

## Research Article

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# The bilateral strength and power asymmetries in untrained boys

**Abstract:** The aim of the study was to identify the level of isokinetic strength and power of lower limbs in 13-year-old untrained boys ( $n=22$ , height:  $158.5\pm 8.0$  cm, mass:  $49.1\pm 12.6$  kg), to determine bilateral deficit between the limbs in the tests and examine their mutual relationship. Maximum peak muscle torque of knee extensors (PTQ) and flexors (PTH) on dominant (DL) and non-dominant leg (NL) were measured by isokinetic dynamometer. Three types of a vertical jump: countermovement jump with (CMJFA) and without arms (CMJ) and squat jump (SJ) were performed on two force platforms.

We found the significant effect ( $p<.01$ ) of independent variables (knee extensors, flexors, AV) and their interaction on PT. AV did not indicate any significant effect on bilateral ratio of knee extensors ( $F_{4,84}=.74$ ,  $p>.05$ ,  $\eta^2=.03$ ), however a significant effect of AV was found in knee flexors ( $F_{4,84}=2.70$ ,  $p<.05$ ,  $\eta^2=.114$ ). The type of jump had no effect on the difference between force exerted by DL and NL ( $F_{1,21}=.102$ ,  $p>.05$ ,  $\eta^2=.01$ ). Bilateral deficit (Q:Q, H:H) did not significantly correlate with bilateral deficit in jumps ( $p>.05$ ).

Despite the possibility of identifying muscle asymmetries in the sense of strength imbalances, their mutual relationship with results in isokinetic dynamometry and power jump tests is still unclear.

**Keywords:** Isokinetic testing; vertical jump; injury prevention; youth; symmetry; imbalance; health

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## 1 Introduction

The life-style of the young generation is influenced by circumstances arising in the last two decades, which have formed the opinions, attitudes and habits of young people. Different elements of physical fitness in children showed a declining trend during the past few decades [1]. The consumer way of life, hypokinesia, a high level of stress stimuli and low level of physical activity (PA) stimuli account for only a part of the negatives leading to maladaptive processes of the organism. People usually perform daily activities with their dominant hand or foot [2]. During their execution, there is a continual overloading of one side of the body and thus muscle imbalances (MI) or asymmetries may appear unless they are adequately compensated. Asymmetrical strength across the lower extremities can be defined as the inability to produce a force of contraction that is equal across the quadriceps and hamstring of both the right and left sides [3]. The bilateral limb deficit describes the differences in maximal, or near maximal force generating capacity of muscles when they are contracted alone or in combination with the contralateral muscles [4].

Before a preparatory period, athletes in most sport disciplines complete diagnostic tests that identify their strengths and weaknesses. Research presents different morphology and MI in athletes with unilateral specific load [5-10]. Muscular strength (MS) and endurance may play a pivotal role in preparing young people for the execution of physical activities. MS is an important component of fitness in health and disease because weak muscles may markedly limit a person's physical fitness and daily physical abilities. Unlike aerobic fitness, which refers to the body as a whole, strength is a local characteristic of each muscle or muscle group. As a result, a person's strength varies from one muscle group to the other, and the correlation between muscle groups is low to moderate. It is possible, for example, for a child to have strong lower limbs and weak arms or to show major differences in strength of the right and left sides of the body [11]. To assess MS in

youths, tests such as sit ups, number of push ups, curls, standing long jump, etc, are often used in practice. These tests require multi-joint movements and therefore they do not evaluate strength of an isolated muscle group. On the basis of these tests it is not possible to observe and quantify detailed characteristics of MS and strength imbalances (SI). Testing of isokinetic strength provides an objective approach in diagnostics and simpler quantification of MS and SI in children. Different aspects of lower limb strength and power are frequently examined using the isokinetic knee joint test and vertical jump test [12]. Nevertheless, in this field there are many gaps dealing with its manifestation among youths [12-15]. Holm, Fredriksen, Fosdahl and Vollestad [16] present the basic normative data of muscular strength in isokinetic modes in youths aged 7 to 12. Degache, Richard, Edouard, Oullion and Calmels [13] present basic values of isokinetic strength of extensors and flexors in the young trained population (n=79). The limit of this study is the assessment of peak torque only in two levels of angular velocity ( $60^{\circ}\cdot s^{-1}$ ,  $180^{\circ}\cdot s^{-1}$ ). In addition, these studies do not examine bilateral deficit of lower limb MS.

A vertical jump (VJ) performed under laboratory conditions is a functional test which is especially used for assessing lower limb power. Furthermore, there are several tests to measure lower limb power and the most commonly used are countermovement jump with arms included and countermovement jump with arms excluded [17-20] and squat jump [17,19,21]. However, the above mentioned studies do not deal with the bilateral deficit and its relationship to other SI in the untrained population. Although asymmetrical strength has been linked to a variety of pathological conditions, relatively little research is currently conducted to identify these deficits in children without regular physical activity. This raises the question whether there is significant correlation between bilateral strength deficit during the testing of isokinetic strength at different angular velocities of movement and bilateral deficit of muscular strength produced in take-off in different types of VJ in young untrained boys. To the author's best knowledge, there are no data on bilateral deficit in isokinetic strength and vertical jumping in pre-pubertal untrained boys.

The aim of the presented study was to identify the level of isokinetic strength and power of lower limbs in untrained boys, to determine bilateral deficit between the limbs in the conducted tests and examine their mutual relationship.

## 2 Materials and methods

The presented study used a cross-sectional design to investigate the level of isokinetic strength of knee extensors (KE) and flexors (KF), power assessment (jump tests) and the relationship between bilateral force deficit (BFD) between isokinetic strength and maximum strength generated in take-offs.

### 2.1 Participants

The screened sample consisted of 13-year-old untrained boys (n=22, body height:  $158.5\pm 8.0$  cm, body weight:  $49.1\pm 12.6$  kg, body fat percentage:  $17.8\pm 4.5\%$ , fat free mass:  $42.6\pm 8.9$  kg). All participants attended primary school and did not perform any regular physical activity [except for Physical Education at school (2 x 45 min/week)]. The participants were selected according to the following eligibility criteria (Table 1) All subjects performing tests on lower limb asymmetry had not undergone any surgery on the knee joint and two days before testing they did not undergo any exhausting physical load. Legal representatives of all tested subjects were notified of the content and implementation of testing procedures and endorsed it with their signatures. The research was approved by the Ethical committee of Faculty of Physical Education and Sports, Charles university in Prague. Measurement were carried out in accordance with ethical standards of

**Table 1:** Eligible criteria.

Inclusion Criteria:
Age: 13 years old
Gender: Male
Sport Activities: without regular and intentional physical activity (< 1 hour per week / beyond compulsory school physical education), not registered in any sport club
Without former injury of knee (ACL injuries, cartilages, meniscus) and ankle
Upon approval by parents with testing
Exclusion criteria:
Former injury of knee or ankle (limitation of movement > 2 weeks)
Participant's disapproval with testing
Legal representative's (parents) disapproval with testing
Registration in sport club

Declaration of Helsinki and ethical standards in sport and exercise science research [22].

## 2.2 Data collecting

### 2.2.1 Anthropometric data

Before testing muscular strength, participants took part in basic measurement of anthropometric parameters. Body height was measured using a digital stadiometer (SECA 242, Hamburg, Germany) and body weight using a digital scale (SECA 769, Hamburg, Germany). Fat mass was detected using the bioimpedance method according to manufactured regression equation (TANITA MC-980MA, Tanita Corporation, Japan).

### 2.2.2 Isokinetic dynamometry

Muscular strength of lower limbs was assessed using a Cybex Humac Norm isokinetic dynamometer (Cybex NORM®, Humac, CA, USA). Maximum peak muscle torque of knee extensors ( $PT_Q$ ) and flexors ( $PT_H$ ) on dominant (DL) and non-dominant leg (NL) during concentric contraction were measured at five angular velocities of movement (60, 120, 180, 240 and  $300^\circ \cdot s^{-1}$ ). Limb dominance was determined by determining which foot each participant preferred to kick a ball with. The tested subject sat on the seat of the dynamometer which was ergonomically set with the arm of the dynamometer according to the instructions and individual somatic characteristics of the participant. The axis of the dynamometer arm's rotation was visually adjusted according to a laser point with the axis of knee rotation. PT was controlled and modified by gravitational influence at each velocity. The motion range was  $90^\circ$  (maximum extension was marked and set as "anatomic zero  $0^\circ$ "). The participant's trunk and thigh of the tested limb were fixed by means of the dynamometer's fixing straps so that movement was isolated to single joint movement only (knee extension – flexion). The participant held the side handles of the device during the measurement. The testing protocol consisted of three attempts at knee flexion and extension at the monitored velocities (from the lowest to the highest velocity). The procedure from the lowest to the highest velocity has been standardized and recommended by Wilhite, Cohen and Wilhite [23]. Before testing at each velocity, participants completed 4 training trials at submaximal intensity. This procedure is in accordance with methodological recommendations for

testing isokinetic strength on isokinetic dynamometer in youths [24]. Visual feedback and verbal stimulation were given during the testing.

### 2.2.3 Power assessment

Jump height (JH) and force exerted under each foot separately was measured using two side-by-side mounted force platforms Kistler B8611A, 400 Hz (KISTLER Instrumente AG, Switzerland). For data processing, software BioWare 4.0.0 and MatlabR2013 were used. For height of the jump, the calculation from the velocity of Centre of Gravity was used. All participants performed three types of a VJ: countermovement jump with arms included ( $CMJ_{FA}$ ), countermovement jump with arms excluded (CMJ) and squat jump (SJ).

Before measurement all tested subjects completed a short warm-up (dynamic half squats 3 sets@10 repetitions, forward lunges 3 sets@10 repetitions) and static stretching of lower limb muscles (6 minutes). Before each type of VJ participants had three training trials. Participants completed three trials in each type of VJ. Rest interval between trials was 60s. The trial with the highest achieved value of JH was selected for further result processing. In addition to JH we assessed bilateral force deficit (BFD) of the maximum force exerted between the legs at take-off as follows:

$$\text{Bilateral force deficit} = \frac{\text{Dominant limb score} - \text{Non-dominant limb score}}{\text{Dominant limb score}} \times 100 (\%)$$

## 2.3 Statistical and data analysis

Research data were processed using repeated measures analysis of variance (RM ANOVA) for dependent variables (peak torque, Q:Q ratio, H:H ratio, JH, BFD). Independent variables at assessment of PT included angular velocity (AV), limb dominancy, muscle group (KE, KF) and during assessment of jump performance it was type of jump ( $CMJ_{FA}$ , CMJ and SJ). Normality of data was verified, for the purpose of using parametric methods, using Shapiro-Wilk test. To evaluate equality of variances, Levene's test was used. The criterion of sphericity as one of the conditions of ANOVA was assessed by the Mauchly's test ( $\chi^2$ ).

Multiple comparisons of means of the monitored groups were carried out using Bonferroni's correction for p-values of post hoc tests. Effect size coefficient was assessed using "Partial Eta Squared -  $\eta_p^2$ ". Pearson

correlation coefficient ( $r$ ) was used to determine the inter-relationships between variables. The probability of type I error ( $\alpha$ ) was set at 0.05 in all statistical analyses. Statistical analysis was carried out using IBM® SPSS® v21 (Statistical Package for Social Science, Inc., Chicago, IL, 2012).

### 3 Results

The results revealed a significant effect ( $p < .01$ ) of independent variables (Muscle group – knee extensors or flexors and angular velocity) and their interaction on muscular strength of lower limb recorded by isokinetic dynamometry (Table 2). Limb dominance did not have any significant effect on muscular strength of lower limbs in the monitored group.

Bonferroni’s *post hoc* test showed significant differences in muscular strength between 60,120 and 180°·s<sup>-1</sup> velocities ( $p < .01$ ). Results of peak muscle torque and its

comparison between the dominant and non-dominant limbs are listed in Table 3.

Angular velocity did not indicate any significant effect on bilateral ratio of knee extensors ( $F_{4,84} = .74, p > .05, \eta_p^2 = 0.03$ ). Differences between the dominant and non-dominant limbs were as follows:  $PT_{Q60} = 14 \pm 1$  N·m,  $PT_{Q120} = 13 \pm 35$  N·m,  $PT_{Q180} = 12 \pm 3$  N·m<sup>-1</sup>,  $PT_{Q240} = 10 \pm 2$  N·m and  $PT_{Q300} = 13 \pm 2$  N·m. However, a significant effect of angular velocity on strength asymmetry was found in knee flexors ( $F_{4,84} = 2.70, p < .05, \eta_p^2 = .114$ ).  $PT_{H60} = 12 \pm 2$  N·m,  $PT_{H120} = 22 \pm 4$  N·m,  $PT_{H180} = 25 \pm 5$  N·m,  $PT_{H240} = 19 \pm 2$  N·m and  $PT_{H300} = 24 \pm 5$  N·m.

Type of jump significantly influenced jump height in the tested group ( $F_{2,42} = 24.79, p < .01, \eta_p^2 = .54$ ). Countermovement jump with an arm swing was significantly higher than countermovement jump with arms excluded or squat jump ( $p > .05$ ). The type of jump had no effect on the difference between force exerted by DL and NL ( $F_{1,21} = .102, p > .05, \eta_p^2 = .01$ ). Results of jumps, bilateral deficits and significance between DL and ND are presented in Table 4.

**Table 2:** Effect of the monitored independent variables on isokinetic strength (dependent variable).

Variables	Type III Sum of Squares	df	Mean Square	F	Sig.	$\eta_p^2$
Limb dominancy (LD)	143.18	1	143.18	.45	.50	.00
Muscle group (MG)	200433.82	1	200433.82	624.30	.00‡	.60
Angular velocity (AV)	61377.08	4	15344.27	47.79	.00‡	.31
LD*MG	575.02	1	575.02	1.79	.18	.00
LD*AV	320.21	4	80.05	.25	.91	.00
MG*AV	9560.62	4	2390.16	7.44	.00‡	.07
LD*MG*AV	117.65	4	29.41	.09	.99	.00
Error	134842.41	420	321.05			

Legend: df – degrees of freedom, ‡ – significant differences at  $p < .01$

**Table 3:** Peak muscle torque in the monitored velocities and its comparison between the dominant and non-dominant limbs (Data are presented in mean ± SE).

Angular velocity	$PT_{Q-DL}$ (N·m)	$PT_{Q-NL}$ (N·m)	Q:Q ratio (%)	$PT_{H-DL}$ (N·m)	$PT_{H-NL}$ (N·m)	H:H ratio (%)
60°·s <sup>-1</sup>	106±6	101±5	14±1	45±4	43±4	12±2
120°·s <sup>-1</sup>	88±4	83±6	13±3	39±3	41±4	22±4
180°·s <sup>-1</sup>	75±4	73±5	12±3	31±3	36±3‡	25±5
240°·s <sup>-1</sup>	65±4	64±3	10±2	29±3	30±3	19±2
300°·s <sup>-1</sup>	59±4	55±3	13±2	24±2	24±3	24±5

Legend: ‡ – significant differences at  $p < .01$  when comparing the two limbs

**Table 4:** Jump tests scores for dominant and non-dominant limbs.

Variable	Jump height (cm)	F <sub>max-DL</sub> (N)	F <sub>max-NL</sub> (N)	BFD (%)
CMJ <sub>FA</sub>	23.3±1.0	605±34	568±34 <sup>‡</sup>	8.1±1.2
CMJ	20.4±0.8	628±35	605±37	8.7±1.0
SJ	20.4±0.8	575±29	533±28 <sup>‡</sup>	8.5±1.0

Legend: CMJ<sub>FA</sub> – countermovement jump with arms included, CMJ – countermovement jump with arms excluded, SJ – squat jump, DL – dominant leg, NL – non-dominant leg, BFD – bilateral force deficit, † – significant differences at  $p < .01$  when comparing the two limbs

**Table 5:** Correlations between bilateral strength imbalances in the monitored variables.

Variable	PT <sub>Q60</sub>	PT <sub>Q120</sub>	PT <sub>Q180</sub>	PT <sub>Q240</sub>	PT <sub>Q300</sub>	Variable	PT <sub>H60</sub>	PT <sub>H120</sub>	PT <sub>H180</sub>	PT <sub>H240</sub>	PT <sub>H300</sub>	CMJ <sub>FA</sub>	CMJ	SJ		
PT <sub>Q60</sub>	r	1				PT <sub>H60</sub>	r	1								
	Sig.						Sig.									
PT <sub>Q120</sub>	r	.546 <sup>‡</sup>	1			PT <sub>H120</sub>	r	.458 <sup>†</sup>	1							
	Sig.	.009					Sig.	.032								
PT <sub>Q180</sub>	r	.397	.584 <sup>‡</sup>	1		PT <sub>H180</sub>	r	.335	.479 <sup>†</sup>	1						
	Sig.	.068	.004				Sig.	.128	.024							
PT <sub>Q240</sub>	r	.135	.128	.270	1	PT <sub>H240</sub>	r	.176	.418	.674 <sup>‡</sup>	1					
	Sig.	.548	.569	.225			Sig.	.433	.053	.001						
PT <sub>Q300</sub>	r	-.056	.321	.288	.271	1	PT <sub>H300</sub>	r	.186	.476 <sup>†</sup>	.470 <sup>†</sup>	.662 <sup>‡</sup>	1			
	Sig.	.803	.145	.194	.223			Sig.	.406	.025	.027	.001				
CMJ <sub>FA</sub>	r	-.328	.119	-.026	.196	.301	CMJ <sub>FA</sub>	r	-.311	-.084	-.178	.057	.041	1		
	Sig.	.137	.598	.910	.383	.174		Sig.	.158	.710	.427	.802	.855			
CMJ	r	.065	.396	.329	.238	.266	CMJ	r	.106	.297	.147	.207	.271	.630 <sup>‡</sup>	1	
	Sig.	.776	.068	.136	.287	.232		Sig.	.637	.179	.514	.355	.222	.002		
SJ	r	-.043	-.189	-.159	.279	-.032	SJ	r	-.265	-.239	-.165	-.213	-.046	.194	-.052	1
	Sig.	.849	.400	.480	.208	.886		Sig.	.234	.284	.462	.342	.839	.388	.818	

Legend: CMJ<sub>FA</sub> – countermovement jump with arms included, CMJ – countermovement jump with arms excluded, SJ – squat jump, DL – dominant leg, NL – non-dominant leg, r – Pearson correlation coefficient, † – significant differences at  $p < .05$ , ‡ – significant differences at  $p < .01$

Bilateral deficit between knee extensors and flexors measured by isokinetic dynamometry (Q:Q, H:H) did not significantly correlate with bilateral deficit of MS in VJs (CMJ<sub>FA</sub>, CMJ, SJ). However, significant correlation was recorded in bilateral deficit between CMJ<sub>FA</sub> and CMJ ( $r = .630$ ,  $p < .01$ ). Correlation coefficients of the monitored variables are listed in Table 5.

## 4 Discussion

Our tested subjects produced higher PT<sub>Q60</sub> (106±6 N·m) by the dominant limb in comparison to 12-year-old Norwegian boys (99±6 N·m) at the velocity of 60°·s<sup>-1</sup> [16]. Lundgren,

Nilsson, Ringsberg and Karlsson [25] report lower PT<sub>Q60</sub> in 12-year-old Swedish boys (95.5 N·m,  $n=22$ ) and comparable PT<sub>H60</sub> (45.4 N·m). At higher angular velocity (180°·s<sup>-1</sup>), our participants achieved lower values of PT<sub>Q180</sub> (5.2 %) and PT<sub>H180</sub> (29.1%) compared to Swedish boys. Kellis, Gerodimos, Kellis and Manou [26] report higher force achieved by 13-year-old trained boys ( $n=18$ ) at three angular velocities (60,120,180°·s<sup>-1</sup>) for knee extensors and flexors in DL and NL compared to our tested subjects (DL: PT<sub>Q60</sub>=10.4 %, PT<sub>Q120</sub>=12.7 %, PT<sub>Q180</sub>=12.6 %, PT<sub>H60</sub>=39.9 %, PT<sub>H120</sub>=42.5 %, PT<sub>H180</sub>=45.7%; NL: PT<sub>Q60</sub>=13.5 %, PT<sub>Q120</sub>=17.7 %, PT<sub>Q180</sub>=11.8 %, PT<sub>H60</sub>=38.9 %, PT<sub>H120</sub>=38.9 %, PT<sub>H180</sub>=31.5 %). Comparison of MS between these groups is evidence of higher value in trained boys. In case of knee flexors, the difference is four times greater than in knee extensors.



The level of PT significantly declined with increasing angular velocity in both DL and NL. Generally, when the muscle is contracting (concentric contraction) against a high external load, force is high but velocity is low. This relationship between muscular strength and velocity of contraction is called Hill's curve [27]. The Hill's curve is based on the principle that the maximum time necessary for contact between actin and myosin filaments decreases with higher velocity of concentric activity (Huxley's model); therefore, the length of the contact phase reduces in the overall cycle. Cross-bridge forms between actin and myosin have to be re-released immediately after their connection so there is not sufficient time for power production. Finally, the proportion of combined bridges in the muscle is reduced and the produced strength is lower [28].

Limb dominance did not have any significant effect on isokinetic muscular strength of lower limbs in the tested group. When interpreting bilateral deficit results, it is necessary to assess them in terms of their dominance. Newton, Gerber, Nimphius, Shim, Doan, Robertson, Pearson, Craig, Hakkinen and Kraemer [29] published significant differences between DL and NL in peak and average force in the following tests: bilateral squat, bilateral and single VJs, isokinetic flexion and extension at 60 and 240°·s<sup>-1</sup> and five hop test. However, comparison of differences between the right and left leg did not reveal any significant differences. Significant differences between the DL and NL during concentric contraction at a velocity of 60°·s<sup>-1</sup> in adult elite athletes ( $Q:Q_{\text{Ratio}}=10.53\pm 9.44\%$ ,  $H:H_{\text{Ratio}}=10.30\pm 5.69\%$ ) were published by Jones and Bampouras [30]. Bilateral deficit higher than 10% was detected between muscular strength of knee flexors in favour of the non-dominant limb in soccer players [9]. A significant difference in MS in favour of the DL (3-10 %) was identified in 13-year-old soccer players [26]. This difference was, according to the authors, caused by the fact that the DL is "more preferred to kick" and the NL "is used for standing". This indicates the fact that there are strength imbalances in athletes which have the character of maladaptation on the athlete's specific load. However, Lanshammar and Ribom [31] present significant differences in MS of flexors in favour of the non-dominant limb (8.6 %) and extensors in favour of the DL (5.3 %) in adult untrained women (n=159, age=20-39 years). Keeley, Plummer and Oliver [3] present in twenty-two collegiate graduate students stronger DL (extensors and flexors) at lower angular velocity (60°·s<sup>-1</sup>) and NL (extensors and flexors) at higher velocity (180°·s<sup>-1</sup>).

In our study we did not prove any significant influence of muscle AV on bilateral deficit of knee extensors; however, in the case of knee flexors, this difference was

significant. Bilateral deficit of knee flexors was higher at higher AVs and could have been caused by low neuromuscular adaptation to this type of muscle contraction. Iga, George, Lees and Reilly [32] present comparison of MS between trained and untrained 15-year-old boys at low (60°·s<sup>-1</sup>) and high (250°·s<sup>-1</sup>) angular velocity. The difference of MS at lower velocity was 15-18 % and at higher velocity 25-37 %. On the contrary, insignificant effect of AV on bilateral deficit of knee extensors and flexors in young soccer players was published by Malý, Zahálka and Malá [33]. The effect of AV on bilateral deficit of muscular strength requires further research linked to explanation of various independent variables (age, type of physical activity or inactivity, gender, the level of skills, etc.).

In our study, participants achieved significantly higher results in VJ with arm swing ( $CMJ_{FA}$ ) than in jump without arm swing (CMJ). When performing the VJ with arm swing, higher values of JH are reached, which is the result of upper limbs' work during the take-off, as well as braking and acceleration impulses conducted during the downward movement and subsequent take-off [21]. This fact can be confirmed by a study Reiser, Rocheford and Armstrong [34], in which the authors suggest that effective inclusion of upper limbs may improve the jump height by 25%. However, among young untrained boys there were individuals whose difference between the two types of jump was small or none in intra-individual assessment. We believe that this fact was caused by a lower level of coordination in terms of timing of arm swing and eccentric-concentric work of lower limbs with the aim of synergistically acting on force exertion and rate force development in the take-off phase. The height of VJ with arm swing  $CMJ_{FA}$  was significantly higher compared to the SJ jump test. It is the result of the use of eccentric muscle work in the first type of jump ( $CMJ_{FA}$ ) and arm swing, as well. A muscle in eccentric contraction is able to produce greater power than in concentric contraction. Power output can be further increased in actions where eccentric contraction is immediately followed by concentric contraction where elastic characteristics of muscle are used (stretch-shortening cycle). When a muscle is stretched, specific mechanoreceptors located within the muscle (muscle spindle fibres) are also stretched and send feedback to the central nervous system. This feedback causes an immediate signalling of the muscle fibres to contract to prevent potential tissue damage from over-stretching [35]. In synchronous activity with character of concentric contraction this stretch reflex may cause higher rate of force development of the movement.

In our study we detected an insignificant difference in the height achieved between the countermovement

jump and squat jump. This result may be caused by insufficiently developed force in thigh muscles and not using plyometric effect in downward and upward phases or low intra- and inter-muscular coordination of the movement. Wilmore and Costill [36] suggested that the expression of strength in childhood and adolescence relies upon the myelination of motor nerves and neural maturation which is not complete until sexual maturity is reached. These results can be caused by the fact that peak strength velocity occurs about a year after peak height velocity (13.4–14.4 years in boys) (De Ste Croix, Armstrong, & Welsman, 1999). Muscle strength of KE and KF increases between 11<sup>th</sup> and 15<sup>th</sup> year in boys up to 50%. The most progressive increase occurs between 12<sup>th</sup> and 14<sup>th</sup> year [13]. Development of muscle strength in youths depends on factors such as age, anthropometric parameters (body height, body weight) and sexual maturation (Beunen & Malina, 1988).

Maximum force ( $F_{max}$ ) exerted during the take-off phase was significantly higher in favour of the dominant limb in CMJ<sub>FA</sub> and SJ jumps ( $p < .01$ ). BFD of the exerted force was not significantly different depending on the type of jump ( $p > .05$ ). Difference in  $F_{max}$  between the limbs ranged between 8.11–8.65 %. Power produced by the limbs can differ based on several factors such as coordination, limb dominancy, previous injury or current muscle asymmetry [37]. Fitness coaches and doctors suppose that greater muscle asymmetry between the limbs increases the risk of injury. More attention should be paid to boys whose difference between the limbs is  $>15\%$  [33, 38, 39]. Veligeikas and Bogdanis [40] present in pre-pubertal boys (10–12 years old) bilateral deficit of  $9.0 \pm 1.6\%$  (CMJ<sub>FA</sub>). However, the authors used bilateral jump deficit index on the basis of comparison of one leg jump height related to two leg jump height (performance in right + left leg jump height) / two-leg jump height  $\cdot 100$ ).

Intra-individual assessment of our participants revealed values higher than 10 % in 9 subjects (CMJ<sub>FA</sub>), 8 subjects (CMJ) and 8 subjects (SJ). Based on these results we may conclude that this asymmetry occurs in more than a third of untrained 13-year-old children. The bilateral limb deficit may reflect neural inhibition during bilateral contraction [4] and may be related to a reduced capacity to recruit fast-twitch fibres [41], but is not due to changes in antagonist muscle activity [42].

Bilateral deficit of knee extensors and flexors' strength evaluated by isokinetic dynamometry ( $Q:Q_{ratio}$ ,  $H:H_{ratio}$ ) did not significantly correlate with BFD in jumps (CMJ<sub>FA</sub>, CMJ, SJ), nor in JH. Menzel, Chagas, Szmuchrowski, Araujo, de

Andrade and de Jesus-Moraleida [39] in research of professional soccer players present upon factor analysis that isokinetic testing and power testing (CMJ) tests were widely independent methods for the assessment of bilateral differences of lower limbs. On the contrary, Impellizzeri, Rampinini, Maffiuletti and Marcora [43] present a moderate relationship ( $r = .48$ ) between bilateral strength asymmetry in VJ and isokinetic dynamometry in adult athletes. Iossifidou, Baltzopoulos and Giakas [12] report insignificant correlation of peak power in the SJ and in isokinetic testing at angular velocity of  $60^\circ \cdot s^{-1}$  and significant correlation at velocity of  $300^\circ \cdot s^{-1}$  in adults. Cometti, Maffiuletti, Pousson, Chatard and Maffulli [44] present insignificant correlation between performance in isokinetic tests and jump height (SJ, CMJ) in adult soccer players. According to the authors, isokinetic tests do not reflect the movement of the limbs involved during jumping. Jones and Stratton [14] publish significant correlation between bilateral ratio of muscular strength in leg-press and drop jumps tests ( $r = .698$ ,  $p < .05$ ) in adult athletes. Jumping motion and leg-press exercise requires the activation of all lower limb muscle groups and joints; it is a closed chain exercise. In the case of isokinetic dynamometry, a muscle is isolated and it is a single joint motion and an open chain exercise. BFD produced during the take-off phase did not have any significant effect on jump height ( $p > .05$ ). Yoshioka, Nagano, Hay and Fukashiro [2] monitored the effect of bilateral asymmetry of muscle strength on the height of a SJ using a computer simulation study. When examining model jump with bilateral deficit of 10 % of force exerted between the limbs, the authors publish almost identical jump height (symmetry model = .389 m and asymmetry model = .387 m); movement time from start to take-off was also the same (.267 s and .268 s) and peak ground reaction forces ( $3.16$  and  $3.13 \text{ N} \cdot \text{body weight}^{-1}$ ). However, the authors publish higher ground reaction force of the stronger leg of the model-asymmetry jump compared to the weaker leg. In our study, participants exerted greater force using the dominant limb in SJ test ( $547.68 \text{ N}$ ) compared to the non-dominant limb ( $532.46 \text{ N}$ ). These results indicate that the stronger leg propelled a heavier load than the weaker leg. Yoshioka, Nagano, Hay and Fukashiro [2] suggest that bilateral work differences between limbs are mainly due to the differences in muscle force rather than the differences in muscle length changes. This points out the fact that this difference is caused by physiological strength characteristics and not by kinematic changes.

The main limitations of this study are sample size and the measure of generalizing the results for population. The next issue is purposive selection of participants, the absence of randomized selection and selection of both genders. Another limitation of the study is the absence of eccentric evaluation of knee flexors and extensors. The analysis other variables of isokinetic strength (work, time to peak torque etc.) and their correlation could bring other interesting results. In further research, also terrain motor test could be used for identifying strength asymmetries aimed to elimination of high demands on technical equipment and its applicability in school or clinical practice.

## 5 Conclusion

The results indicated a significant effect of muscle group and contraction velocity on isokinetic strength of lower limbs. Limb dominance did not significantly influence isokinetic strength of knee extensors and flexors but in power assessment boys generated greater power using the dominant limb. Countermovement jump with arm swing was significantly higher than the jump with arms excluded (CMJ) and squat jump (SJ). From the perspective of lower limb bilateral imbalances (dominant, non-dominant), we did not record any significant relationship between asymmetry found in isokinetic dynamometry (five angular velocities, concentric contraction) and jump assessment (three types of jumps). A significant relationship was detected in bilateral force imbalance between  $CMJ_{FA}$  and CMJ jumps. Laboratory tests (unilateral isokinetic testing and bilateral jump assessment) revealed significant differences between observed muscular group (KE, KF), or dominant and non-dominant limbs in untrained children. Despite the possibility of identifying muscle asymmetries in the sense of strength imbalances, their mutual relationship with results in isokinetic dynamometry and power jump tests is still unclear. In addition, while several studies have employed isokinetic testing and jump assessment to assess the strength and bilateral imbalances, it appears that it is necessary to define normative data for evaluation of the selected variables among youths.

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