however, it has been reported that specific demands in various sports produce differences in muscle strength ratios (Ratamess, 2008).

Since landing impact forces with immediate subsequent rapid actions, especially insufficient strength of H muscles are associated with ACL injury among female handball players, thus eccentric isokinetic torque evaluation of the knee muscles seems to be crucial. Regarding the fact that the normalized eccentric PT values in H and Q muscles in a similar senior (DL: H = 1.4 and Q = 2.8 Nm/kg; NL: H = 1.4 and Q = 2.9 Nm/kg) and a similar junior population (DL: H = 1.5 and Q = 3.0 Nm/kg; NL: H = 1.4 and Q = 2.9 Nm/kg) were comparable at the beginning of the pre-season (Xaverova et al., 2015), the values observed in this study were not reported as insufficiently low. Although the results may be compared with previous studies on female athletes (Andrade et al., 2012; Brophy et al., 2010; Cook et al., 2004; Lund-Hanssen et al., 1996), the comparison of eccentric strength is possible only with one reference value (Xaverova et al., 2015).

Bilateral strength deficit

Bilateral strength asymmetries may possibly affect player's performance either by increasing the risk of injury or by limiting the player, thus favouring their stronger side. Correction of such an imbalance may improve performance and also reduce the risk of injury (Newton et al., 2006). In the present study, a significant decrease in asymmetry with a large effect was found in BSD in H muscles in the concentric mode between the in-season cessation and the end of pre-season conditioning (from 13.6 to 6.7%, $p = 0.009$, $r = 0.78$). Generally, a bilateral difference of 10–15% between muscle groups may be considered significant and could be a criterion to hold an athlete out of practice or competition until the strength asymmetry is corrected (Maly et al., 2015), therefore conditioning after rest in our study had a positive effect on muscle imbalances. A trend of higher BSD in H and Q muscles (> 10%) was observed in the eccentric mode of testing in comparison with the concentric mode of testing in three individual measurements. In any case, by placing too much emphasis on the stronger leg, players may increase the potential for injury when considering eccentric strength (Lockie et al., 2012).

There are two different approaches to bilateral strength comparisons in term of PT - preference of the dominant leg and preference of the stronger leg (% Def) (Beam and Gene, 2014). Regarding the fact that a higher incidence of ACL injuries (by 68%) on their NLs (DL = preference to kick a ball) was observed in female soccer players (Brophy et al., 2010), this approach was used for the purposes of the present study. Moreover, a clear trend of the stronger leg in both testing modes throughout all testing sessions in the concentric and eccentric mode was not observed. Specifically, when referring to the jump shot handball skill, neither the stronger take-off leg nor non-take-off leg dominance is observed. Furthermore, the weaker leg is limited in horizontal ground reaction force production during the stance phase of running in comparison with the stronger leg, which leads to a potential reduction in step length and an inefficient step pattern (Brughelli et al., 2010).

Ipsilateral hamstring to quadriceps ratio

Hamstrings and quadriceps muscles serve as important dynamic stabilizers of the knee joint. Unless agonist-antagonist muscle groups are in a certain balance, the weaker muscle group as well as the corresponding joint are usually more predisposed to injury. The value of 100% (or 1.0 ratio) indicates a balance between peak torque of knee flexors and extensors and therefore, the optimal ability of dynamic stabilization of the knee joint (Coombs and Garbutt, 2002).

Although a significant increase with large effects of time in the average H_{CONC}/Q_{CONC} in the DL between the in-season cessation and rest followed by individual conditioning block (from 0.53 to 0.57, $p = 0.016$, $r = 0.72$) and between the in-season cessation and the end of the pre-season (from 0.53 to 0.56, $p = 0.026$, $r = 0.67$) was detected, its level was low compared with the critical value (0.6). This is also true for eccentric muscle strength insufficiency of the hamstring muscles over the whole observed period when referring to the border value of the H_{ECC}/Q_{CONC} ratio (0.7) (Coombs and Garbutt, 2002) as the players' H_{ECC}/Q_{CONC} ratios varied between the values of 0.63–0.68. On the other hand, the conditioning program did not include the generally recommended hamstring eccentric exercises (Al Attar et al., 2017; Mjølsnes et al., 2004). Therefore, it may be concluded that the off-season rest, followed by non-specific 4 weeks of individual conditioning is not sufficient to improve H_{ECC}/Q_{CONC}, but may improve the H_{CONC}/Q_{CONC} in the DL. Combining the in-season rest period with specific exercises aimed at the lower extremities may effectively reduce the risk factors for ACL injuries.

No repeated measures studies concerning changes in conventional and/or functional H/Q ratios during the annual training cycle in female athletes have been found; therefore, the results of the present study are hard to compare. Nevertheless, the current knowledge about female handball players reporting H_{CONC}/Q_{CONC} at the level of 0.56 (Andrade et al., 2012; Lund-Hanssen et al., 1996) and 0.56–0.58 (Xaverova et al., 2015) indicates that handball may be considered a sport discipline with overloaded Q muscles that can negatively affect knee joint dynamic stability. To the best of our knowledge, there is only one study reporting the H_{ECC}/Q_{CONC} in female handball players with a ratio of 0.66 (DL) and 0.67 (NL) in players with experience in the woman's national team, and a ratio of 0.66 (DL) and 0.62 (NL) in players with experience in the junior national team at the beginning of the pre-season (Xaverova et al., 2015).

The ipsilateral ratios H_{CONC}/Q_{CONC} and H_{ECC}/Q_{CONC} relate to knee extension; however, injuries in handball mostly occur in two specific types of movement: single-leg landing, especially after a jump shot and rapid change of direction initiated on one leg, that is during knee flexion which can be described by the H_{CONC}/Q_{ECC} (De Ste Croix, 2012). These injuries occur as a result of large external valgus moment and external rotation moment in combination with a translatory shift of the tibia relative to the femur usually in large knee angles close to full extension (Bahr and Krosshaug, 2005). These injuries usually happen during defensive play, and are more frequent in high-level competition or after years of training (Myklebust et al., 2003). Knowing this, it is quite surprising that the use of H_{CONC}/Q_{ECC} in athletes is infrequent. Aagaard et al. (1998) reported a H_{CONC}/Q_{ECC} around 0.30 at a velocity of 240°/s in male and female track and field athletes suggesting that the H muscles had a reduced capacity for dynamic knee joint stabilization during forceful knee flexion movements with simultaneous eccentric quadriceps muscle contraction. The H_{CONC}/Q_{ECC} decreases with increases in flexion velocity that is contrary to the functional ratio representative for knee extension (H_{ECC}/Q_{CONC}) that increases with increases in extension velocity (Aagaard et al., 1998). The H_{CONC}/Q_{ECC} in the present study was more or less stable under the value of 0.5 at a velocity of 60°/s. An insufficient level of H muscles during this action may alternate the natural landing technique with further mechanisms leading to injury. Moreover, it was also reported that knee valgus alignment typical for females may increase the risk of injury, which is even higher with fatigue accumulated during a game or over a long training session (De Ste Croix, 2012).

Despite this fact, besides the H_{CONC}/Q_{CONC}, two other functional ratios (H_{ECC}/Q_{CONC} and H_{CONC}/Q_{ECC}) that account for the role of the antagonist in knee joint stabilisation have been observed in ACL injury specific knee angles (Aagaard et al., 1998). This may be explored in further studies. Although flexibility of the knee joint muscles influences muscle strength production (Ayala et al., 2012), flexibility was not investigated in the present study. Another limitation of the study refers to a small sample size; therefore, this fact has to be taken into account in data interpretation. However, similar numbers of participants involved in studies on high-performance athletes are common in the literature (Lehnert et al., 2014a, b; Xaverova et al., 2015). Moreover, for practical implications, when considering confidence intervals in the observed variables, it is important to realize that a group average tends to mask norm ranges of individual bilateral and ipsilateral asymmetries.

Conclusions

The off-season rest period followed by the conditioning block had two main positive effects, a reduction in BSD and an increase in the H_{CONC}/Q_{CONC}. However, the requirements for strength improvement in a 10-week conditioning cycle are generally higher than it was observed. Therefore, the presented conditioning program should be improved in the area of specific lower extremity exercises, which may support the positive influence of off-season conditioning.

Coaches should include a training rest period after the competitive period to decrease the bilateral strength deficit and support further fitness development. Furthermore, coaches and conditioning specialists should report representative values of muscle strength levels (e.g. isokinetic peak torque) with a clear record of the phase of the annual training cycle.

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