Comparison between gymnasts and non-gymnasts in isometric strength of the lower limbs

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Abstract

Muscle asymmetries in gymnasts are common and can lead to injury. We aimed to determine differences in hip, knee, and ankle strength between female gymnasts and non-gymnasts, and secondly, to determine the effect of strength training intervention. Fifteen 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 hip (extensor, flexor, abductor, adductor, internal and external rotator), knee and ankle flexors and extensors on a dynamometer. Inter-limb asymmetries (ILAs) were compared across strength outcomes (MVC torque) and groups. ILAs was calculated based on the strength measurements. The gymnasts were retested after 8 weeks, during which the participants performed 5 weeks of regular training and 3 weeks of targeted strength training intervention. We found significant differences between groups in most observed hip strength parameters, but not in knee and ankle strength. The intervention did not significantly affect any parameter of ILAs. Gymnasts and non-gymnasts differ in hip strength parameters. A longer intervention program may decrease ILA parameters.

Key Words: asymmetries; muscle strength; dynamometry; gymnasts.

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Artistic gymnasts (AG) are typically introduced to regular systematic training at a very young age. At an early stage, artistic gymnastics training involves continuous high-impact loads, performed at high-volumes (i.e. long hours of practice and a high number of drill repetitions).[1-3] Young gymnasts typically train between 16 and 30 hours [1,4-9] and even up to 40 hours per week.[6-8] Some studies suggest that early specialization is necessary to achieve elite level in highly technical sports, such as gymnastics.[4] Gymnasts must be in excellent physical condition and acquire a variety of skills specific to gymnastics. AG requires a high level of strength, power, speed, flexibility, and balance.[10,11] Skills and routines are practiced repeatedly to achieve excellence. This can lead to fatigue and more frequent injuries in gymnasts.[1,2,12] The incidence of injuries in female gymnasts ranges from 1.52 to 22.7 per 1000 hours of training.[5,7] The incidence probably varies with age, training/competition level, training period, location of the study, study design, and other factors.[7] Female gymnasts must have a good balance and strength to avoid injuries to the lower limbs, especially knees and ankles, which are more common in female than in male gymnasts.[7,11] Lower limb injuries represent from 54.1 % to 70.2 % of all injuries in female gymnastics.[7] Several studies have suggested that acute injuries occur due to the overload occurring during jumping (especially landing).[13-16]

In addition to good balance and strength, body asymmetries are an important risk factor for injuries and may be associated with decreased performance.[17-19] Inter-limb asymmetries (ILAs) > 15 % have been associated with increased injury incidence in athletes and non-athletes.[20-22] Šarabon and Kozinc (2019)[23] considered body (a)symmetries in the following specific contexts: i) the level of an individual joint; ii) the joint-muscle chains, and iii) the sagittal plane, which divides the body into a right and left part. Exell, Robinson, and Irwin (2016)[24] believe that asymmetry of movement, which has been frequently investigated, is indeed an essential part of gymnastics. Typically, more inter-limb differences are found in the lower extremities during bilateral exercises than during unilateral exercises.[6,18,19,25] This is confirmed by research conducted on different types of somersault landing. Maloney (2019)[26] suggests that exercise-based interventions, notably resistance exercise can reduce asymmetries and improve athlete's performance. However, Bishop, Turner, and Raed (2017)[27] argue that

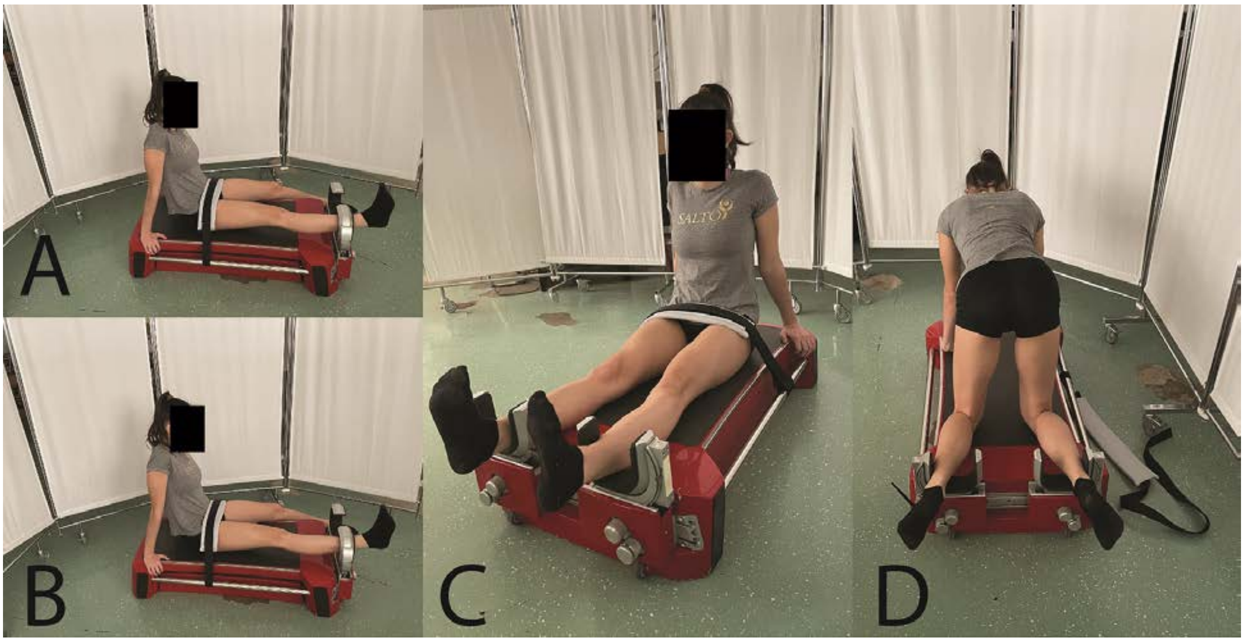

Fig 1. *Strength measurement of hip: extension (A), flexion (B), abduction and adduction (C), external and internal rotation (D)*

ILAs and their effects on physical or sports performance are less well known. As asymmetries remain a major problem in gymnastics and effective interventions to reduce asymmetries are scarce, this study aimed: i) to determine differences in the hip, knee, and ankle strength performance between gymnasts and non-gymnasts and ii) to examine the effect of intervention programs that we conducted on the experimental group (EG) of young gymnasts to reduce asymmetries (based on initial measurements of strength parameters of hip, knee, and ankle joint). We expected differences in strength parameters between the EG (young gymnasts) and the control group consisting of non-gymnasts. We hypothesized that the intervention program will reduce asymmetries in EG.

Materials and Methods

Participants

The sample consisted of 30 girls, which were divided into two groups. The experimental group (EG) consisting of artistic gymnasts (n = 15, age = 11.19 ± 1.89 years, height = 143.63 ±12.28 cm, body mass = 37.25 ± 10.34 kg) took part in gymnastics training (3.4 ± 1.80 years, 22 ± 6 weekly training hours). The control group (CG,) consisted of physically inactive girls (n = 15, age = 10.92 ± 1.96 years, height = 146.71 ± 11.28 cm, and body mass = 35.80 ± 11.03 kg). The inclusion criteria for the EG were good physical health during the measurements, age between 9 and 15 years, and participation in the training process of SK Salto. Inclusion criteria for the physically inactive group (CG) were a maximum of 2 hours of

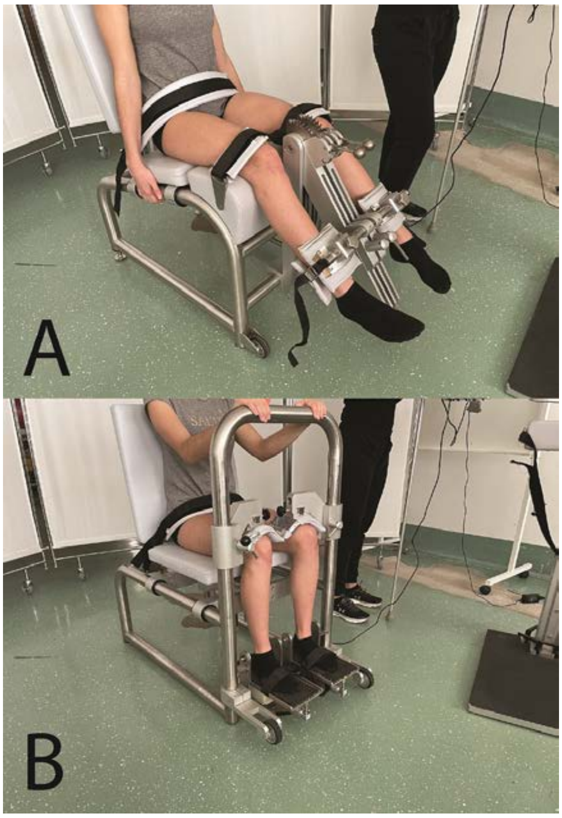

Fig 2. *Strength measurement of knee (A) and ankle (B) (flexion and extension).*

Table 1. *Descriptive statistics for all outcome parameters.*

Outcome/task		Mean	SD	Min	Max
Peak torques at the hip (Nm)	Hip Abduction – left	51.32	0.60	50.38	51.90
	Hip Abduction - right	52.14	0.16	51.64	52.88
	Hip Adduction - left	47.45	1.24	46.29	48.06
	Hip Adduction - right	46.99	0.82	45.54	47.97
	Hip Internal rotation - left	23.07	0.74	22.61	23.82
	Hip Internal rotation - right	24.47	0.75	23.78	25.46
	Hip External rotation - left	20.49	0.26	20.17	20.75
	Hip External rotation - right	20.47	0.22	20.30	20.72
	Hip Flexion - left	53.87	0.53	52.41	56.23
	Hip Flexion - right	51.51	1.30	20.42	52.73
	Hip Extention - left	54.30	1.09	52.96	55.02
	Hip Extention - right	56.77	0.93	55.57	57.38
Peak torques at the knee (Nm)	Knee Extention - left	63.97	1.58	63.28	65.12
	Knee Extention - right	66.69	0.87	66.09	67.17
	Knee Flexion - left	35.48	1.89	34.39	36.36
	Knee Flexion - right	41.52	1.11	40.14	42.36
Peak torques at the ankle (Nm)	Ankle Plantar flexion - left	74.65	3.04	70.34	80.24
	Ankle Plantar flexion - right	85.91	2.37	80.55	90.24
	Ankle Dorsiflexion - left	14.66	0.24	14.16	15.20
	Ankle Dorsiflexion - right	19.99	0.26	19.27	20.57

SD–standard deviation; Min–minimum; Max–maxmimum

physical activity per week and no skeletal, nerve, muscle, or connective tissue injuries during the last 12 months.
Prior to the experiment, we introduced the project to the coaches and parents or legal guardians of participants. The parents or legal guardians of all participants provided written consent for involvement in the study. The study was conducted in accordance with the Declaration of Helsinki and the experiment was approved by National Medical Ethics Committee for research on children and adolescents, obtained 23th of January 2018, (approval no: 0120-631/2017/2).

Study design, tasks, and procedures:

In this intervention study, the pre- and post-intervention measurements weres performed in the kinesiology laboratory on the 22nd and 23rd of March 2019. EG was tested on the first day and CG on the second day. The testing session lasted approximately 90 min per participant. The second set of measurements was performed on after 8 weeks, as the intervention period had concluded. In these 8 weeks, the gymnasts first performed 5 weeks of general training, followed by 3 weeks of asymmetry-reducing intervention program, based on strength exercises.
Participants, after arriving in the laboratory, changed their clothes and started warming up. All participants were barefoot and wore sports bras and tight sports shorts. The warm-up consisted of 6min of walking on a stepper, stretching exercises for the main muscle groups, and 10 squats for muscle activation. After warming up, the participants were assigned to one of the five measurement stations i) dynamometry of trunk-knee-ankle, ii) flexibility, iii) dynamometry of handgrip and shoulder strength, iv) force plate, and v) dynamometry of hip. This paper examines the results of dynamometry for the strength measurements of the hip, knee, and ankle joint. Each joint was asseseed on a different station, and the order of the stations was randomized across participants.

Strength assessment

All strength measurements were conducted with isometric dynamometers (S2P, Science to Practice, Ltd., Ljubljana, Slovenia). The participant was instructed to perform the task "as fast and as intense as possible" and to maintain the maximal effort for 3-5 s. The participant was loudly verbally encouraged throughout the trial in order to facilitate the maximal effort. Between each trial the participant rested for 30 s to fully recover and for the measurer to save the data and prepare for the next trial. The rest was 60 s when they needed to switch the leg or task. All strength measurements were conducted unilaterally. At each task, the participants performed 3 repetitions with each leg; we analyzed the maximum value of the three measurements for each limb and each task. For all tasks the peak torque was determined as the maximum value in a 1-second interval.

Table 2. *Differences between experimental and control group in strength measurements of lower limbs.*

Outcome/Task		EG (N = 15)		CG (N = 15)			
		Mean	SD	Mean	SD	p	ES
Peak torques at the hip (Nm)	Hip Abduction – left	62.7	20.57	45.2	16.28	**0.015***	0.95
	Hip Abduction - right	63.1	19.64	46.5	16.4	**0.018***	0.92
	Hip Adduction - left	55.4	18.33	44.6	15.94	0.098	0.62
	Hip Adduction - right	54.4	18.37	44.3	16.33	0.122	0.58
	Hip Internal rotation - left	28.6	11.97	22.4	8.63	0.113	0.60
	Hip Internal rotation - right	30.8	12.46	22.2	7.21	**0.017***	0.85
	Hip External rotation - left	25.7	8.51	18.5	6.62	**0.015***	0.94
	Hip External rotation - right	24.9	6.95	18.6	6.24	**0.014***	0.95
	Hip Flexion - left	68.4	21.16	47	17.97	**0.006***	1.09
	Hip Flexion - right	66.4	20.92	44.1	12.53	**0.001****	1.29
	Hip Extention - left	70.1	24.56	49	17	**0.010***	1.00
	Hip Extention - right	72.4	24.95	48.5	17.03	**0.005***	1.12
Peak torques at the knee (Nm)	Knee Extention - left	82.5	37.72	59.5	26.81	0.065	0.70
	Knee Extention - right	81	29.79	64.5	29.04	0.136	0.56
	Knee Flexion - left	43.9	17.27	34.6	14.22	0.141	0.59
	Knee Flexion - right	47.9	22.28	39.8	15.23	0.078	0.43
Peak torques at the ankle (Nm)	Ankle Plantar flexion - left	83	41.53	72.6	34.4	0.127	0.28
	Ankle Plantar flexion - right	92.5	45.6	85.7	43.09	0.295	0.15
	Ankle Dorsiflexion - left	13.5	7.522	15.6	5.796	0.993	-0.31
	Ankle Dorsiflexion - right	17.9	9.921	21	7.589	0.730	-0.36

EG–experimental group, CG–control group; SD–standard deviation; ES–effect size (Hedges);
* - $p < 0.05$; ** - $p < 0.001$.

Hip strength measurements were performed on a MuscleBoard dynamometer (S2P, Science to Practice, Ltd., Ljubljana, Slovenia). The tasks were performed in the following order: flexion (FLE), extension (EXT), abduction (ABD) and adduction (ADD), internal (IR) and external rotation (ER) of the hip joint. For details about subject positioning and fixation see Figure 1.

Strength of the unilateral knee EXT and FLE (random order) was also evaluated. The participant was seated on the dynamometer (S2P, Science to Practice, Ltd., Ljubljana, Slovenia) and was tightly fixated over the distal thigh and pelvis using rigid fixation trap (see Figure 2 for details). The dynamometer was set at the knee angle of 60° (0° = full extension) and hip angle of 100°.

Measurements of the ankle joint were performed in a neutral position of the ankle joint, using a custom-made dynamometer (S2P, Science to Practice, Ltd., Ljubljana, Slovenia). The participant was seated with upright trunk posture with upper legs horizontal and 90° hip and knee angle.

Based on the initial measurements and analysis of asymmetries, we performed an individual training intervention that lasted for 3 weeks, aiming to reduce asymmetries in strength parameters of a) hamstring, b) quadriceps, and c) lateral flexion of the trunk. The intervention program was performed only by the experimental group. First, we normalized outcome values of the hip, knee, and ankle isometric strength by the body mass of participants. We considered strong ILAs (> 20 %) as the target of our movement intervention, although different studies suggested that values from 5 % to 20 % normally characterize asymmetry (McGrath et al., 2015).[19,28,29]

Training intervention

After the initial measurements, gymnasts undertook a mixed prevention program that included general and specific individual program. A 5-week-long general prevention program intended for all gymnasts, which consists of different tasks to improve the strength of upper and lower limbs, and trunk. Participants were trained for 45 to 50 minutes three times per week (Monday, Wednesday, and Thursday). Then, in the following 3 weeks, the gymnasts additionally undertook a 3-week-long specific individual intervention program, composed according to the individual`s ILAs > 20 % profile. The duration of the training was individualized based on the number of ILAs, and the training was performed soon after a typical warm-up. Participants were trained three times a week (Monday, Wednesday, and Thursday). The intervention was always performed at the same time of day. The typical training was divided into warm-up (lasting approximately 45 minutes), intervention (lasting approximately 30 - 45 minutes), and

Table 3. *Differences between first and second measurements of experimental group in symmetry index (SI) of strength measurements.*

	Outcome/Task (Nm/kg)	EGpre (N = 9)		EGpost (N = 9)			
		Mean ± SD	SI (%) Mean ± SD	Mean ± SD	SI (%) Mean ± SD	p (SI)	ES
Hip strength	Hip Abduction - left	1.67 ± 0.24	3.51 ± 2.10	1.79 ± 0.32	2.29 ± 1.90	0.159	0.61
	Hip Abduction - right	1.68 ± 0.24		1.78 ± 0.31			
	Hip Adduction - left	1.51 ± 0.20	4.05 ± 3.04	1.39 ± 0.18	3.78 ± 5.32	0.892	0.06
	Hip Adduction - right	1.48 ± 0.15		1.42 ± 0.22			
	Hip Internal rotation - left	0.79 ± 0.26	11.30 ± 9.10	0.83 ± 0.20	11.78 ± 12.53	0.929	0.04
	Hip Internal rotation - right	0.82 ± 0.26		0.91 ± 0.23			
	Hip External rotation - left	0.70 ± 0.14	7.96 ± 5.77	0.66 ± 0.14	9.24 ± 5.69	0.604	0.22
	Hip External rotation - right	0.69 ± 0.12		0.66 ± 0.11			
	Hip Extention - left	1.91 ± 0.52	12.45 ± 7.96	1.82 ± 0.51	10.24 ± 5.60	0.458	0.31
	Hip Extention - right	1.90 ± 0.45		2.04 ± 0.56			
	Hip Flexion - left	1.82 ± 0.33	8.31 ± 3.04	1.72 ± 0.32	6.47 ± 6.60	0.535	0.36
	Hip Flexion - right	1.75 ± 0.35		1.72 ± 0.30			
Knee strength	Knee Extention - left	1.76 ± 0.64	10.97 ± 5.52	1.66 ± 0.29	6.51 ± 4.58	0.08	0.84
	Knee Extention - right	1.89 ± 0.70		1.59 ± 0.32			
	Knee Flexion - left	1.20 ± 0.30	17.22 ± 6.43	0.96 ± 0.34	19.93 ± 17.24	0.156	0.21
	Knee Flexion - right	1.40 ± 0.24		1.06 ± 0.27			
Ankle strength	Ankle Plantar flexion - left	2.26 ± 0.61	11.52 ± 10.41	1.97 ± 0.62	9.55 ± 8.54	0.603	0.21
	Ankle Plantar flexion - right	2.35 ± 0.60		2.18 ± 0.64			
	Ankle Dorsiflexion - left	0.40 ± 0.06	24.20 ± 10.95	0.41 ± 0.10	19.16 ± 10.76	0.353	0.46
	Ankle Dorsiflexion - right	0.52 ± 0.08		0.50 ± 0.08			

EG–experimental group, CG–control group; SD–standard deviation; ES–effect size (Hedges);
* - p < 0.05; ** - p < 0.001.

exercises in apparatus (all 4 women´s apparatuses and lasting 180 - 195 minutes). Specifically, the program included tasks for: a) balance, which consisted of single leg standing on the Airex and single leg drop jump with stability to be held for 5 seconds, b) flexibility (psoas stretching with a partner and stretching the external hip rotator), and c) strength tasks, which consisted of bird dog with single leg lift and single leg slide, single leg step-up and jump on the box, and side plank on the floor. Training volume and intensity of all the tasks were gradually increased during the three week period. Participants performed 3 sets of balance and flexibility tasks and 3 - 4 sets of strength tasks. Subjects rested for 2 - 3 minutes between the sets.

Statistical analysis

For all isometric outcome measures of hip, knee and ankle strength, the average value of the three trials for each task and side was considered for calculating inter-limb asymmetry (ILA), using the equation:

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

Inter-limb asymmetries that deviated by more than 20 % were considered clinically significant.

***Table 4.** Differences between experimental and control group in symmetry index (SI) of strength* measurements.

	Outcome/Task (Nm/kg)	EG (N = 15)		CG (N = 15)			
		Mean ± SD	SI (%) Mean ± SD	Mean ± SD	SI (%) Mean ± SD	p (SI)	ES
Hip strength	Hip Abduction - left	1.68 ± 0.29	3.61 ± 2.74	1.27 ± 0.25	19.56 ± 14.80	**0.000****	1.45
	Hip Abduction - right	1.70 ± 0.27		1.27 ± 0.56			
	Hip Adduction - left	1.47 ± 0.18	3.58 ± 3.74	1.23 ± 0.54	4.47 ± 3.20	0.49	0.25
	Hip Adduction - right	1.44 ± 0.17		1.22 ± 0.56			
	Hip Internal rotation - left	0.77 ± 0.22	14.43 ± 10.16	0.60 ± 0.21	13.03 ± 8.25	0.68	0.15
	Hip Internal rotation - right	0.82 ± 0.22		0.61 ± 0.25			
	Hip External rotation - left	0.69 ± 0.13	6.54 ± 5.18	0.50 ± 0.21	6.78 ± 4.91	0.89	0.05
	Hip External rotation - right	0.68 ± 0.11		0.51 ± 0.21			
	Hip Extention - left	1.90 ± 0.44	10.41 ± 7.45	1.35 ± 0.63	12.33 ± 10.18	0.66	0.16
	Hip Extention - right	1.94 ± 0.40		1.35 ± 0.65			
	Hip Flexion - left	1.83 ± 0.31	8.61 ± 4.42	1.29 ± 0.63	15.73 ± 10.43	**0.03***	0.80
	Hip Flexion - right	1.78 ± 0.32		1.17 ± 0.40			
Knee strength	Knee Extention - left	2.15 ± 0.58	14.61 ± 9.22	1.61 ± 0.29	23.32 ± 15.87	**0.02***	0.90
	Knee Extention – right	2.16 ± 0.52		1.72 ± 0.69			
	Knee Flexion – left	1.20 ± 0.27	13.99 ± 8.03	0.95 ± 0.22	20.82 ± 16.82	0.07	0.69
	Knee Flexion – right	1.37 ± 0.25		1.01 ± 0.39			
Ankle strength	Ankle Plantar flexion – left	2.36 ± 0.54	10.97 ± 9.49	1.99 ± 0.42	24.11 ± 19.81	**0.03***	0.81
	Ankle Plantar flexion - right	2.64 ± 0.57		2.63 ± 1.85			
	Ankle Dorsiflexion - left	0.40 ± 0.06	28.24 ± 17.02	0.44 ± 0.10	30.21 ± 11.70	0.72	0.13
	Ankle Dorsiflexion - right	0.62 ± 0.35		0.57 ± 0.21			

EG–experimental group, CG–control group; SD–standard deviation; ES–effect size (Hedges);
* - p < 0.05; ** - p < 0.001.

Statistical analysis was conducted with IBM SPSS Statistic 26 (IBM, New York, USA). For all parameters we calculated descriptive statistics (mean value ± standard deviation, minimum and maximum value). We used the intraclass correlation coefficient ICC to test then intrarater reliability of the strength measurements, which reflects the variation of data measured by 1 rater across initial and final measurements. Values were analyzed using 1-way variance with a 95 % confidence interval. ICCs were interpreted according to Koo and Li (2016)[30], where ICC >0.90 = excellent, 0.75–0.90 = good, 0.50–0.74 = moderate and <0.50 = poor. The ICC calculated in this study (0.96; range = 0.93 - 0.99) demonstrated excellent intra-session reliability. Before analysing the differences, we tested normality of distribution using the Shapiro-Wilk test. To determine the differences between experimental and control groups, we used the t-test for independent samples for normally distributed parameters and Mann-Whitney U-test for the non-normally distributed parameters. The paired-t test was used to determine the intervention effects in the experimental group. Significance level was set at $\alpha < 0{,}05$.

Results

Three participants from EG were injured and did not complete all initial strength measurements of the ankle and knee. Descriptive statistics regarding all isometric strength assessments are presented in Table 1.

Table 2 summarizes the differences between EG and CG in all isometric strength measures. Note that we consider the mean value of three measurements per participant.

Statistically significant differences between EG and CG ($p < 0.05$; ES = 0.85 – 1.29) were detected in all observed parameters of hip strength, except for the ADD of the left (ES = 0.62) and right leg (ES = 0.58), and IR of the left hip (ES = 0.60). Meanwhile, there were no statistically significant differences between groups in knee (ES =

Table 5: *Pre and post measurements of experimental group in strength measurements of lower limbs.*

Outcome/Task		**EGpre (N = 9)** Mean	SD	**EGpost (N = 9)** Mean	SD	p	ES
Peak torques at the hip (Nm)	Hip Abduction – left	62.06	20.39	66.95	24.81	0.112	0.22
	Hip Abduction - right	62.97	20.33	66.61	24.57	0.157	0.18
	Hip Adduction - left	56.80	20.74	52.43	18.79	0.160	0.22
	Hip Adduction - right	55.97	20.33	53.61	20.58	0.481	0.12
	Hip Internal rotation - left	29.32	13.21	31.24	12.97	0.435	0.15
	Hip Internal rotation - right	30.96	13.83	33.96	13.41	0.096	0.22
	Hip External rotation - left	25.65	8.29	24.92	10.45	0.673	0.08
	Hip External rotation - right	20.67	5.88	24.37	8.21	0.793	0.04
	Hip Flexion - left	67.69	20.10	64.83	25.41	0.517	0.12
	Hip Flexion - right	65.98	25.58	64.20	23.16	0.583	0.07
	Hip Extention - left	70.19	27.94	68.90	31.35	0.762	0.04
	Hip Extention - right	70.76	25.94	77.77	36.77	0.195	0.18
Peak torques at the knee (Nm)	Knee Extention - left	75.47	28.21	60.25	24.24	**0.013***	0.58
	Knee Extention - right	78.90	31.60	58.65	24.45	**0.001****	0.72
	Knee Flexion - left	43.08	17.41	33.82	17.87	**0.004***	0.52
	Knee Flexion - right	51.26	19.01	37.76	20.35	**0.004***	0.68
Peak torques at the ankle (Nm)	Ankle Plantar flexion - left	81.77	28.78	69.65	27.69	**0.026***	0.43
	Ankle Plantar flexion - right	89.99	29.93	78.08	29.72	**0.032***	0.40
	Ankle Dorsiflexion - left	14.99	5.60	15.23	6.84	0.510	-0.04
	Ankle Dorsiflexion - right	19.70	7.20	18.27	6.61	0.268	0.21

EGpre–initial measurement of experimental group; EGpost–post measurement of experimental group; SD–standard deviation; ES–effect size (Hedges); * - p < 0.05; ** - p < 0.001

0.43 – 0.70) and ankle strength measurements (ES = -0.36 – 0.28).

Table 3 shows the inter-limb asymmetry (ILA) of isometric strength parameters between two sessions of the experimental group. Due to injury or absence from the first or the second measurements, we excluded 6 participants. For further analysis, we included 9 participants.

After the intervention, participants exhibited reduced ILAs of hip extension, ankle plantar flexion, and dorsiflexion, but the difference was not statistically significant ($p > 0.05$; ES = 0.21 and 0.51, respectively). ILAs did not significantly change in hip abduction (ES = 0.61) and adduction (ES = 0.06), knee extension (ES = 0.88), and ankle dorsiflexion (ES = 0.21). Meanwhile, ILAs increased for some parameters, but not statistically significantly for hip internal and external rotation (ES = 0.04 - 0.22) and hip and knee flexion (ES = 0.21 - 0.36).

Table 4 shows the inter-limb asymmetry (ILA) of isometric strength parameters between two groups.

Statistically significant differences between EG and CG ($p < 0.05$; ES = 0.80 – 1.42) were detected in the ILAs of the hip ABD and FL, knee EX and APF. Meanwhile, there were no statistically significant differences between groups in ILAs of the hip ADD, IR and ER (ES = 0.05 – 0.24), knee FL (ES = 0.68) and ankle ADF (ES = 0.13).

Table 5 presents the results of the pre and post measurements of the experimental group (all isometric strength parameters), which were performed after detecting inter-limb asymmetries.

Statistically significant differences between pre and post intervention in the EG ($p < 0.005$; ES = 0.52 – 0.72) were found in all knee parameters, and in plantar flexion of both ankles (left and right) ($p < 0.05$; ES = 0.40). The results were higher in pre session. Meanwhile, there were no statistically significant differences between pre and post intervention measurements in the EG in any of the hip parameters (ES = -0.20 – 0.22) and ankle dorsiflexion (ES = - 0.04 – 0.21).

Discussion

The purpose of the present study was twofold: i) to determine differences in the hip, knee, and ankle strength performance between gymnasts and non-gymnasts, and ii) to examine the effect of intervention programs that we conducted on the experimental group (EG) of young gymnasts to reduce asymmetries, based on initial measurements of strength parameters of hip, knee, and ankle joint. The results showed statistically significant differences between the groups only for some hip strength parameters (Table 2). The intervention program indicated improvement in symmetries of all knee strength parameters and plantar flexion of both ankles.

To the best of our knowledge, there are no published studies examining the isometric strength of the lower limb measures of young female gymnasts and non-gymnasts. Our results showed that gymnasts had a significantly higher peak torque (PT) of both legs on hip measurements compared to non-gymnasts. Similar results were observed in only one other study, which tested athletes with patellar tendinopathy using a handheld dynamometer.[31]

Only one study, conducted on male basketball players, used a fixed dynamometer to assess PT of the hip muscles.[32] However, it cannot be easily compared to our study conducted on young female gymnasts. Of note, hip muscles and their imbalance or deficit have been identified as risk factors for lower limb (LL) injuries.[33]

Our results of isometric knee strength measurements are similar to those of a study comparing female basketball and volleyball players[28] and a study examining different sports in both genders.[34] We did not detect significant differences in the values of flexion and extension PT of knee strength, unlike the study of Šarabon, Smajla, Maffiuletti, Bishop (2020)[35] which assessed male basketball, soccer and tennis players. The study reported significant differences between sports in both flexion and extension PT of the knee. Moreover, the study observed differences between female basketball players and gymnasts in terms of knee flexion and extension strength.[36] The results showed 60 % higher values for knee flexion strength and 43 % higher values for knee extension strength compared to our study. Our results could be comparable, if the values were normalized to gymnast's body weight and a younger sample of gymnasts (age 19.5 years). Our results partially match the findings of a study conducted on elite and non-elite female athletes. The study found that the groups differed significantly in PT of extensor muscles but not in PT of flexor muscles.[37] Adequate strength and ratio of the lower limbs, particularly the knee muscles, is necessary in many gymnastics tasks (e.g., landing, cutting, jumping, accelerating). PT and rate of torque development (RTD) are important variables of isometric strength in determining the athlete´s risk of injury.[28,36]

We are aware of only one study that measured MVC torque of ankle plantar flexion (APF) and dorsiflexion (ADF) of the ankle joint using an electric dynamometer. The study reported slightly lower reliability of APF and ADF compared to our study (ICC = 0.93 and 0.83; 0.99, respectively) and the values of PT of APF and ADF were higher compared to our study, which is probably due to a sample of older athletes with and without medial tibial stress syndrome (MTSS).[38] Ankle injuries are the most common form of injury in gymnastics. A few studies suggest that good ankle proprioception is necessary to prevent ankle injuries and that it predicts sports performance.[11,39] Impaired hip abductor strength may also increase the risk for an ankle injury.[40]

In addition, our study observed that intervention programs indicate improvement in inter-limb asymmetries (ILAs) of the lower limbs, nevertheless there were non-significant pre-post differences. Unfortunately, there are no published studies examining intervention programs to reduce ILAs in young female gymnasts. We found several studies that investigated the effects of different training interventions of varying lengths (4-week,[41] 6-week,[12,42], 7-week,[43] or 8-week[44,45]) conducted on young female gymnasts, which had different outcomes than our study. While these studies collectively show that resistance exercise in gymnasts can improve jumping performance, speed, change of direction ability and sport-specific skills, our study was the fist to assess the effect of resistance exercise on single-joint strength.

ILA of the hip peak torque that we observed was similar to that reported in a study conducted on male basketball players,[32] which could be attributable to shorter training history, as our sample was very young. Previous studies have assessed ILAs of isometric strength measurements of knee flexion and extension in athletes with varying age and skill level.[34,35] Our results showed slightly lower ILAs of the knee flexion and extension compared to the mentioned studies.

The most important limitations of our study are the relatively small sample size, lack of the control group for the intervention period, and absence of the follow-up measurements. In the studies with intervention effects, the sample size varied but was comparable to our study,[12,41,43] while some studies had larger sample sizes.[42,44,45] However, we found excellent reliability for all strength measures. Another limitation of our study is the inclusion of only female subjects and participants' wide age range, spanning from childhood to early adolescence. Another limitation is the duration of intervention, which was shorter than in other comparable studies and varied from 4-weeks,[41] to 6-weeks,[12,42] to7-weeks,[43] to a maximum of 8-weeks.[44,45] Due to the aforementioned limitations, we cannot generalize the results outside of the population of young female gymnasts. Finally, the biological maturation of the participants was not assessed. Since the biological maturation could be a confounding factor for torque values, as well as asymmetries, future studies should consider it as control variable for their assessments.

This study explored differences in lower limb isometric strength between gymnasts and non-gymnasts, and investigated whether the intervention lowered ILAs in healthy gymnasts. The two groups of participants differed significantly in hip abduction, internal and external rotation, flexion, and extension isometric strength when hip, knee, and ankle isometric strength were measured. The intervention did not reduce ILAs in female gymnasts. Interestingly, the intervention statistically significantly decreased isometric strength in knee flexion and extension and in ankle plantar flexion. At the same time, hamstrings remained stronger than quadriceps. Strong hamstrings may protect against anterior cruciate ligament injuries, especially during jump landing when the training program consists of an eccentric exercise.[28]

Overall, gymnastics coaches should consider ILAs for preventing injury during training. Gymnastics training, which usually consists of plyometric training, should include the prevention portion of our brief exercise intervention.

Acronyms

ABD – abduction
ADD – adduction
AG – artistic gymnastics
APF – ankle plantar flexion
DPF – ankle dorsiflexion
ER – external rotation
EXT – extension
FLE – flexion
ILAs – inter-limb asymmetries
IR – internal rotation
MVC – maximal voluntary contraction

Authors contributions

Both authors UČ and NŠ contributed to the paper equally and approved the edited paper.

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Conflict of Interest

The authors have no conflict of interest to declare.

Ethical Publication Statement

We confirm that we have read the Journal’s position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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