DE GRUYTER Open Med. 2019; 14: 207-216

Research Article

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Morphological and isokinetic strength differences: bilateral and ipsilateral variation by different sport activity

https://doi.org/10.1515/med-2019-0014
received July 15, 2018; accepted December 23, 2018

Abstract: Background: The purpose of this study was to investigate the morphological and isokinetic strength asymmetry and magnitude in young athletes.

Methods: One hundred and thirty nine male subjects (soccer, floorball, non-athletes) were measured for proportion of muscle mass between upper extremities (BADΔ) and lower extremities (BLDΔ). Moreover, the peak muscle torque of knee extensors (PTE) and flexors (PTF), ipsilateral (H:Q) and bilateral strength ratio (Q:Q, H:H) were measured.

Results: We found significant differences in observed parameters with respect to different sport activities (F = 13.02, p = 0.00, η_p^2 = 0.80). Higher values of BADΔ were observed in the non-active (0.19 ± 0.11 kg) group compared with soccer players (0.10 ± 0.11 kg). We found a lower value of BLDΔ in floorball players (0.32 ± 0.11 kg) compared with soccer players (0.58 ± 0.27 kg) and non-active boys (0.63 ± 0.28 kg). Results revealed significantly higher PTE in soccer players compared with non-active boys and floorball players and higher Q:Q ratio in soccer players (10.99 ± 7.75%) compared with non-active boys (7.47 ± 5.92%).

Conclusions: This study revealed that there are morphological and strength asymmetries in the observed groups, which may have potential maladaptive effects (e.g. uncompensated overload of extremity) in athletes affected by specific load.

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Keywords: Isokinetic testing; Body composition; Maladaptation; Fitness performance

1 Introduction

Adolescence is characterised by the period of rapid growth between childhood and adulthood, when humans undergo physiological, psychological, and social development [1]. The components of health-related physical fitness in adolescents are cardiovascular endurance, muscular strength, endurance, flexibility, and body composition. Organized physical activity influences the optimal level of body composition with a high proportion of muscle mass, lean body mass and body cell mass, a low proportion of fat mass, and a high value of phase angle, as a predisposition for optimal muscle work [2]. Even short-term sport-specific training has shown to decrease the percentage of body fat in youth athletes [3]. Sedentary life-style, especially among urban school children, leads to retardation of growth and functional development of boys and girls, reduced adaptive capacity of young adolescents, and increased frequency and duration of diseases [4].

People usually perform daily activities with their dominant hand or foot [5]. It is believed that the lifelong preference for one extremity, e.g., the left arm or the left leg, as well as a predilection for a certain direction when turning around or rotating about one's longitudinal axis, could lead to asymmetry, which manifests in morphology or strength characteristics and can even be osseous in the case of competitive athletes. Especially when unilateral load (or preferred limbs) is involved in sport specific movement, different kinds of morphological and strength asymmetries can appear.

Morphological asymmetry, a difference between the right and the left sides of the body, that occurs in sport [6] can involve both side-to-side differences between extremities, pelvis, and trunk as well as total body, with upper and lower body diversification. Analysis of such asymmetry mostly concerns body dimension (length of limbs), level of body fat, lean mass, and body density [7, 8]. In humans, some level of asymmetry in body dimensions is the norm rather than the exception [9], however maladaptive processes caused by asymmetries can lead to a high risk of injury for adolescent athletes later in their sporting careers [10].

Asymmetric 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 right and left sides [11]. Strength differences between legs (bilateral strength asymmetries) and between muscle groups (unilateral strength ratio between hamstring and quadriceps) have been reported to appear in youth athletes. Moreover, it seems that some strength and power differences are not significantly related to each other [12, 13]. Chronic loading of one body side over time may lead to strength asymmetries and imbalances in tissue adaptation. These factors may negatively influence performance and cause injury to athletes [14]. Ferreira et al. [15] reported superior strength asymmetries in soccer players at a higher competitive level than those at a lower level. A study by Lehance et al. [16] examined muscle strength on isokinetic dynamometer in the preparatory period in elite soccer players (n=57), and found that up to 56% of the players are at risk of muscle strength imbalances for knee flexors or extensors. The authors reported a higher proportion of muscle strength imbalances in young soccer players than in senior players. Croisier et al. [17] indicated that the isokinetic strength assessment before the start of the season enables identification of strength indicators as predictors of possible muscle injury in athletes. In addition, significant changes in isokinetic strength parameters during an annual training cycle in youth players was reported [18]. Authors reported that functional strength ratio hamstring to quadriceps revealed that that muscle strength imbalance of the knee flexors and extensors changed throughout the annual training cycle. There are limited investigations of a combination of muscle strength performance and strength asymmetries in young athletes. Because of these reported limitations and differences , we applied investigations to three different groups of young males.

The purpose of this study was to investigate the morphological and isokinetic strength asymmetry and magnitude in youth soccer players, floorball players and non-active boys.

2 Methods

2.1 Study design

Cross-sectional study design was used in this investigation. The design was explained to all participants. Informed consent was signed and collected from parents before assessments were performed. The study was approved by the ethical committee of the Faculty of Physical Education and Sport, Charles University, Prague, Czech Republic. Measurements were recorded in accordance with the ethical standards of the Declaration of Helsinki and ethical standards in sport and exercise science research [19].

2.2 Subject sample

The research participants were 96 volunteered young male athletes from the highest youth division of their sport specializations and 43 non-active subjects. Participants were grouped by their sport activity, namely, soccer (S, n = 76, age = 14.7 ± 0.3 years), floorball (F, n = 22, age = 14.4 ± 0.5 years), and non-active (N, n = 43, age = 14.6 ± 0.4 years). The basic anthropometric data are presented in Table 1. The average training period for soccer was 7.2 ± 2.9 years, during which, they had 5–6 training sessions per week, each lasting 1.5 hours, and 1 match. The average period of floorball practice was 5.9 ± 3.3 years, comprising 4-5 training session per week of duration 1.5 hours and 1 match. Non-active participants had no organized physical activity, except for physical education (2 hours per week, with each session lasting 45 minutes) in schools.

2.3 Data collection

2.3.1 Anthropometric data, body composition, morphological asymmetry

Body height was measured using a digital stadiometer (SECA 242, Hamburg, Germany) and body mass was measured using a digital scale (SECA 769, Hamburg, Germany). Data identifying body composition were recorded under the same conditions, during morning hours. The participants used no medication, and had not reduced their body weight prior to the measurement, either radically or in the long-term before competitions. To assess body composition, we used a bioelectrical impedance analysis (Tanita MC-980MA, Tanita Corporation, Japan). Standardized conditions for bio-impedance measurement were maintained [20]. The following indicators were observed: body height (BH), body mass (BM), relative fat free mass (FFM%), percentage of fat mass (FM%), and proportion of muscle mass (non-dominant and dominant arm (BAD_{Δ}) and non-dominant and dominant leg - bilateral differences (BLD_{Δ})).

2.3.2 Isokinetic dynamometry

The muscular strength of the lower limbs was assessed using an isokinetic dynamometer (Cybex NORM®, Humac, CA, USA). The maximum peak muscle torque (PT) of the knee extensors (PT_Q) and flexors (PT_H) of the dominant (DL) and non-dominant leg (NL) during concentric contraction were measured at three angular velocities (60, 180, and 300°s^{-1}). Due to better comparison of isokinetic strength, we expressed strength in relative values (normalized to body mass). Limb dominance was resolved by determining which foot the participant preferred to use for kicking a ball. The test subject sat on an ergonomically set dynamometer seat, with the arm of the dynamometer adjusted according to the instructions and individual somatic characteristics of the participant. The axis of the dynamometer arm rotation was visually adjusted to the axis of knee rotation with a laser point. PT was controlled and modified by gravitational influence at each velocity. The motion range was 90° (maximum extension was marked and set as anatomic zero "0°"). The participant's trunk and thigh of tested leg were fixed by straps because of the isolation of the examined movement. 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). Before testing at each velocity, the participants completed four training trials at submaximal intensity. Visual feedback and verbal stimulation were given during the testing.

2.4 Statistical analyses

Data are expressed as the mean ± standard deviation (SD). Parametric procedures were chosen after verification of normality in data distribution using the Shapiro-Wilk test. Multivariate analysis of variances (MANOVA) with Bonferroni post-hoc tests were used for between group comparisons (independent variable) of all observed parameters (depended variables). When the criterion of sphericity as an assumption for data processing, assessed by the Mauchly's test (χ^2), was not met, degrees of freedom were adjusted by means of Greenhouse-Geisser's (GG) sphericity correction, and the statistical significance was assessed based on the degrees of freedom. To evaluate the equality of error variances, Levene's test was used. Single data points were identified as an outlier value if found to be out of the interval of mean ± 2*standard deviation. The "Partial eta square" coefficient (η_p^2), which explains the proportion of variance of the factor, was used to assess effect size as follows: η_p^2 = 0.02 was considered a small effect, η_p^2 = 0.13 was considered a medium effect, and η_p^2 = 0.26 was considered a large effect [21]. The p-value was set at 0.05 in all statistical analyses. The probability of type II error (beta) was controlled by post-hoc (retrospective) analysis and was set at 0.2 (conventional value). Power analysis was performed using G*Power (version 3.1.9 Kiel University, GER). Statistical analyses were carried out using IBM® SPSS® v24 (Statistical Package for Social Sciences, Inc., Chicago, IL, USA, 2012).

3 Results

MANOVA revealed significant differences in observed parameters with respect to different sport activities of subjects ($F = 13.02$, $p = 0.00$, $\eta_p^2 = 0.80$).

3.1 Anthropometric and body composition parameters

The independent variable (Sports activity) had significant effects on BM ($F_{2,138} = 5.77$, $p = 0.004$, $\eta_p^2 = 0.08$), BF ($F_{2,138} = 15.48$, $p = 0.000$, $\eta_p^2 = 0.18$), and FFM ($F_{2,138} = 15.48$, $p = 0.000$, $\eta_p^2 = 0.18$). Bonferroni post hoc analysis revealed significant differences between groups (Table 1).

3.2 Fluid segmental distribution differences between limbs

A significant effect of sports activity on fluid segmental distribution in all the observed parameters was observed (Table 2). Significant morphological differences were detected in both upper (BAD_{Δ}) and lower extremities (BLD_{Δ}). Bonferroni post hoc analysis revealed significantly higher values of BAD_{Δ} in non-active individuals (0.19 ± 0.11 kg) than in soccer players (0.10 ± 0.11 kg). Moreover, we found significantly lower value of BLD_{Δ} in floorball players

(0.32 ± 0.11 kg) than in soccer players (0.58 ± 0.27 kg) and non-active boys (0.63 ± 0.28 kg).

3.3 Isokinetic strength differences of knee extensors and flexors

We found the independent variable (Sports activity) to have significant effects on isokinetic strength of knee extensors in all observed contraction velocities (Table 3). Results revealed significantly higher strength of knee extensors (dominant and non-dominant leg) in soccer players compared with non-active boys and floorball players (except the performance at slowest contraction velocity in non-preferred leg). In contrast, no significant effect (p > 0.05) of sport activity (between groups effect) was found in strength of knee flexors during slowest angular velocity (Table 3). Soccer players reached the highest performance of knee flexors in higher angular velocities (180 and 300°s^{-1}).

3.4 Bilateral and ipsilateral strength ratio differences

In terms of bilateral strength ratios, we found a significantly higher quadriceps to quadriceps (Q:Q) ratio in soccer players (10.99 ± 7.75%) than in non-active boys (7.47 ± 5.92%). No other significant differences in bilateral strength comparison were found (Table 4). On the other hand, we found a significant effect of sport activity factor on ipsilateral ratio of both legs (dominant, non-dominant) at each velocity (60,180,300 °s^{-1}). Bonferroni post hoc tests revealed the highest ratio for soccer players, and lowest ratio in non-active boys.

4 Discussion

4.1 Anthropometric and body composition parameters

This study revealed the lowest level of body proportion in floorball players (lowest body height and mass) and

Table 1: Differences in anthropometric and body composition parameters between groups

Parameters	Soccer n = 76	Floorball n = 22	Non-active n = 43	ANOVA F	p	η_p^2	Post–hoc test	
BH (cm)	165.48 ± 9.26	159.86 ± 12.65	165.40 ± 9.51	2.95	0.041	0.04		
BM (kg)	53.77 ± 8.01	49.16 ± 8.94	58.74 ± 15.98	5.77	0.004	0.08	F vs N	
BF (%)	13.40 ± 2.81	10.76 ± 3.83	16.79 ± 6.34	15.48	0.00	0.18	S vs F,N	F vs N
FFM (%)	86.60 ± 2.81	89.24 ± 3.83	83.21 ± 6.44	15.48	0.00	0.18	S vs F,N	F vs N

Abbreviations: BH – body height, BM – body mass, FM% – percentage of fat mass, FFM – fat free mass, S – soccer, F – Floorball, N – Non-active

Table 2: Fluid segmental distribution differences between limbs with respect to different sport activities

Parameters	Soccer n = 76	Floorball n = 22	Non-active n = 43	ANOVA F	p	η_p^2	Post–hoc test	
DA (kg)	3.74 ± 1.55	2.48 ± 0.57	4.59 ± 1.08	19.18	0.00	0.22	S vs F,N	F vs N
NA (kg)	3.79 ± 1.50	2.34 ± 0.59	4.50 ± 1.18	20.21	0.00	0.23	S vs F,N	F vs N
BADΔ (kg)	0.10 ± 0.11	0.15 ± 0.08	0.19 ± 0.11	11.9	0.00	0.15	S vs N	
DL (kg)	13.58 ± 2.68	10.34 ± 1.24	15.10 ± 1.59	33.91	0.00	0.33	S vs F,N	F vs N
NL (kg)	12.69 ± 2.46	10.34 ± 1.24	14.47 ± 1.39	28.97	0.00	0.3	S vs F,N	F vs N
BLD_{Δ} (kg)	0.58 ± 0.27	0.32 ± 0.11	0.63 ± 0.28	11.25	0.00	0.14	F vs S, N	

Abbreviations: DA – dominant arm, NA – non-dominant arm, BADΔ – bilateral arms differences, DL – dominant leg, NL – non-dominant leg, BLDΔ – bilateral legs differences, S – soccer, F – Floorball, N – Non-active higher relative fat free mass in soccer and floorball players compared with non-active boys (Table 1). Results indicate greater quality of body composition in favour of sporting population. The amount of fat free mass and its components is determined by genetics (constitutional type), age (on-going ontogenesis), and type of training (energy coverage) that the athletes undergo. Sportsmen with high-quality strength training will thus achieve a higher value of muscle mass than the general adolescent population of similar age [22]. The groups of soccer and floorball players registered the higher quality of body composition compare to non-active boys (Table 1). The effort to eliminate some percentage of fat mass and the preference of a higher proportion of active components is associated with a closer relationship between active mass and success in the sport. Franchini et al. [23] reported that there is a significant relationship between the percentage of fat mass and the level of maximum oxygen consumption by athletes ($r = -0.83$; $p < 0.01$). The reported percentage of body fat in non-active boys ranges from 18 – 24.2% [3, 24, 25] and 9.9 –16.0% within active ones [3, 26, 27]. We found a significant difference in the fat mass distribution of active vs. non-active adolescents. The groups of floorball and soccer players had significantly lower fat mass and higher FFM than the non-athletes ($p < 0.01$). The reason for this difference, as suggested by the higher quality of BC for athletes, could be on-going ontogenesis and a high frequency of training sessions and large volume of loading in team sports such as soccer and floorball. Reduction of excessive fat mass in adolescents through controlled physical activity creates appropriate conditions for a high quality of life among the general population. However, it is important to consider a very important triangle comprising “load – nutrition – regeneration”. Optimal growth and muscle development are only possible when training intensity, nutritional intake, and recuperation are well balanced [28].

4.2 Fluid segmental distribution differences between limbs

By monitoring maladaptive changes based on sport practice, it was assumed that in adolescent athletes, when frequented muscle groups of particular sport activity (upper and lower limbs) are being selected, motor performance is executed unilaterally. When one limb becomes more preferred by neural-motor pattern (leg technique within

Table 3: Isokinetic strength ($Nmkg^{-1}$) differences of knee extensors and flexors with respect to different sport activities at different contraction velocities (60, 180, 300°s^{-1}).

Parameters	Soccer n = 76	Floorball n = 22	Non-active n = 43	ANOVA *F*	*p*	η_p^2	Post–hoc test
KE_{DL60}	2.51 ± 0.34	2.49 ± 0.34	2.25 ± 0.38	8.05	0.00	0.10	N vs S,F
KE_{DL180}	1.83 ± 0.24	1.65 ± 0.21	1.57 ± 0.28	16.48	0.00	0.19	S vs F,N
KE_{DL300}	1.41 ± 0.18	1.29 ± 0.25	1.18 ± 0.19	20.43	0.00	0.23	S vs F,N
KE_{NL60}	2.38 ± 0.28	2.36 ± 0.29	2.20 ± 0.38	4.70	0.01	0.06	S vs N
KE_{NL180}	1.77 ± 0.27	1.50 ± 0.25	1.56 ± 0.27	13.30	0.00	0.16	S vs F,N
KE_{NL300}	1.36 ± 0.19	1.11 ± 1.18	1.15 ± 0.23	20.11	0.00	0.23	S vs F,N
KF_{DL60}	1.48 ± 0.27	1.37 ± 0.25	1.37 ± 0.29	2.84	0.06	0.04	
KF_{DL180}	1.11 ± 0.22	0.91 ± 0.22	0.98 ± 0.27	7.42	0.00	0.10	S vs F,N
KF_{DL300}	0.84 ± 0.17	0.69 ± 0.23	0.68 ± 0.25	10.61	0.00	0.13	S vs F,N
KF_{NL60}	1.40 ± 0.22	1.34 ± 0.21	1.32 ± 0.35	1.34	0.27	0.02	
KF_{NL180}	1.05 ± 0.25	0.86 ± 0.16	0.96 ± 0.29	5.12	0.01	0.07	S vs F
KF_{NL300}	0.79 ± 0.19	0.65 ± 0.20	0.64 ± 022	8.78	0.00	0.113	S vs F,N

Abbreviations: KE – knee extensors, KF – knee flexors, DL – dominant leg, NL – non-dominant leg, S – soccer, F – Floorball, N – Non-active

Table 4: Bilateral and ipsilateral strength differences (%) of knee extensors and flexors with respect to different sport activities at different contraction velocities (60, 180, 300°s^{-1}).

Parameters	Soccer n = 76	Floorball n = 22	Nonactive n = 43	ANOVA F	p	η_p^2	Post–hoc test
$Q{:}Q_{60}$	10.99 ± 7.75	9.18 ± 8.01	7.47 ± 5.92	3.26	0.04	0.05	S vs N
$Q{:}Q_{180}$	8.25 ± 6.86	10.27 ± 6.71	7.65 ± 5.97	1.19	0.31	0.02	
$Q{:}Q_{300}$	8.11 ± 6.34	10.77 ± 6.96	7.65 ± 5.97	1.73	0.18	0.02	
$H{:}H_{60}$	10.86 ± 8.44	7.73 ± 5.18	10.21 ± 6.53	1.50	0.23	0.02	
$H{:}H_{180}$	11.55 ± 9.26	11.77 ± 8.18	10.51 ± 8.37	0.23	0.79	0.00	
$H{:}H_{300}$	14.67 ± 13.39	15.36 ± 9.55	11.30 ± 9.75	1.35	0.26	0.02	
$H{:}Q_{DL60}$	60.32 ± 13.66	54.49 ± 11.58	51.37 ± 7.94	8.20	0.00	0.11	S vs N
$H{:}Q_{DL180}$	61.01 ± 14.53	53.14 ± 12.19	50.02 ± 11.65	10.08	0.00	0.13	S vs F,N
$H{:}Q_{DL300}$	58.88 ± 12.82	51.27 ± 14.53	48.19 ± 12.50	10.06	0.00	0.13	S vs N
$H{:}Q_{NL60}$	57.72 ± 9.40	55.41 ± 11.42	52.51 ± 9.65	3.90	0.02	0.05	S vs N
$H{:}Q_{NL180}$	59.45 ± 9.80	52.83 ± 11.96	51.35 ± 11.20	9.16	0.00	0.12	S vs F,N
$H{:}Q_{NL300}$	57.68 ± 12.76	52.81 ± 11.45	47.60 ± 16.95	7.19	0.00	0.09	S vs N

Abbreviations: Q:Q – quadriceps to quadriceps strength ratio, H:H – hamstring to hamstring strength ratio, H:QDL – hamstring to quadriceps strength ratio on dominant leg, H:QNL – hamstring to quadriceps strength ratio on dominant leg, S – soccer, F – Floorball, N – Non-active

soccer or arm technique of floorball) there will be bilateral morphological asymmetry in the proportion of muscle mass in upper or lower limbs. This hypothesis was confirmed when the bilateral comparison of the muscle mass proportion between the preferred and non-preferred lower limbs showed a significantly higher proportion of muscle mass (soccer players = 0.58 ± 0.27 kg compared with floorball players = 0.32 ± 0.11 kg). Surprisingly, we found the highest morphological asymmetry (BAD_Δ) in upper extremities in non-active boys in contrast with athlete groups. This could be caused by every day preference of dominant limb during daily activities. We consider the biggest evaluated asymmetry we monitored for non-active adolescents to be the consequence of the low level of physical activity and reason is that sedentary lifestyle has a significant impact on the postural parameters in many young boys and girls [29]. Excessive fat mass and low representation of active muscle body mass in turn may contribute to the development of many health disorders, including disorders of the musculoskeletal system. Moreover, it could be the reason that players from athlete groups perform strengthening exercises, including exercises focused on both upper extremities within the training process which could prevent from these asymmetries.

Floorball players showed higher levels of bilateral morphological asymmetry (BAD_Δ = 0.15 ± 0.08 kg) compared with soccer players (BAD_Δ =0.10 ± 0.11 kg), although the difference was not statistically significant. Evaluated asymmetries may be caused by functional adaptations. In other words, the body successfully adapts to the asymmetrical loading demands of the sport in order to decrease the excessive strain on some tissues and some level of asymmetry may be a natural effect of lateral dominance due to the unilateral nature of the sports discipline.

It is obvious that morphological side–to–side diversification depends on sport specificity [7]. Asymmetry of floorball is caused by non-linear bending, torque movements, and overloading of lumbar spine with shortening of pectoral muscle groups. The absence or insufficient use of compensational exercises leads to disruption of motor patterns and formation of muscle asymmetries, incorrect body posture, shoulder protraction, hyperlordosis, hyperkyphosis, and scoliosis. Studies have shown that muscle asymmetries and overloading of muscle tissue of floorball players can lead to injuries [30, 31].

In soccer, lateral dominance can be defined as footedness: the preferred foot for kicking the ball, and the limb that mobilizes through an open kinetic chain. Asymmetry is a product of unilateral kicking and greater movement repetition of the dominant limb. Participation in asymmetric sport disciplines is connected with asymmetric changes in soft tissues [32]. Asymmetries and shortened muscles may have severe similar physical consequences, increasing the risk of injury and negative affected sport performance [33].

4.3 Isokinetic strength differences of knee extensors and flexors

Soccer players showed the highest values of isokinetic muscle force performance for knee extensors and flexors regardless of monitored contraction speed (Table 3). Floorball and soccer players reached greater muscle force of knee extensors (Preferred lower limb: ~ 2.50 $Nmkg^{-1}$, Non-preferred lower limb: ~ 2.37 $Nmkg^{-1}$) compared with the non-active group (Preferred lower limb: 2.25 $Nmkg^{-1}$, Non-preferred lower limb: ~ 2.20 $Nmkg^{-1}$). Holm et al. [34] indicated a greater muscle force in 14 year old soccer players (2.69 ± 0.29 $N.m.kg^{-1}$). De Ste Croix et al. [35] reported the muscle force of non-active boys as 2.44 $N.m.kg^{-1}$. The greatest muscle force of knee flexors was reported for soccer players (Preferred lower limb: 1.48 ± 0.27 $N.m.kg^{-1}$, Non-preferred lower limb: 1.40 ± 0.25 $N.m.kg^{-1}$). Holm et al. [34] reported larger values (1.72 ± 0.28 $N.m.kg^{-1}$) within the same age group of soccer players. Differences between monitored groups were not statistically significant (Table 3).

The isokinetic strength of extensors and flexors significantly declined with increasing contraction velocity (Table 3). This is in line with other studies [33, 36]. Generally, with increasing velocity of movement in the concentric contraction, the force that muscle is able to exert decreases. This relationship between muscular strength and speed of contraction is known as Hill's curve. Based on this curve, we expected a greater production of muscle force. Expectations were mostly at high velocity results of active groups ($300°s^{-1}$), mainly because of potentially larger neuro-muscular adaptation aimed for substantial production of force in a relatively short time period. (Rate of force development, RFD). In sport, activities requiring a high level of RFD (rebounds, impacts, speed of direction change, acceleration, deceleration, shooting, etc.) occur frequently and can cause an adaptation effect in favour of athletes. The results of our study showed significantly higher muscle strength of soccer player's knee extensors and flexors in comparison with floorball players and non-active boys.

4.4 Bilateral and ipsilateral strength ratios differences

Bilateral difference in soccer players` knee extensor muscle force (10.99 ± 7.75%) was significantly higher compared with the non-active group (7.47 ± 5.92%). Bilateral difference of floorball players` knee extensors was lower (9.18 ± 8.01%), although not significant in comparison with other groups (Table 4). Greater bilateral strength asymmetries were found in knee flexion (H:H) than in knee extension (Q:Q) in the group of soccer players and non-active boys (Table 4). For adult soccer players, Magalhaes et al. [37] also reported greater level of bilateral muscle asymmetry of knee flexors (HH = 10.6 ± 8.0%) in comparison with extensors (QQ = 7.3 ± 6.5%). The bilateral deficit of knee flexors was greater at higher angular velocities and could have been caused by low neuromuscular adaptation to this type of muscle contraction [12]. Kellis et al. [38] reported significant differences in muscle strength in favour of preferred leg in 13-year old soccer players. This difference was caused by the fact that the preferred leg is "more preferred for passing, shooting", compared with the non-preferred leg "which is used for support during (standing leg) the kicking phase". Davies, et al. [39] reported that values differing by 10% to 15% are usually considered to be indicative of significant asymmetry. Higher values of deficit indicate a muscle imbalance, which may predispose the subject to possible muscle-related injuries such as strains and tendinitis. Knapik et al. [40] stated that the athletes with muscle strength imbalances higher than 15% at bilateral comparison of extremities had 2.6-times higher frequency of injuries, compared with athletes where this difference was lower than 15%. With increasing angular velocity as well, bilateral difference of knee flexors increased. This is in line with the other studies [37].

Houweling et al. [41] considered monitoring of the bilateral ratio of the knee flexors strength (H:Q) at velocity $60°s^{-1}$ as the most valid indicator reflecting previous injury of this risk muscle group in soccer. Moreover, the H:Q ratio has been used to examine the similarity between hamstring and quadriceps moment-velocity patterns and to assess the knee functional ability and muscle balance [42]. We found the highest values of hamstring-to-quadriceps ratio for all angular velocities in the soccer players group (Table 4). Soccer players had significantly higher HQ ratio compared with non-active boys (all measurements) and floorball players (in angular velocity $180°s^{-1}$). This contrast can be explained by the advanced knee flexors specific load adaptation that soccer requires. The lowest ratio was observed for non-active boys. This result is presumably a result of insufficient neuromuscular specific adaptation for particular movement pattern. Baratta et al. [43] reported that participants who do not regularly exercise their hamstrings had a significant decrease in hamstring activation compared with normal healthy subjects and athletes with regularly activity. Hoffman et al. [44] considered 6:10 as the accepted value of the H:Q ratio. Kong & Burns [45] reported the range as 42–80% for healthy men and women. In a recent study [46], the authors reported a significant relationship between the ipsilateral isokinetic strength ratio and shooting accuracy of the kicking leg.

5 Conclusion

The main finding of the present study is that differences in the type of physical activity cause differences in morphological and muscle force asymmetries even during pubescence. The conclusion from this study was that the increasing level of strength imbalances before and after loading (due to fatigue) might affect motor performance, potentially leading to much stronger knee extensors than knee flexors (an injury-related parameter) in elite soccer players. The highest morphological asymmetry in upper extremities (BAD_{Δ}) was found in non-active boys compared with the athlete groups. Conversely, the highest morphological asymmetry in lower extremities (BLD_{Δ}) was detected in soccer players. Greater bilateral strength asymmetries were found in knee flexion (H:H) than in knee extension (Q:Q) in the groups of soccer players and non-active boys. Therefore, more attention should be paid to knee flexion in pubescent athletes. Moreover, the highest values of hamstring-to-quadriceps ratio were found in soccer players for all angular velocities. The study revealed that there are strength imbalances in athletes, which may have potential maladaptive effects in athletes affected by specific load.

Low level of body composition, muscle force, and strength asymmetry found in the non-active population reflected a low level of physical fitness and lack of compensation for unilateral load (daily living activities). Monitoring the morphological and muscle force asymmetries of the sport-active adolescent population is important for the optimal physical development of an individual.

In terms of practice, these results may be of help for physiotherapists, doctors, fitness coaches, and other clinical staff working with young athletes to protect youth before injuries occur and to take into consideration during preparation (design of training programs to comprehensively develop motor performance and hold on to health at a good level).

Acknowledgement: This research was supported by GACR 16-21791S, UNCE HUM32

Conflict of interest statement: Authors state no conflict of interest

References

[1] Atwater E. Adolescence Prentice Hall. New Jersey. 1992

[2] Mala L, Maly T, Zahalka F, Dragijsky M. Changes in body composition due to weight reduction by elite youth judo athletes in short period pre-competition. Archives of Budo Science of Martial Arts and Extreme Sports. 2016;12:197-203

[3] Wyszyńska J, Podgórska-Bednarz J, Drzał-Grabiec J, Rachwał M, Baran J, Czenczek-Lewandowska E, et al. Analysis of relationship between the body mass composition and physical activity with body posture in children. Bio Med Research International. 2016

[4] Burdyukova E, Pustovalov D, Oranskaya A, Pertsov S, Gurevich K. Mechanisms of maladaptation to physical exercise in moscow school children. Bulletin of experimental biology and medicine. 2012;153(4):428-430

[5] Yoshioka S, Nagano A, Hay DC, Fukashiro S. The effect of bilateral asymmetry of muscle strength on the height of a squat jump: a computer simulation study. Journal of Sports Sciences. 2011;29(8):867-867

[6] Auerbach BM, Ruff CB. Limb bone bilateral asymmetry: variability and commonality among modern humans. Journal of Human Evolution. 2006;50(2):203-218

[7] Krzykała M. Dxa as a Tool for the Assessment of Morphological Asymmetry in Athletes. Dual Energy X-Ray Absorptiometry: InTech; 2012

[8] Mala L, Maly T, Camilleri R, Dornowsk M, Zahalka F, Petr M, et al. Gender differences in strength lateral asymmetries, limbs morphology and body composition in adolescent judo athletes. Archives of Budo. 2017;13:377-385

[9] Al-Eisa E, Egan D, Wassersug R. Fluctuating asymmetry and low back pain. Evolution and Human Behavior. 2004;25(1):31-37

[10] Malá L, Zahálka F, Maly T. Bio impedance for Analysis of Body Composition in Sports. Bioimpedance in Biomedical Applications and Research: Springer; 2018. p. 243-256

[11] Keeley DW, Plummer HA, Oliver GD. Predicting asymmetrical lower extremity strength deficits in college-aged men and women using common horizontal and vertical power field tests: A possible screening mechanism. The Journal of Strength & Conditioning Research. 2011;25(6):1632-1637

[12] Maly T, Zahalka F, Mala L, Cech P. The bilateral strength and power asymmetries in untrained boys. Open Medicine. 2015;10(1):224

[13] Menzel H-J, Chagas MH, Szmuchrowski LA, Araujo SR, de Andrade AG, de Jesus-Moraleida FR. Analysis of lower limb asymmetries by isokinetic and vertical jump tests in soccer

players. The Journal of Strength & Conditioning Research. 2013;27(5):1370-1377
[14] Xaverova Z, Dirnberger J, Lehnert M, Belka J, Wagner H, Orechovska K. Isokinetic strength profile of elite female handball players. Journal of Human Kinetics. 2015;49(1):257-266
[15] Ferreira JC, Araujo SRS, Pimenta EM, Menzel H-JK, Medeiros FB, Andrade AGPd, et al. Impact of competitive level and age on the strength and asymmetry of young soccer players. Revista Brasileira de Medicina do Esporte. 2018;24(5):357-360
[16] Lehance C, Binet J, Bury T, Croisier J-L. Muscular strength, functional performances and injury risk in professional and junior elite soccer players. Scandinavian Journal of Medicine & Science in Sports. 2009;19(2):243-251
[17] Croisier J-L, Ganteaume S, Ferret J. Pre season isokinetic intervention as a preventive strategy for hamstring injury in professional soccer players. British Journal of Sports Medicine. 2005;39(6):379
[18] Lehnert M, Xaverová Z, Croix MDS. Changes in muscle strength in U19 soccer players during an annual training cycle. Journal of Human Kinetics. 2014;42(1):175-185
[19] Harriss D, MacSween A, Atkinson G. Standards for ethics in sport and exercise science research: 2018 update. International Journal of Sports Medicine. 2017;38(14):1126-1131
[20] Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gómez JM, et al. Bioelectrical impedance analysis–part I: review of principles and methods. Clinical Nutrition. 2004;23(5):1226-1243
[21] Cohen J. Quantitative methods in psychology: A power primer. Psychol Bull. 1992;112:1155-1159
[22] Bell W, Evans W, Cobner D, Eston RG. The regional placement of bone mineral mass, fat mass, and lean soft tissue mass in young adult Rugby Union players. Ergonomics. 2005;48(11-14):1462-1472
[23] Franchini E, Nunes AV, Moraes JM, DelVecchio FB. Physical fitness and anthropometrical profile of the Brazilian male judo team. Journal of Physiological Anthropology. 2007;26(2):59-67
[24] Ellis KJ, Shypailo RJ, Abrams SA, Wong WW. The Reference Child and Adolescent Models of Body Composition: A Contemporary Comparison. Annals of the New York Academy of Sciences. 2000;904(1):374-382
[25] Weber DR, Moore RH, Leonard MB, Zemel BS. Fat and lean BMI reference curves in children and adolescents and their utility in identifying excess adiposity compared with BMI and percentage body fat–. The American Journal of Clinical Nutrition. 2013;98(1):49-56
[26] Nikolaidis P. Age-related differences in countermovement vertical jump in soccer players 8-31 years old: the role of fat-free mass. American Journal of Sports Science and Medicine. 2014;2(2):60-64
[27] Wells JC, Williams JE, Chomtho S, Darch T, Grijalva-Eternod C, Kennedy K, et al. Body-composition reference data for simple and reference techniques and a 4-component model: a new UK reference child–. The American Journal of Clinical Nutrition. 2012;96(6):1316-1326
[28] Clarys P, Geelen B, Aerenhouts D, Deriemaeker P, Zinzen E. Estimation of body composition in adolescent judo athletes. Journal of Combat Sports and Martial Arts. 2011;2(2):73-77
[29] Latalski M, Bylina J, Fatyga M, Repko M, Filipovic M, Jarosz MJ, et al. Risk factors o fpostural defects in children at school age. Annals of Agricultural and Environmental Medicine. 2013;20(3)
[30] Snellman K, Parkkari J, Kannus P, Leppälä J, Vuori I, Järvinen M. Sports injuries in floorball: a prospective one-year follow-up study. International Journal of Sports Medicine. 2001;22(07):531-536
[31] Wikström J, Andersson C. A prospective study of injuries in licensed floorball players. Scandinavian Journal of Medicine & Science in Sports. 1997;7(1):38-42
[32] Ducher G, Courteix D, Meme S, Magni C, Viala J, Benhamou C. Bone geometry in response to long-term tennis playing and its relationship with muscle volume: a quantitative magnetic resonance imaging study in tennis players. Bone. 2005;37(4):457-466
[33] Maly T, Zahalka F, Mala L. Unilateral and ipsilateral strength asymmetries in elite youth soccer players with respect to muscle group and limb dominance. International Journal of Morphology. 2016;34(4)
[34] Holm I, Steen H, Olstad M. Isokinetic muscle performance in growing boys from pre-teen to maturity. An eleven-year longitudinal study. Isokinetics and Exercise Science. 2005;13(2):153-158
[35] De Ste Croix M, Armstrong N, Welsman J, Sharpe P. Longitudinal changes in isokinetic leg strength in 10-14-year-olds. Annals of Human Biology. 2002;29(1):50-62
[36] Lehnert M, Urban J, Procházka JH, Psotta R. Isokinetic strength of knee flexors and extensors of adolescent soccer players and its changes based on movement speed and age. Acta Gymnica. 2011;41(2):45-53
[37] Magalhaes J, Oliveir A, Ascensao A, Soares J. Concentric quadriceps and hamstrings isokinetic strength in volleyball and soccer players. Journal of Sports Medicine and Physical Fitness. 2004;44:119-125
[38] Kellis S, Gerodimos V, Kellis E, Manou V. Bilateral isokinetic concentric and eccentric strength profiles of the knee extensors and flexors in young soccer players. Isokinetics and Exercise Science. 2001;9(1):31-39
[39] Davies GJ, Heiderscheit B, Brinks K. Test interpretation. Isokinetics in Human Performance. 2000:3-24
[40] Knapik JJ, Bauman CL, Jones BH, Harris JM, Vaughan L. Pre season strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. The American Journal of Sports Medicine. 1991;19(1):76-81
[41] Houweling TA, Head A, Hamzeh MA. Validity of isokinetic testing for previous hamstring injury detection in soccer players. Isokinetics and Exercise Science. 2009;17(4):213-220
[42] Rosene JM, Fogarty TD, Mahaffey BL. Isokinetic hamstrings: quadriceps ratios in inter collegiate athletes. Journal of Athletic Training. 2001;36(4):378
[43] Baratta R, Solomonow M, Zhou B, Letson D, Chuinard R, D'ambrosia R. Muscular coactivation: the role of the antagonist musculature in maintaining knee stability. The American Journal of Sports Medicine. 1988;16(2):113-122

[44] Hoffman J, Maresh C, Armstrong L. Isokinetic and dynamic constant resistance strength testing: Implications for sport. Physical Therapy Practice. 1992;2:42-53
[45] Kong PW, Burns SF. Bilateral difference in hamstrings to quadriceps ratio in healthy males and females. Physical Therapy in Sport. 2010;11(1):12-17
[46] Maly T, Sugimoto D, Izovska J, Zahalka F, Mala L. Effect of muscular strength, asymmetries and fatigue on kicking performance in soccer players. International Journal of Sports Medicine. 2018;39(4):297-303