ORIGINAL ARTICLE

Relationships between the level of strength of the upper and lower limbs and indicators of technical--tactical preparation of kickboxing fighters in the K1 formula competitions

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Abstract

Background and Study Aim: Strength training is often considered a key element in preparing athletes for combat sports, as it allows them to increase their power capabilities and, through the interaction of motor skills, affects endurance and speed. The purpose of this study it was broaden knowledge about the level of strength of the upper and lower limbs of kickboxing competitors fighting in the K1 formula and to determine its impact on the level of technical-tactical training.

Material and Methods: The study was conducted on a group of 15 high-level kickboxing athletes who regularly participate in K1 competitions. In the study, the level of isometric strength of the extensors and flexors of the upper and lower limbs (elbow and knee joints, respectively) of the left and right sides was measured. For this purpose, the BTE PrimusRS system was used for objective evaluation and functional training (BTE USA, New Hampshire), which in this case served as a dynamometer.

Results: The strength of the upper limbs of the examined athletes, both extensor and flexor muscles of the elbow joint, showed similar levels of development between limbs ($p>0.05$). A similar trend was observed for the lower limbs regarding the strength of the knee flexor muscles. Different levels were demonstrated for extensor strength, with a predominance effect for the right lower limb ($p<0.001$). A statistically significant very strong and powerful positive relationship was found between the effectiveness and efficiency index of the attack and the strength of the extensors and flexors of the lower right limb ($r = 0.62$ to 0.80; $p<0.001$).

Conclusions: Kickboxers exhibit a symmetric profile of upper limb strength. The lead leg of athletes in this profession showed a higher level of muscular strength and offensive activity. The juxtaposition of the results of strength tests and indicators of technical-tactical training shows the need to develop the level of strength of extensors and flexors of the lower limbs, which may translate into the development of the fighter's starting condition.

Keywords: combat sports • explosive strength • isometric strength • strength training • technical-tactical performance

Conflict of interest: Authors have declared that no competing interest exists

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INTRODUCTION

Kickboxing – combat sport where the form of combat are strikes, performed by hands and legs [32].

K1 rules – the rules of kickboxing fighting, placing the least restrictions on the rules. In K1, all techniques found in kickboxing are allowed, performed without any limitation on the strength of the blows [37].

Strength – is the body's ability to overcome external resistance or the resistance of its own body in static conditions or in low-speed, high-intensity movements [25].

Technical-tactical indicators – calculated on the basis of specialized formulas, characterize the technical-tactical performance of athletes [5].

Combat sports are a group of disciplines in which participants compete with each other through physical contact [1]. Many people believe that muscular strength is one of the most important factors determining success in these disciplines [2-6]. Strength can be defined as the ability to apply pressure or generate power, which can manifest itself in various forms, such as punching power, kicking [7], grabbing and explosive strength [8, 9].

Strength training is often considered a key element in preparing athletes for combat sports, because it allows them to increase their strength capabilities through the combination of motor skills affecting endurance and speed [10]. The improvement of strength variables is also related to the effectiveness of technical activities [11]. Some combat sports, such as boxing and kickboxing, require particularly high punching power [12, 13], while others, such as judo or wrestling, require grip and take-off power [14]. Regardless of what combat sport you practice, strength training can be very beneficial for better performance. Through regular strength training, which, as mentioned, increases power and endurance, one can better cope with the demands of training and competition [15]. However, it is worth remembering that strength training is only one element of an athlete's preparation and should be combined with other forms of training, such as endurance or technical training, to achieve optimal results [3].

In kickboxing, as in many other combat sports, the strength of the strike is one of the most important elements determining the success of the competitor, because, among others, it decides about the end of the fight before time by knockout [12, 16, 17]. Strength training allows to indirectly increase speed, which is an element of the fighter's dynamics ultimately translating into the strength of the blow [18, 19].

A review of the literature on strength training in kickboxing indicates that there are several ways to implement it that can be effective for competitors practicing this discipline [20]. One of them is training with external resistance, which consists in performing exercises in series using the heavy athletic or bodybuilding method [21, 22]. Kickboxing competitors most often use multi-joint exercises such as squats, deadlifts or barbell presses [23]. Another way is functional training, which focuses on strengthening muscles in a way that corresponds to their natural movements and functions (in competing and everyday life) [24]. Exercises such as weightlifting in various body positions and performing exercises with the use of specialist equipment such as TRX, power ban, kettlebell, Bulgarian bag, etc. are used here [25].

Research shows that the implementation of strength training with external resistance can bring benefits to kickboxing competitors, such as increasing the strength and power of the lower and upper limbs [26]. Whereas functional training can contribute to improving the quality and effectiveness of the athletes' technique and its effectiveness in sports combat [27]. Therefore, the purpose of this study it was broaden knowledge about the level of strength of the upper and lower limbs of kickboxing competitors fighting in the K1 formula and to determine its impact on the level of technical-tactical training.

MATERIAL AND METHODS

Participants

The study was conducted on a group of 15 high-level kickboxing fighters who regularly compete in K1 competitions. Sample size was calculated using G*Power 3.1.9.7 software (G*Power Team, Düsseldorf, Germany). The surveyed athletes ranged from 18 to 30 years old. The inclusion criterion was the start of the training, coach's opinion and lack of injury. A detailed anthropometric description of the study group is presented in Table 1.

Table 1. General characteristics of the kickboxing, K1 athletes (n = 15) studied.

Variable	M	SD	Min	Max	Q1	Q3
Body mass [kg]	81.63	9.73	68.20	95.40	73.20	91.30
Body height [cm]	179.71	4.85	170.10	188.40	177.50	181.55
Body Mass Index (BMI)	25.35	3.62	21.00	33.00	23.25	27.30

M arithmetic mean; **SD** standard deviation; **Min** minimum; **Max** maximum; **Q1** bottom quartile; **Q3** upper quartile

Survey design

The surveys were conducted in the morning according to the scheme presented in Figure 1.

Test procedures

Force measurement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Bioethics Committee at the Regional Medical Chamber in Kraków, Poland (No. 287/KBL/OIL/2020).

In the study, the level of isometric strength of the extensors and flexors of the upper and lower limbs (elbow and knee joints, respectively) of the left and right sides was measured. For this purpose, the BTE PrimusRS system for objective evaluation and functional training (BTE Technologies, Hanover, USA) was used, which in this case served as a dynamometer. A dedicated 701 tool was used for the measurements. The axis of the dynamometer head was set flush with the anatomical axis of rotation of the examined joint individually for each examined person.

The measurement protocol included the following measurements:

- isometric strength of extensors and flexors of the upper limbs performed in a standing position in which the examined person had their feet slightly hip width apart. The upper limb was bent in the elbow joint at an angle of 90^{o}, the shoulders were parallel to the ground. The subjects performed three 4 seconds long maximum contractions of the flexors and then the extensors of the upper limbs.

- isometric strength of extensors and flexors of the lower limbs, which was performed in a sitting position using a specialized chair, which is part of the BTE PrimusRS system. The lower

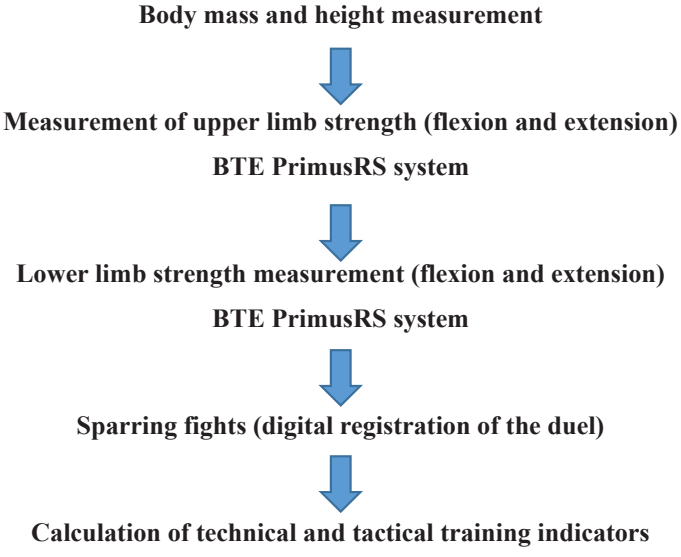

Figure 1. The course of the study.

limb was bent at the knee joint at an angle of 90^0, hands on the stomach or chest, while the trunk, hips and the middle part of the thigh were stabilized with stabilizing straps. The subjects performed three maximal contractions of the extensors and then the flexors of the lower limb for 4 seconds (Figure 2).

Sparring fights

The contestants were grouped according to weight categories, which were determined during the body weight measurement using the Tanita DC-360S scale (Tanita Corporation, Tokyo, Japan). The fights took place in the ring placed in a neutral environment which none of the subjects was associated with. The fights were conducted according to K1 rules adopted by the World Association of Kickboxing Organizations (WAKO). The contestants fought three times for 2 minutes with one minute breaks. The duel was overseen by a qualified licensed referee. In the vantage point, a GoPro HERO10 (GoPro Inc, San Mateo, USA) camera was placed on a specialized frame giving a full view of the ring and recorded the material for the analysis of the fight.

Analysis of the fight

The analysis of the fight was carried out by two master class trainers and one referee. The researchers recorded on special measurement cards the techniques that were successful and all offensive techniques. Observational data were averaged and entered into a Microsoft Excel (Microsoft Corporation, Redmond, USA) spreadsheet, where technical-tactical training indicators (attack activity, attack effectiveness, attack efficiency) were calculated using the specialized formulas listed below (equations 1-3) [28]:

Attack activity (Aa):

$$Aa = \frac{number\ of\ recorded\ attacks\ by\ the\ competitor}{number\ of\ fights\ by\ the\ tested\ competitor} \quad (1)$$

In the current study, each competitor fought one fight.

Attack Effectiveness (Sa):

$$Sa = \frac{n}{N} \quad (2)$$

where **n** is the number of successful attacks rated at 1 point (in K1 formula, each clean hit on an opponent gives 1 point); **N** the sum of observed fights for a given fighter (in the present study, each fighter fought one fight).

Attack Efficiency (Ea):

$$Ea = \frac{number\ of\ successful\ attacks}{number\ of\ all\ attacks} \times 100 \quad (3)$$

Figure 2. Photograph of the course of the BTE PrimusRS force test.

Assessment criteria

The following assessment criteria were adopted:

- a successful attack is defined as a technical action for which a point was awarded;
- the number of all attacks determines all offensive techniques (effective and ineffective).

Statistical analysis

Statistical analysis of the collected empirical data was carried out in the PQStat ver. 1.8.4 software (PQStat Software, Poznan, Poland). Descriptive statistics were calculated: arithmetic mean (M), standard deviation (SD or ±), minimum value (Min), maximum value (Max), lower and upper quartiles (explanations under the tables). The normality of the distribution was checked and confirmed by the Shapiro-Wilk test. To assess statistically significant differences, the Student's *t*-test for dependent variables was used, $p<0.05$ was assumed as the level of statistically significant differences. The effect size was calculated using d-Cohen assuming the following thresholds: 0.20 weak effect, 0.50 moderate effect, 0.80 strong effect. To assess the relationship between the examined variables, the persona linear correlation was used in the range of 0.0 to 0.5 weak correlation, 0.5 to 1.0 strong correlation, in the case of negative relationships –0.5 to 0.0 weak correlation, –1.0 to –0.5 strong correlation.

RESULTS

Regarding the assessment of upper limb extension strength, it was found that the group of examined athletes exhibited a similar level of development for the comparative analysis between the right and left limbs. Marginally higher results were noted, with signs of a weak effect, concerning the right upper limb (Table 2).

Based on the analysis of mean values, a similar trend of development was observed in the level of strength of the upper limb flexors. The right limbs of the examined athletes (insignificantly, with a weak effect) showed a more favourable result in the test compared to the left limbs (Table 3).

The results of our own research revealed significant variability in the level of strength of the knee extensor muscles among the examined kickboxers. A significantly higher level, with a strong effect, was noted for the right lower limb (Table 4).

Table 2. The level of strength of the upper limbs in extension.

Variable	M	SD	Min	Max	Q1	Q3	t	p	d
upper limb extension-right [N]	162.65	25.92	123.74	214.87	150.95	174.06	0.32	0.75	0.08
upper limb extension-left [N]	160.69	20.94	121.25	192.32	148.02	173.64			

M arithmetic mean; **SD** standard deviation; **Min** minimum; **Max** maximum; **Q1** bottom quartile; **Q3** upper quartile; **t** Student's *t*-test; **p** level of significance for differentiation; **d** Cohen effect size for differentiation; **N** Newton

Table 3. The level of strength of the upper limbs in flexion.

Variable	M	SD	Min	Max	Q1	Q3	t	p	d
upper limb flexed-right [N]	235.99	30.65	179.72	284.35	220.40	256.84	0.69	0.51	0.19
upper limb flexed-left [N]	230.26	28.40	175.50	280.88	218.07	248.84			

M arithmetic mean; **SD** standard deviation; **Min** minimum; **Max** maximum; **Q1** bottom quartile; **Q3** upper quartile; **t** Student's *t*-test; **p** level of significance for differentiation; **d** Cohen effect size for differentiation; **N** Newton

Table 4. Lower limb extensor strength level.

Variable	M	SD	Min	Max	Q1	Q3	t	p	d
lower limb extension-right [N]	1619.79	269.47	1155.60	1859.09	1427.54	1842.12	**3.95**	**0.001**	**0.35**
lower limb extension-left [N]	1529.03	240.54	1066.20	1815.60	1347.66	1701.88			

statistically significant correlation (bold font): **M** arithmetic mean; **SD** standard deviation; **Min** minimum; **Max** maximum; **Q1** bottom quartile; **Q3** upper quartile; **t** Student's *t*-test; **p** level of significance for differentiation; **d** Cohen effect size for differentiation; **N** Newton

Table 5. Lower limb flexor strength level.

Variable	M	SD	Min	Max	Q1	Q3	t	p	d
lower limb flexed-right [N]	1135.95	217.98	720.27	1389.87	1029.21	1302.18	0.64	0.52	0.21
lower limb flexed-left [N]	1175.27	153.43	944.61	1471.72	1061.41	1278.21			

M arithmetic mean; **SD** standard deviation; **Min** minimum; **Max** maximum; **Q1** bottom quartile; **Q3** upper quartile; **t** Student's *t*-test; **p** level of significance for differentiation; **d** Cohen effect size for differentiation; **N** Newton

In the case of the level of strength of the muscles flexing the lower limbs, higher values were recorded for the left limb of kickboxers. However, the demonstrated differences were slight, without signs of statistical significance (Table 5).

Effective blows accounted for 58.33 % of the share of all offensive techniques inflicted.

The values of the indicators of technical and tactical preparation in the form of attack activity, attack effectiveness and attack efficiency are presented in Table 6.

Regarding the associations between strength proficiency and technical-tactical training of the examined kickboxers, statistically significant positive correlations were observed in the comparison of the right lower limb with the level of effectiveness and efficiency of attack. The proficiency of the flexor muscles of the right knee joint showed a very strong association with indicators of attack effectiveness and efficiency. Similarly, for extensor strength, a very clear association with effectiveness and a strong one with attack efficiency were noted (Table 7).

Table 6. Values of technical-tactical training indicators.

Indicators	M	SD	Min	Max	Q1	Q3
Attack activity (Aa)	116.93	27.91	80.00	196.00	106.50	127.50
Attack effectiveness (Sa)	58.33	15.10	30.00	72.00	47.50	70.00
Attack efficiency (Ea)	46.72	9.43	28.68	57.13	41.90	51.65

M arithmetic mean; **SD** standard deviation; **Min** minimum; **Max** maximum; **Q1** bottom quartile; **Q3** upper quartile

Table 7. Relationship between technical-tactical training indicators and the level of strength.

Indicators	Attack activity	Attack effectiveness	Attack efficiency
upper limb extension-right	r = 0.45; p = 0.18	r = 0.18; p = 0.62	r = 0.17; p = 0.64
upper limb extension-left	r = –0.02; p = 0.96	r = 0.18; p = 0.61	r = 0.17; p = 0.63
upper limb flexion-right	r = 0.28; p = 0.44	r = 0.38; p = 0.27	r = 0.22; p = 0.55
upper limb flexion-left	r = –0.25; p = 0.49	r = 0.22; p = 0.54	r = 0.15; p = 0.67
lower limb extension-right	r = 0.63; p = 0.82	**r = 0.76; p =0.001**	**r = 0.62; p = 0.02**
lower limb extension-left	r = 0.11; p = 0.70	r = 0.45; p = 0.09	r = 0.31; p = 0.27
lower limb flexion-right	r = 0.22; p = 0.41	**r = 0.78; p =0.001**	**r = 0.80; p<0.001**
lower limb flexion-left	r = 0.20; p = 0.48	r = –0.14; p = 0.62	r =–0.003; p<0.99

statistically significant correlation (bold font): a near-complete relationship r>0.90; a very high association r = 0.70 to 0.90; high association r = 0.50 to 0.70; moderate association r = 0.30 to 0.50

In terms of quantity, the highest efficiency, illustrated by the mean number of strikes with the lower limbs, was observed for the right leg. Taking into account the type of technique, the highest activity was characteristic of the low kick-right technique.

However, concerning defensive actions (defence against low kick), the highest utilization was demonstrated for the left limb.

A detailed description of the number of performed kicks and defence against low kick is presented in Table 8.

DISCUSSION

In the study, the level of strength fitness of the upper and lower limbs of kickboxing competitors participating in the K1 formula was diagnosed,

Table 8. Number of kicks and blocks during the fight.

Variable	M	SD	Min	Max	Q1	Q3
foot kick-left	19.50	15.89	1	46	5.75	24.50
foot kick-right	24.80	7.95	10	39	21.25	28.50
low kick-left	5.90	5.38	0	17	2.25	9.00
low kick-right	14.90	8.98	0	33	10.25	19.25
defence against low kick-right	0.40	0.96	0	3	0.00	0.00
defence against low kick-left	9.40	4.83	5	20	6.00	10.50
all kicks	44.30	15.65	23	69	29.75	53.00

M arithmetic mean; **SD** standard deviation; **Min** minimum; **Max** maximum; **Q1** bottom quartile; **Q3** upper quartile

and the level of technical-tactical training was assessed. The strength of the relationship between the coexistence of the above variables was also interpreted.

Scientists associated with the milieu of stand-up combat sports (e.g. karate, boxing, kickboxing) and mixed combat plane (e.g. sports ju-jitsu) unanimously agree about the important role of strength skills in these disciplines [12, 29, 28, 3, 26]. In our research, we used the BTE PrimusRS specialist dynamometer for the first time. Analysing the level and differentiation of strength abilities of the upper limbs, a non-significantly higher effectiveness of the right limb was found in relation to the left one in the examined athletes. This phenomenon occurred both in the case of isotonic contractions of the extensor and flexor muscles of the elbow joint.

It can therefore be concluded that in this comparison, the subjects are characterized by similar competences, and the above-mentioned aspects of motor fitness could most likely be similarly shaped and improved in the training process in accordance with the broadly understood principle of versatility of muscular work [30, 31]. During a fight, a kickboxing competitor spends most of the time in the guard from which he performs a series of blows at different angles with both upper limbs [32]. As a result, he must strongly and symmetrically engage various muscle groups of the arms [33]. The slight advantage of the right limb can be explained by the fact that it was the subjects' dominant hand.

The dynamometer measurement showed a varied level of development of the strength fitness of the lower limbs. In the case of the strength of muscles flexing the knee joint, insignificantly higher values were recorded for the left limb of kickboxers. The competitor of the K1 formula defends oneself from low circular kicks by characteristic blocks with the lower limbs (thigh lift with the knee and hip joint flexed) strongly engaging the thigh and knee flexors [34, 35]. The target of such strikes is the thigh, and not blocking them impairs mobility, can be very painful and may lead to the end of the fight [16, 36]. The fighting stance of a right-handed K1 competitor is characterized by a forward lunge of the left leg, as a result of which it becomes a frequent target of attack. The answer is increased defence by blocking [11]. In our research, during the observation of three-round sparring, the advantage of the low kick block for the left limb in relation to the right one was noted, which may explain the observed advantage of the strength of the left limb flexors. The results of own research showed a significant difference in the strength of the muscles that straighten the knee joint of kickboxers. A higher significant level was noted for the right limb. In the case of the left limb, this aspect may not be evenly shaped and improved in their training structure [17]. It seems that the reason should be sought in the specificity of the discipline [32]. A K1 right-handed fighter will have his right leg in the back position, which means that it is immediately ready for offensive actions, especially with low round kicks. With it, he will strike more often with greater force, strongly exploiting the strength of the extensor muscles. To deliver a kick with the left leg of similar potential, the competitor performs a kind of jump (in order to move the left leg back). This technique is less commonly used. In our observations of K1 duels, there was a definite advantage in the number of kicks with the right leg compared to the left leg. This probably has an impact on the kinetics of lower limb strength development and indicates that the K1 formula puts higher demands on the strength competence of the right leg extensors for right-handed fighters. The observed asymmetry of strength capabilities of the lower limbs may result from the technical and tactical style imposed by the discipline.

In assessing the level of technical and tactical skills of the fighters', specialized formulas were used, which are reliable indicators of these aspects [37]. While providing the technical and tactical characteristics of the examined fighters, it was noted that the indicators of activity, efficiency and effectiveness of the attack were much higher than those obtained by participants and finalists of local tournaments, and lower than those obtained by the finalists of the World Championships [37].

Long-term sports training requires a continuous influx of various types of information. An essential issue may include, among others, clear information regarding the mutual relationships between individual aspects (e.g., strength fitness vs. technical-tactical performance). Recent research indicates that lower values of indicators characterizing fat tissue and growth-weight features, as well as body composition of kickboxers, favor the optimization of technical-tactical performance [38]. Therefore, one may pose the question: what

priority of strength fitness should characterize a K1 kickboxer to maximize their chances of success in their discipline?

In terms of interrelationships between strength fitness and technical-tactical training of the examined kickboxers, statistically significant correlations were noted in the case of juxtaposing the lower right limb with the level of effectiveness and efficiency of the attack. The effectiveness of the knee flexor muscles showed a very strong relationship with the effectiveness ($r = 0.78$; $p = 0.001$) and attack efficiency ($r = 0.80$; $p<0.001$) indicators. The same in the case of extensors, there was a very clear relationship with effectiveness ($r = 0.76$; $p = 0.001$) and a strong relationship with attack efficiency ($r = 0.62$; $p = 0.02$). Attention is also drawn to the high value of the extension force coefficient for attack activity $r = 0.63$ (statistically insignificant). Such results confirm previous conclusions and also prove that a high level of strength fitness of the right lower limb will be conducive to optimal efficiency and effectiveness of technical and tactical skills in sports combat. It is worth noting that Ambroży et al. [17] proved that round kicks from above were the most effective technique and often ended the fight with a knockout. Interesting and related conclusions were presented in earlier studies that emphasized significant interdependencies, among others, between the explosive strength of legs and technical-tactical training [3]. It is also emphasized that in kickboxing, a high level of dynamic strength of the lower limbs will determine the effectiveness of kicks and the increase in technical and tactical indicators [39]. The results of our own research correspond positively with the research of Thai boxers, which showed a significant co-occurrence of the increase in the level of strength abilities with a prolonged period of training study [40].

It should also be remembered that the outcome of a confrontation with an opponent (sports competition, sparring) at the championship level will be determined by the comprehensive development of the athlete. In addition to aspects such as motor preparation, effort abilities, special fitness, and technical-tactical performance, volitional traits and mental readiness immediately before the fight are also crucial [41].

CONCLUSIONS

The analysis reveals that the extensor muscles of the right leg are statistically significantly stronger than those of the left leg, leading to a higher frequency of hits. This disparity in strength between the limbs underscores a critical aspect of physical conditioning for kickboxing athletes. Moreover, the data indicates that kickboxing competitors generally exhibit a comparable degree of upper limb effectiveness, suggesting a uniformity in training focus or natural ability across participants in this sport. Importantly, the muscle strength of the lower limbs is identified as a pivotal factor influencing both the effectiveness and efficiency of kickboxers' attacks, especially among those competing under the K1 ruleset. This insight underscores the integral role of lower limb conditioning in enhancing competitive performance in kickboxing.

Practical implications

The juxtaposition of the results of strength tests and indicators of technical-tactical training shows the need to develop the level of strength of extensors and flexors of the lower limbs, which may translate into the development of the fighter's starting condition.

REFERENCES

1. Kalina RM. Teoria sportów walki. Warszawa: Centralny Ośrodek Sportu; 2000 [in Polish]
2. Tassiopoulos I, Nikolaidis PT. Acute effect of official kickboxing game on handgrip muscle strength: winners vs. losers. J Phys Educ Sport 2013; 13(2): 266-269
3. Ruddock AD, Wilson DC, Thompson SW et al. Strength and Conditioning for Professional Boxing: Recommendations for Physical Preparation. Strength Cond J 2016; 38(3): 81-90
4. Witkowski K, Piepiora P, Grochola M. The knee joint extensor and flexor strength indicators in judo female athletes. Arch Budo Sci Martial Art Extreme Sport 2018; 14: 215-225
5. Rydzik Ł, Ambroży T. Physical Fitness and the Level of Technical and Tactical Training of Kickboxers. Int J Env Res Pub He 2021; 18(6): 3088
6. Laett CT, Silva R, Cossich CFS et al. Maximum and explosive strength in Brazilian kickboxing athletes: asymmetries between limbs and the relationship with the single jump distance. Sport Sci Health 2023; 19(10): 241-247
7. Cronin J, Lawton T, Harris N et al. A Brief Review of Handgrip Strength and Sport Performance. J Strength Cond Res 2017; 31(11): 3187-3217
8. Dias JA, Wentz M, Külkamp W et al. Is the handgrip strength performance better in judokas than in non-judokas? Sci Sports 2012; 27(3): e9-e14

9. Bonitch-Góngora JG, Almeida F, Padial P et al. Maximal isometric handgrip strength and endurance differences between elite and non-elite young judo athletes. Arch Budo 2013; 9(4): 239-248
10. Sharkey BJ, Gaskill S. Fizjologia sportu dla trenerów. Warszawa: Centralny Ośrodek Sportu; 2013 [in Polish]
11. Ambroży T, Rydzik Ł, Kwiatkowski A et al. Effect of CrossFit Training on Physical Fitness of Kickboxers. Int J Env Res Pub He 2022; 19(8): 4526
12. Filimonov VI, Koptsev KN, Husyanov ZM et al. Boxing: Means of increasing strength of the punch. Yessis M, translator. Natl Strength Cond Assoc J 1985; 7(6): 65-66
13. Machado SM, Souza RA, Simão AP et al. Comparative study of isokinetic variables of the knee in taekwondo and kickboxing athletes. Fit Perf J 2009; 8(6): 407-411
14. Henry T. Resistance Training for Judo: Functional Strength Training Concepts and Principles. Strength Cond J 2011; 33(6): 40-49
15. Jeffreys I, Moody J, editors. Strength and Conditioning for Sports Performance. 2nd ed. New York: Routledge; 2021
16. Ouergui I, Hssin N, Haddad M et al. The effects of five weeks of kickboxing training on physical fitness. Muscles Ligaments Tendons J 2014; 4(2): 106-113
17. Ambroży T, Rydzik Ł, Kędra A et al. The effectiveness of kickboxing techniques and its relation to fights won by knockout. Arch Budo 2020; 16: 11-17
18. Buse GJ, Santana JC. Conditioning Strategies for Competitive Kickboxing. Strength Cond J 2008; 30(4): 42-48
19. Buse GJ. Kickboxing. In: Kordi R, Maffulli N, Wroble RR, Wallace WA, editors. Combat Sports Medicine. London: Springer; 2009: 331-350
20. Mismar BA, Al-Omer OM. The Impact of a Proposed Training Program to Develop Selected Physical Abilities among Kickboxing Players. Int J Innov Creat Change 2021; 15(2): 175-195
21. DiNubile NA. Strength Training. Clin Sports Med 1991; 10(1): 33-62
22. Kruszewski M, Kępa G, Merda W. Trening kulturystyczny w okresie przygotowawczym. Warszawa: Wydawnictwo Akademii Wychowania Fizycznego; 1997 [in Polish]
23. Rippetoe M, Kilgore L. Starting Strength: Basic Barbell Training. 3rd ed. Wichita Falls: Aasgaard Co; 2011
24. Boyle M. New functional training for sports. 2nd ed. Champaign: Human Kinetics; 2016
25. Nowak M, Ambroży T. Współczesny trening obwodowy w teorii i praktyce. Kraków: Fall; 2015 [in Polish]
26. Slimani M, Chaabene H, Miarka B et al. Kickboxing review: anthropometric, psychophysiological and activity profiles and injury epidemiology. Biol Sport 2017; 34(2): 185-196
27. Ouergui I, Delleli S, Bouassida A et al. Technical–tactical analysis of small combat games in male kickboxers: effects of varied number of opponents and area size. BMC Sports Sci Med Rehabil 2021; 13(1): 158
28. Ambroży T, Nowak M, Mucha D et al. The influence of an original training programme on the general physical fitness of ju-jitsu trainees. Ido Mov Cult 2014; 14(4): 69-76
29. Imamura H, Yoshimura Y, Uchida K et al. Maximal oxygen uptake, body composition and strength of highly competitive and novice karate practitioners. Appl Hum Sci 1998; 17(5): 215-218
30. Janikowska-Siatka M. Materiały pomocnicze do ćwiczeń z metodyki wychowania fizycznego. Kraków: Akademia Wychowania Fizycznego imienia Bronisława Czecha; 2006 [in Polish]
31. Ouergui I, Houcine N, Marzouki H et al. Development of a noncontact kickboxing circuit training protocol that simulates elite male kickboxing competition. J Strength Cond Res 2015; 29(12): 3405-3411
32. Di Marino SA. Complete Guide to Kickboxing. New York: Enslow Publishing; 2018
33. Sterkowicz S, Lech G, Blecharz J. Effects of laterality on the technical/tactical behavior in view of the results of judo fights. Arch Budo 2010; 6(4): 173-177
34. Hölbling D, Preuschl E, Hassmann M et al. Kinematic analysis of the double side kick in pointfighting, kickboxing. J Sports Sci 2017; 35(4): 317-324
35. Podrigalo LV, Volodchenko AA, Rovnaya OA et al. The prediction of success in kickboxing based on the analysis of morphofunctional, physiological, biomechanical and psychophysiological indicators. Phys Educ Stud 2018; 22(1): 51-56
36. Lystad RP. Injuries to Professional and Amateur Kickboxing Contestants: A 15-Year Retrospective Cohort Study. Orthop J Sports Med 2015; 3(11): 2325967115612416
37. Rydzik Ł. Indices of technical and tactical training during kickboxing at different levels of competition in the K1 formula. J Kinesiol Exerc Sci 2022; 32(97): 1-5
38. Niewczas M, Wąsacz W, Ambroży T et al. The relationship between body composition before a sports fight and the technical and tactical performance of kickboxing athletes. Arch Budo Sci Martial Art Extreme Sport 2023; 19: 197-210
39. NCD Risk Factor Collaboration (NCD-RisC). Heterogeneous contributions of change in population distribution of body mass index to change in obesity and underweight. eLife 2021; 10: e60060
40. Wąsacz W, Rydzik Ł, Ouergui I et al. Comparison of the Physical Fitness Profile of Muay Thai and Brazilian Jiu-Jitsu Athletes with Reference to Training Experience. Int J Env Res Pub He 2022; 19(14): 8451
41. Rydzik Ł, Wąsacz W, Ambroży T et al. Kickboxing on Theta and Beta2 waves: unravelling the mind's secrets through QEEG analysis. Arch Budo Sci Martial Art Extreme Sport 2023; 19: 211-218

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