STRENGTH AND JUMPING ASYMMETRIES IN GYMNAST AND THEIR NON-GYMNAST PEERS

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Abstract

While many studies investigated inter-limb asymmetries (ILAs) in different athletes, little is known about ILAs in the population of gymnasts. The first aim of our study was to compare differences between gymnasts and their non-gymnast peers in isometric knee maximal and rapid strength parameters (peak torque - PT and rate of torque development - RTD) and countermovement jump (CMJ) parameters (height, maximal force), as well as in ILAs in all outcome measures. The second aim of the study was to assess the relationship between ILA of maximal force and the ILAs of the isometric knee strength parameters. 15 gymnasts (aged 11.19 ± 1.89 years) and 15 non-gymnasts (aged 10.92 ± 1.96 years) performed unilateral isometric maximal voluntary contractions of the knee flexors and extensors on a dynamometer and CMJ on a force plate. ILAs were calculated and compared between groups across all outcome measures. We found that gymnasts reached statistically significant better results than non-gymnasts in most isometric knee strength parameters and CMJ height, but not on RTD of left knee flexion and maximal force in the CMJ. Meanwhile, we did not find significant differences between groups in ILAs. Linear regression showed no correlations between the ILAs measures separately for the groups. Even though we did not find any differences between the groups in the ILAs, we should be aware of it to prevent injury in young girls.

Keywords: *isometric knee strength, countermovement jump, artistic gymnastics.*

INTRODUCTION

Artistic gymnastics is characterized by early inclusion and consequently early specialization, with the goal of competing at an elite level (Caine et al., 2003). Therefore, the training routine of gymnasts lasts between 16 to 30 hours (Buckner, Bacon & Bishop, 2017; Caine et al., 2003, 2008; Frutuoso, Diefenthaeler, Vaz & Freitas, 2016; Hart, Meehan, Bae, D`Hemecourt & Stracciolini, 2018) and even up to 40 hours per week (Caine et al., 2003; Edouard et al., 2018; Frutuoso et al., 2016; Hart et al., 2018). Such exposure to a large number of training hours and high level of gymnastics are associated with an increased incidence of injury (Edouard, Steffen, Junge & Engebretsen, 2018; O'Kane, Steffen, Junge & Engebretsen, 2011; Saluan, Styron, Ackley, Prinzbach & Billow, 2015; Seegmiller & McCaw, 2003). The injuries in female gymnasts most commonly occur at the lower extremities, particularly at the ankle and at the knee (Kirialanis et al., 2002; Kirialanis, Malliou, Beneka & Giannacopoulos, 2003; O'Kane et al., 2011; Seegmiller & Mccaw, 2003; Slater, Campbell, Smith & Straker, 2015; Sweeney, 2020). Most studies report these injuries occur during landing/jumping (Moresi, Bradshaw, Thomas, Greene & Braybon 2013; Seegmiller & Mccaw, 2003; Slater et al., 2015).

Imbalances (e.g., during movement) and body asymmetries can lead to injury risk. Asymmetries can be present between agonist and antagonist muscles, or between sides of the body (i.e., the inter-limb asymmetries (ILAs) (Keelley, Plummer & Oliver, 2011). ILAs can be calculated as the difference between stronger and weaker, dominant and non-dominant, right and left, or injured and non-injured limbs. ILAs > 15% have been found to place the athletes at higher risk of injury compared to those who have less than 15% of ILAs (Croisier, 2004; Kabacinski, Murawa, Mackala & Dworak, 2018; Knapik, Bauman, Jones & Harris, 1991; Murphy, Connolly & Beynnon, 2003). Meanwhile, Lilley, Bradshaw & Rice (2007) suggested that ILAs > 10% already pose a risk of injury to gymnasts.

When we talk about asymmetries, it is crucial to detect the risk of injury to gymnasts. Due to the large number of jumps/landings (Kirialanis et al., 2002), the tasks that are associated with most injuries in gymnastics, it is necessary to evaluate the strength and explosive qualities that are crucial in the context of gymnasts` physical abilities and fitness level (Impellizzeri, Rampini, Maffiuletti & Maroca, 2007; Michel, Monèm & Rodríguez, 2014; Moresi, et al., 2013). In recent years, detecting ILAs in athletes' populations to prevent lower extremity injuries has become a popular topic. For evaluating strength parameters, lower limb dynamometry is the most commonly used task (Smajla, Knezevic, Mirkov & Šarabon, 2020; Thompson, et al., 2013; Wilson & Murphy, 1996). Variables representing the strength profile and muscle strength deficit are peak torque (PT) and rate of torque development (RTD) obtained during maximal voluntary contraction (MVC). RTD is more relevant for the rapid strength production than PT, which is less a sensitive measure in the sports that include movement duration of less than ~ 100-200ms (Palmer et al., 2015; Šarabon, Kozinc, Bishop & Maffiuletti, 2020; Thompson, et al., 2013) and may also be useful to distinguish between athletes versus non-athletes. For detecting explosive power capacity (e.g., jumping performance), the countermovement jump (CMJ) is a widely used test in gymnastics (Dallas, Savvathi, Dallas & Maridaki, 2019; Donti, Tsolakis & Bogdanis, 2014; Marina & Torrado, 2013; Michel, Monem & Ferran, 2014; Pentidis, Mersmann, Bohm, Giannakou, Aggelousis & Arampatzis, 2019) and other sports (Bell, Sanfilippo, Binkley & Heiderscheit, 2014; Bencke, Damsgaard, Saekmose, Jørgensen, Jørgensen & Klausen, 2002; Bishop, Read, Chavda, Jarvis & Turner, 2019; Impellizzeri et al., 2007; Petrigna et al., 2019; Schons et al., 2019; Šarabon, Smajla, Maffiuletti & Bishop, 2020; Thompson et al., 2013;Young, Cormack & Crichton, 2011). Moreover, it is considered a reliable and valid test (Fernandez-Santos, Ruiz, Cohen, Gonzales-Montesion & Castro-Piñero, 2015; Marković, Dizdar, Jukić & Cardinale, 2004). CMJ is a vertical jump that can be performed in different ways, such as unilateral or bilateral, with arm swinging or held at the hip, or with additional loading (Young et al., 2011).

This study aimed: a) to compare differences in strength and power parameters between gymnasts and their non-gymnast peers, and b) to examine the relationship between CMJ ILAs parameters and knee isometric strength parameters (knee flexion and extension parameters - T_{max}, RTD), separately for the observed groups. Knee strength parameters and lower limb explosive power are important for performance and injury prevention in gymnasts. Practitioners should be able to detect ILAs and provide interventions to reduce them if needed. It is useful to know whether ILAs in multi-joint movement are related to single-joint ILAs, both from the testing and the intervention perspective. The rationale for the comparison to the control group was to explore whether the selected ILA outcomes can be attributed to specific adaptations to gymnastic training or are present in young people in general.

METHODS

Fifteen female artistic gymnastic athletes (age: 11.19 ± 1.89 years; height: 143.63 ±12.28 cm; weight: 37.25 ± 10.34 kg; BMI: 17.62 ± 2.40; training years 3.4 ± 1.8; weekly training hours: 22 ± 6) and 15 similar-aged female non-gymnast controls (10.92 ± 1.96 years; 146.71 ± 11.28 cm; 35.80 ± 11.03 kg; BMI: 16.36 ± 3.04) participated in the study. Inclusion criteria for our sample was age between 9 and 15 years. The main inclusion criteria for the non-gymnasts were a maximum of 2 hours of physical activity peer week and no skeletal, muscles, nerve or connective tissue injuries during the last 12 months. Inclusion criteria for the gymnasts were good physical health during the measurements and participation in the training process of one of the gymnastic clubs in Slovenia (e.g., SK Salto).

The study was conducted in accordance with the Declaration of Helsinki and the experiment was approved by the National Medical Ethics Committee of the Republic of Slovenia for research on children and adolescents, obtained on 23th of January 2018, (Approval No: 0120-631/2017/2). The subjects, their coaches and their parents/legal guardians were informed about the testing procedures and provided written informed consent prior to the study.

The study was performed in the laboratory of the Faculty of Health Sciences, University of Primorska. The test session lasted approximately 90 min per participant. The participants first completed a 6-min walk on a stepper, followed by dynamic stretches of the main muscle groups, and an activation exercise – 10 squats. The study consisted of five different sections: a) dynamometry of trunk, knee and ankle, b) lower limb passive range of motion assessments, c) handgrip and shoulder strength tests, d) jumps on a force plate, and e) dynamometry of hip. The order of the sections was randomly determined for each participant. In the present work we will consider measurements of isometric knee strength and CMJ on a force plate. Prior to the main measurements, participants underwent familiarization trials of each tasks (knee dynamometry and CMJ).

For the strength tests, the participants were seated in an isometric knee dynamometer (S2P, Science to Practice, Ltd., Ljubljana, Slovenia). The knee angle was set to 60° (0° = full extension) and the hips were set at 100° (0° = neutral position). Each participant was tightly fixed over the distal thigh and pelvis by a tight belt. The distal shin pad of the dynamometer was fixed with a strap 3–5 cm proximal to the medial malleolus. The seat position was individually adjusted and during the measurements, the participants were holding the hand grips along the seat (Figure 1). The participants were instructed to perform the tasks “as fast and as forcefully as possible” (Maffiuletti et al., 2016; Sleivert & Wenger, 1994) and to maintain the maximal effort for 3-5 sec. After the familiarization, the participants performed 3 maximal voluntary contractions (MVC) per task (flexion (FL) and 3 extensions (EX)) unilaterally, in a random order. The participants were loudly verbally encouraged throughout the trial in order to facilitate maximal effort. Between each trial on the same side, the participants rested for 30s, and for 60s when they needed to switch the leg. The rest interval was determined in accordance with previous studies (Harbo, Brincks &

Andersen, 2012; Koblbauer et al., 2011; Kozinc & Šarabon, 2020; Šarabon et al., 2020). We analysed both the maximal torque (T_{max}) and the rate of torque development (RTD) at 0-100ms time window. For all tasks the peak torque was determined as the maximum value in a 1-second interval. The outcome measures of isometric knee strength were normalized with the body weight of participants.

Figure 1. Participant in the isometric knee dynamometer.

The jumping tests were performed on a bilateral force plate (Kistler 3D, 9260AA, Winthertur, Switzerland). After familiarization trials, the participants performed 3 maximal countermovement jumps (CMJ). The rest between repetitions was at least 30 seconds. The participants were instructed to jump "as high as possible" and verbal encouragement was given to ensure maximal effort. The jump task was performed with the hands on the hips (Figure 2). The outcome measures were automatically calculated from the force-time data by the acquisition software (MARS, Kistler, Winthertur, Switzerland). The outcome measures that we included in the analysis were: a) jump height from take-off velocity, maximal force of the left leg, and maximal force of the right leg.

Figure 2. Position of the hands during vertical jump.

For all outcome measures of jumps (height, maximal force of the left leg – $F_{max}L$, maximal force of the right leg – $F_{max}R$) and isometric knee FL and EX strength (T_{max} and RTD), the maximal value of the three trials for each task and each side was considered for calculating inter-limb asymmetry (ILA), using the equation:

$$\text{inter-limb asymmetry}\ (\%) = \left(\frac{\text{stronger} - \text{weeker limb}}{\text{stronger limb}}\right) \times 100$$

Statistical analysis was conducted with IBM SPSS Statistic 26 (IBM, New York, USA). For all outcome measures we calculated descriptive statistics (mean value ± standard deviation, minimum and maximum value). We used the intraclass correlation coefficient (ICC) to test the intra-rater reliability of the strength and jump measurements, which reflects the variation of data measured by 1 rater. ICCs were interpreted according to Koo and Li (2016), where ICC >0.90 = excellent, 0.75–0.90 = good, 0.50–0.74 = moderate and <0.50 = poor. Before analysing the differences, we tested normality of distribution using the Shapiro-Wilk test. To determine the differences between gymnast and non-gymnasts in the strength parameters of the knee and CMJ parameters, we used the t-test for independent samples for normally distributed parameters and Mann-Whitney U-test for the non-normally distributed parameters. To determine the effect size (ES) between the two observed groups (GG and NG), we used Hadges`g (i.e. corrected effect size) due to the small sample size (below 20). The associations between ILA outcomes were assessed with Pearson correlation coefficient which was interpreted as negligible (< 0.1), weak (0.1–0.4), moderate (0.4–0.7), strong (0.7–0.9) or very strong (> 0.9) (Akoglu, 2018). To investigate if the ILAs in single-joint strength outcomes could predict ILA in CMJ, we used a multiple linear regression, whereby the dependent variable was ILA of the maximal force during CMJ, while independent variables were those of the ILAs of the knee isometric strength (KFL T_{max}, KEX T_{max}, KFL RTD, KEX RTD). Significance level was set at $\alpha < 0.05$.

RESULTS

From analysis of isometric knee strength, we excluded 1 participant from gymnasts due to the injury. Also, we excluded 1 participant from gymnasts (injury) and one non-gymnasts (incorrectly performed jump) from the analysis of CMJ. Note that we considered three measurements per participant that were included in the analysis of the reliability test, that demonstrated for the isometric knee outcomes and for the CMJ outcomes, good test reliability, with the confidence interval spanning from moderate to excellent (0.80; range = 0.65 - 0.95; 0.80; range = 0.67 - 0.98, respectively). Bogdanis et al. (2019) detect excellent ICC for the CMJ height of the young gymnasts (0.94).

Descriptive statistics and the differences between gymnasts and non-gymnasts in all outcome measures of the isometric knee strength and CMJ parameters are presented in Table 1. Statistically significant differences between groups ($p < 0.05$; ES = 0.94 – 1.19) were found in most of the isometric knee strength and in the height of the CMJ ($p = 0.02$; ES = 0.86), in favor of gymnasts. Meanwhile, there were no differences detected in the parameter of KFL RTD left ($p = 0.13$, ES = 0.56), and in the maximal force of left and right legs of the CMJ ($p > 0.05$; ES = 0.30 – 0.41).

Table 2 summarizes the differences between gymnast and non-gymnasts in the ILAs of the T_{max} and RTD of the knee flexion and extension and of the maximal force obtained during CMJ. The results showed no statistically significant differences between the observed groups in the ILAs outcome measures.

The Pearson correlation was run to determine ILAs correlations of the knee isometric strength parameters and maximal force of CMJ. Table 3 demonstrates moderate, negative correlation only between T_{max} of KFL and KEX, which was statistically significant ($r = - 0.471$, $n = 29$, $p = 0.01$). Meanwhile, there were no statistically significant correlations between other ILAs parameters.

Multiple linear regression was conducted to explain dependent variable, ILA of maximal force of the CMJ, with the independent variables of the ILAs of knee strength parameters (KFL and KEX T_{max}, KFL and KEX RTD), separately for the observed groups. The results showed that the single-joint ILA outcomes could not explain the ILA in CMJ, in none of the observed groups between parameters (G: $R = .290$, $F = .207$, $p = .928$ and NG: $R = .287$, $F = .179$, $p = .943$, respectively).

Table 1

Differences between gymnast and non-gymnasts for all outcome measures normalized with the body weight.

	Outcome/task	Gymnasts (G) (N = 14)		Non-gymnasts (NG) (N = 14)			
		Mean	SD	Mean	SD	P	ES
KFL	T_{max} left (Nm/kg)	1.19	0.26	0.94	0.22	0.01*	0.99
	T_{max} right (Nm/kg)	1.35	0.25	1.10	0.24	0.01*	0.94
	RTD_{100} left (Nm/kg s)	2.87	1.98	2.33	1.40	0.13	0.56
	RTD_{100} right (Nm/kg s)	4.02	2.71	2.06	1.40	0.01*	0.98
KEX	T_{max} left (Nm/kg)	2.16	0.58	1.59	0.28	0.01*	0.99
	T_{max} right (Nm/kg)	2.21	0.47	1.73	0.30	0.01*	1.00
	RTD_{100} left (Nm/kg s)	8.09	4.56	3.70	1.85	0.005*	1.11
	RTD_{100} right (Nm/kg s)	8.51	3.95	4.16	2.69	0.003*	1.19
CMJ	Height (m)	0.23	0.04	0.19	0.05	0.02*	0.86
	F left (% BW)	117.66	11.19	122.02	16.15	0.41	0.30
	F right (% BW)	118.97	9.67	124.60	16.04	0.27	0.41

Note: KFL–knee flexors, KEX–knee extensors, CMJ–countermovement jump, T_{max}–maximal torque, RTD–rate of torque development, F–relative maximal force, BW–body weight, SD–standard deviation, ES–effect size (Hedges), * - $p < 0.05$, ** - $p < 0.001$

Table 2

Differences in ILAs parameters between the gymnast and the non-gymnast group.

	ILAs	Gymnasts (G) (N = 14)		Non-gymnasts (NG) (N = 14)			
		Mean	SD	Mean	SD	P	ES
KFL	T_{max}	13.52	8.16	17.15	10.21	0.31	0.38
	RTD	34.17	21.58	32.92	26.99	0.89	0.05
KEX	T_{max}	14.59	9.23	11.74	7.63	0.38	0.33
	RTD	29.56	13.70	33.68	21.45	0.55	0.22
CMJ	F_{max}	5.14	3.1	6.88	5.93	0.34	0.36

Note: KFL–knee flexors, KEX–knee extensors, CMJ–countermovement jump, ILAs–inter-limb asymmetries, T_{max}–maximal torque, RTD–rate of torque development, F–relative maximal force, SD–standard deviation, ES–effect size (Hedges), * - $p < 0.05$, ** - $p < 0.001$

Table 3

Pearson correlation coefficient of the ILAs knee strength parameters and ILAs force of CMJ.

ILAs parameters	KFL–T_{max}	KEX–T_{max}	KFL–RTD	KEX–RTD	CMJ–F
KFL–T_{max}					
KEX–T_{max}	-.471**				
	.010				
KFL–RTD	-.035	-.321			
	.856	.089			
KEX–RTD	-.026	.037	.288		
	.893	.850	.130		
CMJ–F	.057	-.083	.221	.049	
	.779	.681	.268	.808	

Note: KFL–knee flexors, KEX–knee extensors, CMJ–countermovement jump, T_{max}–maximal torque, RTD–rate of force development, F–relative maximal force

DISCUSSION

The purpose of the present study was twofold: a) to determine differences in isometric knee strength parameters and CMJ parameters between gymnasts and non-gymnasts, and b) to investigate the relationship between ILAs parameters of CMJ and isometric knee strength parameters (KFL T_{max}, KEX T_{max}, KFL RTD, KEX RTD), separately for the observed groups. The results showed statistically significant differences between the groups for most knee strength parameters and the height of the CMJ, but not for the maximal force of the CMJ. The results showed that there were no correlations in any of the observed parameters, separately for the groups.

To the best of our knowledge, there is no published study that has examined the differences in isometric knee strength between gymnasts and non-gymnasts. Our results showed that gymnasts had significantly higher peak torque (PT) and rate of torque development (RTD) of both legs during flexion and extension of isometric knee strength compared to their non-gymnast peers. One previous study examined the differences between female collegiate basketball players and gymnasts in PT and RTD of isometric knee strength normalized to participant body weight (Thompson et al., 2017), as we did in our analysis. In our study, gymnasts reached lower values of PT and RTD compared to the values of gymnasts in the Thompson et al. (2017) study. It is likely that the differences between the studies are due to the age of the participants, since our study included younger gymnasts (age 11.19 years; compared to 19.5 years of age). In addition, other researchers examining differences between elite athletes and control groups found that PT of knee extensors differed significantly between groups, but not in PT of knee flexors (Markström, Grip, Schelin & Häger, 2019), which partially contrasts with our study as it shows significant differences in both outcome measures. Adequate isometric knee strength provides the basis for the ability to perform many of the primary athletic tasks and prevent lower extremity injuries, particularly anterior cruciate ligament (ACL) injuries, which are more common in female athletes than male athletes (Hewett, Ford, Hoogenboom & Myer, 2010; Keelley et al., 2011; Thompson et al., 2017).

Our study also included force parameters and jump height of the CMJ. The study by Bencke et al. (2002) compared CMJ height between gymnasts, swimmers, handball and tennis players and a study by Bogdanis et al. (2019) compared CMJ height between gymnasts and a control group after the intervention. They found no significant differences in jump height between the observed groups, unlike the studies by Pentidis et al., (2019, 2020) that observed gymnasts and a control group of non-athletes, and the studies (Dallas, Kirialanis & Mellos, 2014; Dallas et al., 2019; Hall et al., 2016; Karagianni et al., 2020; Kinser et al., 2008) conducted on a gymnast and a control group after the intervention. The studies reported significant differences in jump height between the observed groups. Our results are consistent with the findings of previously mentioned studies, showing that gymnasts reached significantly higher jump heights than the control groups. Furthermore, the study by Ceroni, Martin, Delhumeau & Farpour-Lambert (2012), conducted on a large sample of female teenagers, found no significant differences between left and right peak force during CMJ. Since we did not find significant differences between the peak forces, our results could not be compared with the abovementioned study that was performed on non-athletes because they performed the single-leg CMJ, while we performed it with both legs.

Unfortunately, there are no published studies examining inter-limb asymmetries (ILAs) in young female gymnasts. Previous studies conducted on different athletes with varying age and performance levels (Šarabon, Kozinc…, 2020; Šarabon, Smajla…, 2020) reported different results of ILAs from isometric knee strength measurements as we did. Our results showed slightly higher ILAs for parameters of isometric knee strength, while ILAs of maximal force of CMJ are slightly lower in comparison with the mentioned studies. It has to be noted that ILAs in RTD were very large (13.7-34.1 % in the gymnast group), compared to commonly suggested thresholds of 10-15 % for clinical relevance. However, it has been shown that the magnitude of the RTD ILAs is much larger than peak torque ILAs (Šarabon, Kozinc, et al., 2020), which means that the aforementioned magnitude of the threshold for clinical relevance should probably not be applied to RTD outcomes. Bilateral strength asymmetry calculated from CMJ and isometric knee strength measurements are highly reliable measures (Impellizzeri et al., 2007). In this study, correlations among knee isometric strength parameters and CMJ were present only between PT knee flexion and knee extension, unlike in the study of Impellizzeri et al. (2007) conducted on male athletes, which showed a moderate correlation coefficient between two tests (the isometric knee leg press and the CMJ). The results are in contrast with our findings, which demonstrated no significant correlation between the CMJ and the isometric knee tests. Different results of aforementioned studies can be explained by different knee tests (isometric knee leg press vs. our isometric knee extension/flexion test using dynamometry) and participant samples (older male athletes vs. our young female gymnasts). In contrast to the aforementioned study, Kozinc & Šarabon (2020) showed that most coefficients were small and not statistically significant. The choice for assessing each type of ILA should be based on previous evidence and the aim of the testing. For instance, ILAs in strength may be detrimental to jumping and kicking, and ILAs in jumping could be detrimental to agility (Bishop et al., 2018). In case of injury risk tracking, or making decision regarding return to support, both single-joint and multi-joint tasks are probably needed for comprehensive assessment (Kotsifaki et al., 2021). Together with findings from previous studies, our results suggest a largely independent nature of ILAs between multi-joint and single-joint tasks, and even within the tasks to some degree. Therefore, the practitioners cannot generalize ILAs across tasks, i.e., each task should be assessed separately.

There are a few important limitations of our study that we would like to highlight. The sample size was relatively small, but on the other hand, the groups were matched in sample size and age. The size of the sample could be the reason that some moderate differences (e.g., ES = 0.41 for the left leg force in CMJ) between the groups were not statistically confirmed. As for the differences in RTD, it has to be stressed that this metric has a very high between-participant variability, which also reduced the effect sizes and precluded confirming between-group differences. In addition, the biological maturation (Tanner stages) of the gymnasts was not examined, which could affect the results of the asymmetries, since it is known that the observed age of the participants is crucial for biological maturation. In the studies with observed isometric knee strength or CMJ parameters, the sample size varied but is comparable to our study (Bogdanis et al., 2019; Pentidis et al., 2019, 2020; Thompson et al., 2017), while other studies had larger sample sizes (Bencke et al., 2002; Ceroni et al., 2012; Hall et al., 2016; Karagianni et al., 2020; Kinser et al., 2008; Markström et al., 2019). However, the results showed good reliability for all observed parameters.

CONCLUSIONS

This study examined differences in knee isometric strength and CMJ parameters and investigated correlations between ILAs of observed outcome measures between gymnasts and non-gymnast peers. The group of gymnasts showed superior performance in most knee flexion and all knee extension parameters, as well as in CMJ height, compared to the non-gymnast. The results of the ILAs showed that the gymnasts obtained ILAs of knee flexion and extension for the parameter maximal torque of less than 15%, while the group of non-gymnasts achieved for knee flexion 17%. Interestingly, the ILAs parameters were not statistically significantly different between the two groups. Nevertheless, we should be cautious and consider ILAs as an important factor for the prevention of injuries in gymnasts. It is already known that an adequate ration and ILAs of isometric knee strength below 15 % (Croisier, 2004; Kabacinski et al., 2018; Knapik et al., 1991; Murphy et al., 2003), and even below 10 % in gymnasts (Lilley et al., 2007), are crucial to prevent ACL injuries. Furthermore, there were no correlations in any of the knee strength parameters and maximal force of CMJ for each group. Therefore, whether in regard to injury risk or performance assessment, the practitioners cannot generalize ILAs across tasks, which means that each task should be assessed separately.

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