ORIGINAL ARTICLE

The foot structure of combat sports athletes

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C Statistical Analysis
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Abstract

Background and Study Aim: Theorists of combat sports categorize them into sports involving workings of weapons, strokes, and throws and grips of immobilization of the opponent's body. Combat sports, as part of martial arts constitute, therefore, an activity with a high risk of injury, which increases along with the brutalization of contemporary sports rivalry. The aim of this study is to broaden the knowledge about the morphological properties of the feet of advanced judo and karate athletes.

Material and Methods: Seventy judo athletes (aged 17 ±0.7 years, training experience 8.4 ±2.4 years) taking part in Polish National Championships, and 30 Kyokushin karate athletes (aged 19.9 ±3.7 years, training experience 9.4 ±1.9 years) who were members of the Polish national team took part in the study. Judo athletes are characterized by a high variability of body weight, therefore two subgroups were distinguished: subgroup A (BMI <25), and subgroup B (BMI >25), which ensured their greater homogeneity. Men practicing karate Kyokushin (group C) were characterized by lower body weight differences, therefore a division into similar subgroups was not made in their case. Podometric assessment involved the measurements of foot length and foot width (cm) as well as different foot angles (°). For the alpha angle (hallux valgus angle), the normal range of variation is between 0° and 9°.

Results: The width and length of the foot were the highest among the male judo practitioners (subgroups B). The karate Kyokushin athletes have the shortest feet, while the lighter judo athletes the narrowest feet ($p<0.05$). Judo athletes have a slightly longer and wider left foot, which may indicate more frequent loading of the left side of the body during combat and training. The karate athletes did not show this trend. Judo and karate athletes are characterized by higher valgus of the alpha angle of the left foot. The values deformity of the left hallux is more frequent than of the right hallux, and the measured values of the alpha angle were also higher on the left foot.

Conclusions: The results of the present study reveal specific adaptive effects in young men practicing different categories of combat sports. Monitoring of all negative effects of long-term combat sports training should be an important component of evidence-based complementary health prevention programs.

Key words: angles and arches of foot • contact sport • heath prophylactic • judo • karate Kyokushin • Wejsflog index

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INTRODUCTION

Despite their centuries-old tradition and the propagation of moral aspects of martial arts in society [1, 2] combat sports remain contact sports whose essence is the performance of a variety of physical actions, including those directed at the opponent's body. Theorists of combat sports categorize them into sports involving workings of weapons, strokes, and throws and grips of immobilization of the opponent's body [3].

Combat sports, as part of martial arts [3] constitute, therefore, an activity with a high risk of injury, which increases along with the brutalization of contemporary sports rivalry [4]. Competition in combat sports is also conducive to the accumulation of aggression [5], which, if not appropriately channeled, finds its expression in sport. These circumstances encourage unsportsmanlike conduct towards the opponent such as the use of prohibited grips, excessive force, and attacking vulnerable body areas [6-8]. The popularity of martial arts undermines their elitism by attracting random practitioners. Another issue is the phenomenon of neogladiatorship, and an extreme example of this pathology is the promotion, especially in electronic media, of mixed martial arts (MMA) as a sport [9].

The escalation of violence and aggression in combat sports and in neogladiatorship may lead to injuries [10] and it promotes various fears, with anxiety being often the cause of serious errors. Injured combat sports athletes may experience the fear of health loss in the following fight tournament or training. Therefore, posttraumatic stress disorder [11] and anxiety-proneness are observed among combat sports athletes. Absence from training sessions and/or competitions as a result of injury may lead to a decreased in the physical form of the athlete and, in consequence, to exclusion from professional sport.

It has been shown that beside taekwondo, karate is a sport in which injuries occur most often [12]. Karate injuries are equally frequent in the upper and the lower limbs. The most common types of injuries among judo and karate athletes are lacerations, bruises, muscle strains, and sprains, caused by the opponent's attacks, or as a result of falls caused by the opponent [13].

Judo and karate are contact sports where competitors fight without body protectors. Hence, competitors' bare feet are often at risk of injury, which can have a significant impact on the support function of the foot. The feet carry the weight of the whole body and should therefore be properly loaded during physical activity. The midfoot, heel, and foot outsole take over the weight of the whole body to the greatest extent. If the feet are flattened or excessively arched, they do not perform their support function sufficiently. This results in unfavorable overloads of those parts of the foot which are not adapted for this purpose [14]. In the case of athletes, these circumstances and increased training loads can result in premature termination of a sporting career. The feet also fulfill a locomotive function in the bipedal mode of locomotion, and a stabilizing function in maintaining balance [15]. Hence, the properly shaped feet absorb shocks generated during walking or fighting. The correct longitudinal and transverse arches of the foot are an important element of the comfort of smooth performance of combat sports athlete.

The aim of this study is to broaden the knowledge about the morphological properties of the feet of advanced judo and karate athletes.

MATERIAL AND METHODS

Participants

Seventy judo athletes (aged 17 ±0.7 years, training experience 8.4 ±2.4 years) taking part in Polish National Championships, and 30 Kyokushin karate athletes (aged 19.9 ±3.7 years, training experience 9.4 ±1.9 years) who were members of the Polish national team took part in the study.

Study design

The body weight (kg) and body height (cm) of male combat sports athletes were measured, and their body mass index (BMI) was calculated. Judo athletes are characterized by a high variability of body weight, therefore two subgroups were distinguished: subgroup A (BMI <25), and subgroup B (BMI >25), which ensured their greater homogeneity (Table 1). Men practicing karate Kyokushin (group C) were characterized by lower body weight differences, therefore a division into similar subgroups was not made in their case (Table 2). The adoption of these criteria is justified by the specificity of these two types of combat sports. In judo, in junior age category (17-19 years old), there are 8 weight categories (from −55 kg to +100 kg),

Combat sports – the group of sports disciplines, in which the gist of the competition is the direct clash of two competing athletes. They are affiliated to the national and international sports organizations in order to carry out official competition, classification, etc. [3].

Martial arts – *plural noun* any of various systems of combat and self-defence, e.g. judo or karate, developed especially in Japan and Korea and now usually practised as a sport [42].

Combat sport & martial art – relation according to the theory of combat sport: "every combat sport is martial arts but not vice versa"[3, p. 18]

Contact sport – *noun* any sport in which physical contact between players is an integral part of the game, e.g. boxing, rugby or taekwondo [42].

Contusion – *noun* same as **bruise** [42].

Bruise – *noun* a dark painful area on the skin where blood has escaped under the skin following a blow. Also called **contusion** ■ *verb* to cause a bruise on part of the body [42].

Stress – *noun* **1.** physical pressure on an object or part of the body **2.** a factor or combination of factors in a person's life that make him or her feel tired and anxious **3.** a condition in which an outside influence such as overwork or a mental or emotional state such as anxiety changes the working of the body and can affect the hormone balance [42].

Anxiety – *noun* the state of being very worried and afraid [42].

Anxiety-prone *adjective* tending to suffer from anxiety and stress [42].

Physical activity – *noun* exercise and general movement that a person carries out as part of their day [42].

Prophylactic – *noun* a drug or agent that prevents the development of disease [42].

Judogi – is the formal Japanese name for the traditional uniform used for judo practice and competition [Wikipedia].

while in karate Kyokushin, in senior age category (18 years olds), there are 4 weight categories: from −70 kg to +90 kg.

Podometric assessment involved the measurements of foot length and foot width (cm) as well as different foot angles (°). For the alpha angle (hallux valgus angle) (Figure 1), the normal range of variation is between 0° and 9°. Exceeding the upper value indicates the valgus deformity of the hallux. Failure to correct the angle can lead to permanent deformation of the foot bones and severe impairment of foot performance. For the beta angle (the angle of the varus deformity of the fifth toe) (Figure 1) no standards are given in professional literature, however, the higher the value of this angle, the greatest the varus deformity of the fifth toe. For Clarke's angle (measuring the longitudinal arch of the foot) (Figure 2), the following ranges were used: below 30° flat foot; 31° to 40° flattened foot; 41° to 50° normal foot, and above 50° excavated foot. The gamma heel angle measures the transverse arch of the foot (Figure 3). According to the Wejsflog index [16], the standard angle range is 15° to 18°. According to Puszczałowska-Lizis [17] the range below 15° indicates a transverse excavated foot, and above 18° a flattened transverse foot.

Instruments

Somatic measurements were performed with the use of GPM anthropometric instruments (Siber Hegner Machinery Ltd, Switzerland): an anthropometer (measurement accuracy of 1 mm), small spreading caliper (measurement accuracy of 1 mm), and electronic scales (measurement accuracy of 0.1 kg). The podometric measurements were made with a podoscope, which allowed taking photo of the sole side of the feet, and a computer program to determine the values of podometric features.

Statistical analysis

The statistical analysis involved the arithmetic means, standard deviation (SD or ±), and the coefficient of variation (V). Differences between the means were assessed with Student's t-test for independent samples. The Pearson correlation coefficient was calculated for indices of selected empirical variables.

RESULTS

For obvious reasons, judo athletes from subgroup B had a significantly higher body height than judo athletes from subgroup A and karate Kyokushin athletes. In terms of body weight, both judokas with

Kumite – is a semi-contact karate competitive concurrence, where two athletes perform various kicking, punching and blocking techniques towards each other with maximum control in order to gain points and win the match. Destruction is fictive.

Training load – "A simple mathematical model of training load can be defined as the product of qualitative and quantitative factor. This reasoning may became unclear whenever the quantitative factor is called 'workload volume' or 'training volume' interchangeably with 'volume of physical activity'. Various units have been adopted as measures i.e. the number of repetitions, kilometres, tons, kilocalories, etc. as well as various units of time (seconds, minutes, hours) (...) As in the real world nothing happens beyond the time, the basic procedure of improvement of workload measurement should logically start with separation of the time factor from the set of phenomena so far classified together as '***workload volume***'. (...) Due to the fact that the heart rate (HR) is commonly accepted as the universal measure of workload intensity, the product of effort duration and HR seems to be the general indicator of ***training load*** defined as the amount of workload. It is useful in analyses with a high level of generality. (...) In current research and training practice the product of effort duration and HR was referred to as conventional units' or further calculations have been made to convert it into points." [39, p. 238].

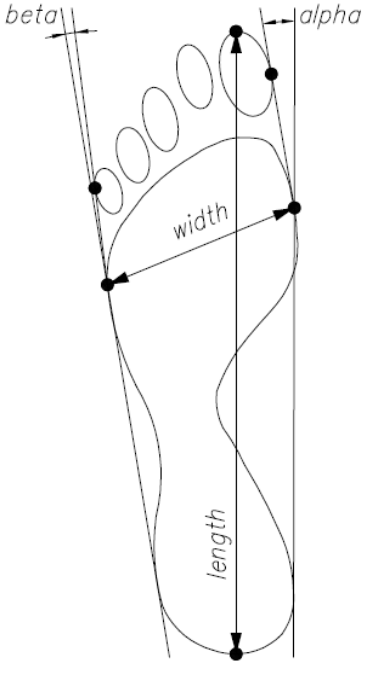

Figure 1. Alpha and beta angles.

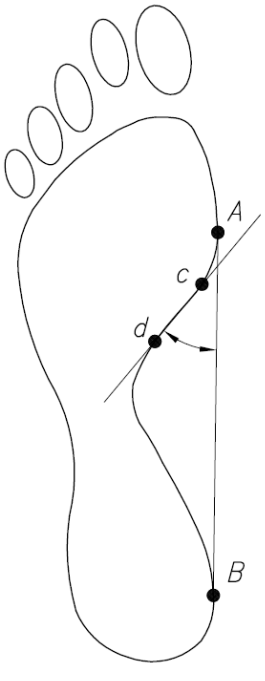

Figure 2. Clarke's angle.

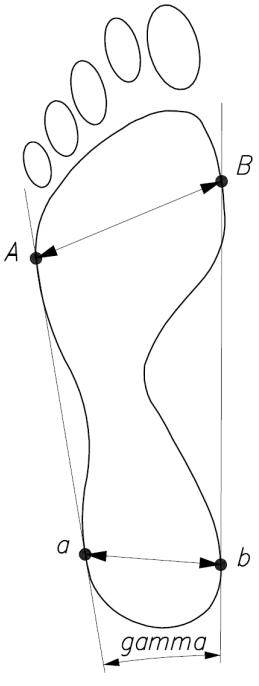

Figure 3. Gamma angle.

Table 1. The statistical characteristics of somatic features.

Feature	Body weight	Body height	BMI
	Judo athletes subgruop A (BMI <25) N = 48		
Mean	65.76	173.58	21.74
Min.	53.00	162.50	17.92
Max.	87.00	197.00	24.57
SD	9.17	7.66	1.83
V	13.95	4.41	8.40
	Judo athletes subgruop B (BMI >25) N = 22		
Mean	97.3	184.1	28.7
Min.	80.3	171.5	25.1
Max.	153.0	198.0	39.0
SD	15.6	7.1	4.1
V	16.0	3.9	14.2
Student's t-test A vs. B	**-14.08**	**-5.98**	**-9.74**
	Karate athletes (C) N = 30		
Mean	72.37	177.40	22.94
Min.	55	161	18.72
Max.	106	190	30.31
SD	10.31	6.67	2.50
V	14.25	3.76	10.92
Student's t-test B vs. C	**5.02**	**2.77**	**4.47**
Student's t-test A vs. C	**−2.91**	**−2.22**	**−2.40**

*p<0.05

BMI >25 and karatekas were significantly prevalent. Significantly higher BMI values and other somatic indices of karate Kyokushin athletes than athletes from subgroup A (Table 1) were found.

The width and length of the foot were the highest among the male judo practitioners (subgroups B). The karate Kyokushin athletes have the shortest feet, while the lighter judo athletes the narrowest feet. The differences were statistically significant. Judo athletes have a slightly longer and wider left foot, which may indicate more frequent loading of the left side of the body during combat and training. The karate athletes did not show this trend (Table 2).

The majority of the measured angles of both feet indicate a better arching of the right foot relative to the left foot, regardless of combat sport and weight category. Alpha angle (hallux valgus angle) does not exceed normal values in combat sports athletes. These values increase in the left foot, regardless of the sport and weight class, while in the right foot, almost all of the examined men have a similar alpha angle. Intergroup differences were statistically non-significant. Judo and karate athletes are characterized by higher values of the alpha angle of the left foot. It was found that the valgus deformity of the left hallux is more frequent than of the right hallux, and the measured values of the alpha angle were also higher on the left foot (Table 3).

The value of beta angle (varus deformity of the fifth toe) is similar among all the studied male athletes (p>0.05). The gamma angle (transverse arch of the foot) was shown to be correct only in the group in male karate Kyokushin practitioners, slightly exceeding of normal values. The differences in BMI between karate and judo athletes are statistically significant. All judokas are characterized by a flattening of the transverse arch of both feet, which may be a sign of excessive strain on the forefoot, excessive weight of the body, or excessive loading of the feet during throws, while "taking on" the opponent's body weight (Table 3).

Table 2. The statistical characteristics of podometric features.

Feature	Left foot		Right foot	
	length	width	length	width
Judo athletes subgruop A (BMI <25) N = 48				
Mean	28.75	9.18	28.57	8.81
Min.	26.30	7.70	24.80	7.30
Max.	31.40	11.00	31.70	10.50
SD	1.35	0.85	1.52	0.75
V	4.71	9.28	5.32	8.49
Judo athletes subgruop B (BMI >25) N = 22				
Mean	30.2	10.5	29.1	10.1
Min.	27.2	8.7	3.5	8.1
Max.	32.9	12.5	32.8	12.1
SD	1.3	1.0	5.9	1.0
V	4.5	9.2	20.2	9.8
Student's t-test A vs. B	**−4.54**	**−2.19**	**−1.48**	**−8.14**
Karate athletes (C) N = 30				
Mean	25.31	9.38	25.23	9.40
Min.	23.3	8.2	23.2	8.5
Max.	27.5	10.5	27.4	10.4
SD	1.00	0.58	0.93	0.56
V	3.97	6.20	3.70	5.94
Student's t-test B vs. C	**11.21**	**3.57**	**2.21**	**2.34**
Student's t-test A vs. C	**11.84**	**−1.09**	**10.69**	**−3.68**

*p<0.05

The Clarke's angle value (longitudinal arch of the foot) indicates the correct arching of the feet of all studied combat sports athletes. The highest statistically significant values were observed in the karate athletes in whom the mean Clarke's angle of the right foot approached the upper limit of normal longitudinal arch of the foot (Figure 4 and 5). It shows a tendency to an excavated foot, which, similarly to a flattened foot, reduces the performance of the foot under excessive load. The lowest, although within the normal range, arch of the foot was found in judo athletes from subgroup A (however, it is the least homogenous group, as evidenced by the values of SD and V). The normal arch of the foot was found in more than 60% of studied combat sports athletes. However, the trend of excessively arched feet was observed among karate Kyokushin athletes, but not in the left feet judo athletes. Men judo athletes are more likely to experience the flattening of the longitudinal arch of the foot - both feet in subgroup A, and the left foot in subgroup A (Table 3).

A rather weak or low correlation between body weight and the angular values of the feet was found in combat sports athletes. Also the correlation between foot length and the alpha angle was low. No significant correlation was found between foot length and Clarke's angle (longitudinal arch of the foot). Foot length shows a negative and moderate relationship with the gamma angle of the right foot among lighter judo athletes and of the left foot in heavier judo practitioners. Positive and moderate correlations with the alpha and gamma angles were found among all male athletes under study. No clear correlation between foot width and Clarke's angle was found. In the case of karate athletes no significant correlation between Clarke's angle and alpha angle was noted, whereas in the case of judo athletes there was a low inverse relationship between a lower longitudinal arch of the foot and greater hallux valgus values (Table 4).

Table 3. The statistical characteristics of arches of the feet.

Feature	Angles of the left foot				Angles of the right foot			
	alpha	beta	gamma	Clarke's	alpha	beta	gamma	Clarke's
Judo athletes subgruop A (BMI < 25) N = 48								
Mean	7.80	19.21	20.30	41.31	6.28	19.56	20.18	42.63
Min.	0.00	8.30	13.50	25.60	0.10	4.80	13.40	22.80
Max.	15.70	32.20	26.80	50.00	20.00	29.90	24.60	54.80
SD	3.81	5.87	2.91	6.38	4.07	5.41	2.78	6.62
V	48.84	30.53	14.35	15.45	64.85	27.65	13.78	15.54
Judo athletes subgruop B (BMI > 25) N = 22								
Mean	8.4	20.7	21.1	42.4	6.2	22.2	21.2	43.8
Min.	1.2	10.0	16.4	30.1	0.4	12.2	15.5	32.0
Max.	17.7	31.6	31.0	50.7	14.4	33.9	26.9	52.5
SD	4.1	5.4	3.6	5.3	3.8	5.3	3.2	5.1
V	48.3	25.9	17.2	12.6	60.9	24.1	15.1	11.7
test t-Studenta A vs. B	−0.54	−1.02	−1.2	−0.73	0.05	−1.89	−1.01	−0.78
Karate athletes (C) N = 30								
Mean	6.34	19.53	15.94	45.50	6.21	20.06	16.87	47.84
Min.	0.8	5.2	11.7	39.1	0.8	0	11.1	39.8
Max.	19.3	32.3	18.2	53.2	16.2	30.6	20.3	59.1
SD	5.05	6.56	1.80	3.67	4.07	5.83	2.00	4.08
V	79.70	33.58	11.31	8.06	65.63	29.05	11.87	8.54
test t-Studenta B vs. C	1.39	0.61	**4.62**	−1.82	0.01	1.12	**4.30**	**−2.39**
test t-Studenta A vs. C	1.43	−0.22	**7.27**	**−3.23**	0.07	−0.38	**5.60**	**−3.82**

*p<0.05

DISCUSSION

The foot, being a distal segment of the kinetic chain [18] of the human body, reacts to all irregularities along the entire length of this chain. This is reflected in the structure of the foot, which may cause or exacerbate the existing irregularities. Dysfunctional feet also impair the functioning of the body and may contribute to abnormal muscle tension, asymmetrical limb and trunk positions, generate pain or scoliosis [19]. It has been shown that injuries are often interrelated and occur in a line from the heel to the hallux [20]. Excessive weight gain results in increased loading of the feet, which in consequence, after exceeding the compensatory capabilities of the structural elements of the feet, leads to the lowering of transverse and longitudinal arches of the foot, and deepening of the valgus deformity of the hallux [21-23]. Negative pressure from excessive body weight is observed among judo competitors and athletes in higher body weight categories. Among them there is a tendency to increase the longitudinal and transverse dimensions of the feet, which, apart from the increased body weight, may be the result of many years of professional sporting activity [24]. The above mentioned athletes also featured the increasing hallux valgus angle and the highest values of the gamma angle. These increased values may indicate a flattening of the transverse arch of the foot. It is a feature conditioned by foot width, which depends to a great extent on the impact of external factors [25].

The situation is different in the case of the longitudinal arch of the foot. Judo athletes with lower body weight relative to body height have the lowest Clarke's angle values. As demonstrated in [26], body weight loss in patients with high BMI does not always go hand in hand with an improved longitudinal arch of the foot. Thus, it is possible that among judo athletes the adverse effect of the specificity of the sport was observed, as they are characterized by much lower values of Clarke's angle than Kyokushin karate athletes. However, while a significantly higher percentage of judo athletes with a lowered longitudinal arch of the

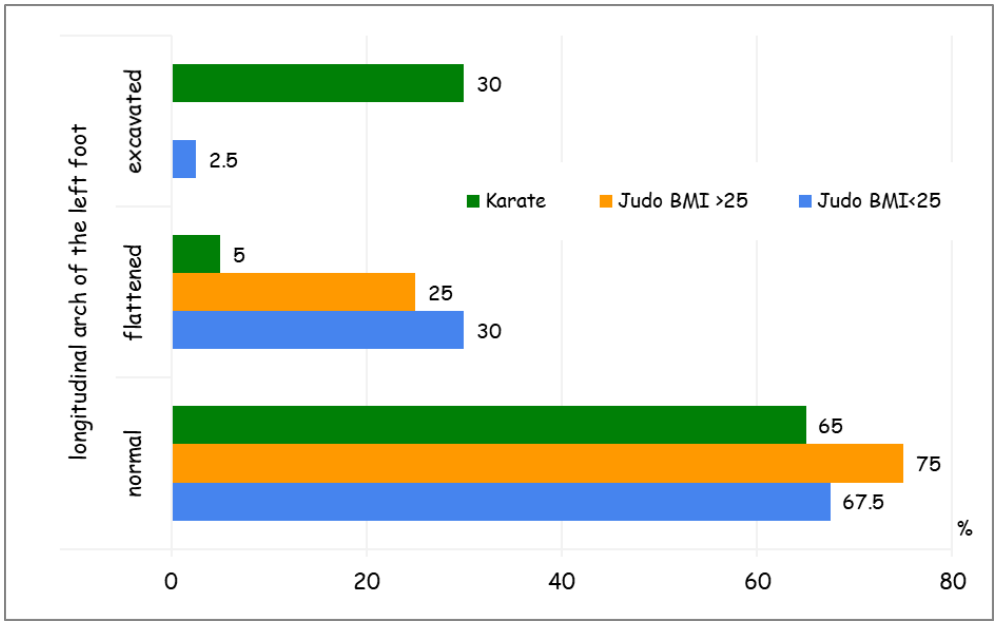

Figure 4. Percentage characteristics of the left foot arch type in the research subgroups.

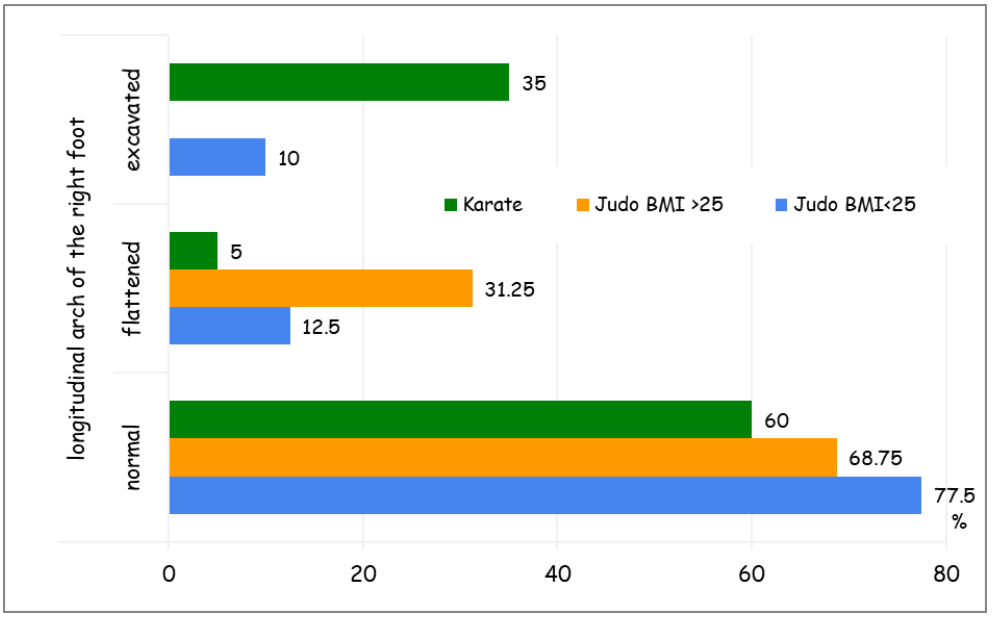

Figure 5. Percentage characteristics of the right foot arch type in the research subgroups.

foot was found, the karate athletes display a tendency for excessive longitudinal arches of the feet. Therefore, it can be stated that even many years of professional karate training are not conducive to the proper structure of the feet [27].

What is more, many of our observations correspond with the results of studies of young fencers. Fencing belongs to the combat sport category of "workings of weapons" [3], where the asymmetrical load on the limbs (legs and arms) is evident [28]. Łagan and Stopka [29] found an asymmetry between the dominant and the non-dominant sides of the fencing posture and the anatomical posture among 12 children (aged 6-12 years) training fencing as an extra activity (i.e. long before taking loads characteristic of professional, long-term training). Judo athletes ("throws

Table 4. Pearson's correlation coefficient between angles of the feet and morphological features.

Body weight			Length foot			Width foot			Clarke's angle
angle									
alpha	Clarke's	gamma	alpha	Clarke's	gamma	alpha	Clarke's	gamma	alpha angle
Judo athletes subgruop A (BMI <25) N = 48									
left foot									
−0.10	−0.12	0.21	−0.11	−0.10	−0.13	−0.03	−0.22	**0.50**	**−0.35**
right foot									
−0.29	−0.10	0.12	−0.28	0.04	**−0.37**	−0.33	0.002	0.19	**−0.34**
Judo athletes subgruop B (BMI >25) N = 22									
left foot									
0.19	0.04	0.08	0.14	0.04	**−0.43**	**0.48**	0.02	0.56	**−0.33**
right foot									
0.13	0.13	0.18	0.04	−0.20	−0.25	0.29	**0.38**	**0.51**	−0.25
Karate athletes N = 30									
left foot									
0.22	−0.12	0.30	0.03	0.27	0.09	0.31	0.18	0.56	0.025
right foot									
0.15	**−0.37**	0.15	−0.11	−0.09	−0.03	0.29	−0.06	**0.51**	0.025

*p<0.05

and grips of immobilisation of opponent's body" category) also generally prefer right-handed grips (right leg in front) or left-handed grips of an opponent's judogi during combat. Therefore, asymmetrical loads on the feet are also characteristic of judo training, and the adjustment effects of this phenomenon are shown in the present study.

Analogy is also warranted with regard to Kyokushin karate athletes ("hits" category of combat sport), especially in the kumite forms (sparring). Moreover, most of this category of combat sports (multiple varieties of karate, kickboxing [30]) feature kicks with unprotected feet. Examples of other sports, in particular football, provide clear evidence that protecting the feet does not guarantee avoiding injuries. As observed among football players of different age groups, kicking the ball or contact with another player generates, in many cases, injuries within the foot [31].

The present study significantly contributes to the knowledge of negative adaptive effects of long-term combat sports practice. There are both logical and ethical premises to generalize these results at least in the categories of "throws and grips of immobilisation of opponent's body" and "hits (strokes)" combat sports. Apart from the repeatedly proven positive effects of martial arts training (including combat sports) [f.i. 32], we consider it necessary to monitor all negative effects as well [5-7, 10, 12, 13, 28-31], including the pathology of mixed martial arts [9, 33]. We believe that as part of the widely promoted innovative agonology [34-36] by the global scientific community, the issues of health prevention and concern for increasing the survival ability of each individual and society as a whole should also include recommendations concerning the knowledge described, inter alia, in this work. An equally important element of broadly understood health promotion based on sport activity is continuous monitoring of training loads [38, 39]. These postulates, in our opinion, fit into an attractive detailed method of innovative agonology, i.e. martial arts bibliotherapy [40, 41]. Honesty dictates that the evidence-based knowledge of both sides of martial arts – health-oriented and extreme pathology – should be made available to the society by credible scientists of various specialties.

CONCLUSIONS

The results of the present study reveal specific adaptive effects in young men practicing different categories of combat sports. Judo athletes are characterized by a flattened transverse arch of the foot, and a correctly shaped longitudinal arch of the foot, while

those representing higher weight categories are characterized by an increasing tendency toward hallux valgus. Kyokushin karate male athletes feature the correct transverse and longitudinal arches of the feet. Monitoring of all negative effects of long-term combat sports training should be an important component of evidence-based complementary health prevention programs.

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