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Current trends in physical and physiological profile of elite WKF karate athletes: a systematic review

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Abstract

Background This qualitative analysis aimed to: identify the physical and physiological factors that characterize elite WKF kumite and kata athletes, identify testing protocols that are used to examine the above mentioned profiles of WKF karatekas and indicate the variables that are significant for elite-level performance.

Methods A search of electronic databases (PubMed, EBSCO, Scopus) was conducted to identify all studies on physical and physiological profile in elite karatekas from 2012 to 2024. A JBI Qualitative Data Extraction Tool for systematic reviews of qualitative evidence was fulfilled in order to determine which variables should be extracted. The quality of the included studies was assessed based on the JBI Critical Appraisal Checklist.

Results 164 full-text articles were evaluated to determine eligibility, while 20 met the inclusion criteria and were subjected to detailed analysis, including risk of bias assessment. Finally, 17 full-text articles were included in the qualitative analysis. The following motor abilities and physiological components were evaluated by researchers: muscular strength (n=8) muscular power (n=11), speed (n=8), agility (n=6), flexibility (n=6), aerobic metabolism (n=9), anaerobic metabolism (n=5).

Conclusions The force-velocity characteristics with the dominant effect of the velocity component seem to be crucial in regard to performance outcomes in WKF karatekas. Moreover, elite karatekas are characterized by high flexibility of the hamstring muscles and well developed speed and agility abilities. The efficiency of aerobic and anaerobic metabolism is significant for high-performance in elite WKF kumite athletes, however aerobic capacity may be crucial. It is difficult to confirm the impact of the above mentioned energy systems on kata performance. Athlete's age category and sex-related variables may affect the level of the analyzed motor abilities.

Keywords Strength, Power, Speed, Kumite, Kata, Aerobic capacity, Anaerobic capacity, Flexibility, Agility, Sex-specific

Background

Among numerous kinds of combat sports that can be listed under the term 'martial arts' [1] karate is believed to be one of the most frequent practiced combat sports

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worldwide [2], especially since it has evolved to became an official Olympic discipline [3]. There are many styles of karate, however only four (Shotokan, Shito-Ryu, Wado-Ryu, Goju-Ryu) are approved by the World Karate Federation (WKF) as part of the Olympic rivalry [4]. WKF karate competitions are currently organized in two equally important sport disciplines i.e., kumite and kata, that are differentiated in the terms of the characteristics of the sport performance and athlete's physical and physiological requirements [5].



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Kumite is a striking karate bout (1.5–3 min of effective fight time) between two opponents that is performed as an intermittent activity, which includes interactions by the referee in order to announce points or penalties [6]. Its structure is characterized by two kinds of physical exertion: (1) exercise at maximal/supramaximal intensity (approximately 1–3 s) i.e., a single punch/kick [7] and (2) exercise at submaximal intensity (up to 15s) [6], i.e., no striking actions between the opponents. Moreover, several factors can impact the effort-pause ratio for high-intensity actions during a kumite bout [8, 9], among which athlete's technical and tactical skills, fight score or opponents pressure can be indicated [10]. In contrast to kumite, a kata bout (lasts approximately from 30s up to 5 min) [11, 12] is known as a predetermined sequences of style-selected offensive and defensive karate techniques that are performed individually or in a team of three athletes, always identically and under situational conditions and established movement patterns [7]. The intensity of a kata bout includes similar kind of activity i.e., submaximal, maximal and supramaximal [8]. Considering the above, elite level karate performance, both in kumite and kata, requires from the athlete a high level of efficiency of all three human's energetic systems [8, 12] however, the contribution of aerobic and anaerobic metabolism can be diverse according to the karate disciplines [8], what indicates a discipline-specific physiological profile.

On the other hand, as karate is a complex sport [13], the specifics of its techniques requires high level of skillrelated components. Therefore, professional athletes need to poses a high level of multiple motor abilities, however there is still no consensus between the researchers according to the primarily physical and physiological determinants of a successful karate performance. Nevertheless, the biomechanical analysis of the motor activities during a karate bout indicates that the majority of the actions consist of explosive movements i.e. punches and kicks [14, 15]. Therefore, karate performance seems to be related to a high level of muscular strength and the athlete's ability to generate high levels of power in a short period of time (Rate of Force Development) [16].

Considering that, strikes in combat sports last from 50 to 300 ms, however during a strike an athlete is unable to develop maximal power [17]. This is mainly because the required time for its development lasts from 600 up to 800 ms [17]. Thus, the velocity of muscular contractions is limited and can be developed only up to a certain point. Given that, athlete's strikes can be based either on (a) high velocity profile or (b) high strength profile, adequately to the selected form of training periodization in the context of the force-velocity curve [18] and discipline requirements. Thus, the proportion of athlete's velocity and strength level can be diverse between both of

the karate disciplines [2] and athlete's age, what can also determine the final karate performance. Moreover, this also can be associated with development of an unique physical and physiological profile [5], including diverse requirements in strength and conditioning.

However, even though in the last few years researchers have become more focused on the issue of physical and physiological determinants that contributes to the success in a karate bout, this issue remains unsolved. Some authors suggest that speed, agility and flexibility are the main motor abilities that determine athlete's high-performance profile [19], whereas others indicate muscular power and strength endurance as the dominant abilities in karate [20–22] at the same time indicating the need for further and deeper analyses. However, it is still difficult to indicate an optimal protocol to assess the intrinsic determinants of athlete's performance in WKF karate.

Physical and physiological profile of karate athletes has been a subject of previous qualitative analysis [23], yet since in the last years the number of research manuscripts that addressed the abovementioned issue is constantly increasing, there is a need to conduct an update in this field. Moreover, as since 2012 WKF kata and kumite competition rules have been significantly modified, it is justified to perform additional systematic research in order to present the current trends accordioning to the physical and physiological profile of elite WKF karatekas that would be directly focused on investigating the above mentioned issue in the context of karate in the Olympic formula (WKF) including both karate disciplines (kumite, kata). Given the above cited findings and the gap in the scientific literature it seems justified to perform additional research in order to evaluate the current trends in physical and physiological profile of WKF karate athletes. This may improve the process of athlete's selection to particular karate discipline and may also help to apply the most appropriate training methods in order to enhance sport performance. Therefore, this systematic review aimed to: (1) identify the physical and physiological factors that characterize elite WKF kumite and kata athletes, (2) identify testing protocols that are used to examine the above mentioned profiles of WKF karate athletes accordingly to theirs competitive age groups, karate specialization (kumite/kata) and evaluated motor ability, and (3) indicate the variables that are significant for elite-level performance in WKF karate.

Methods

Study design

The methodology of this systematic review was developed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [24].

Inclusion and exclusion criteria

In this qualitative analysis inclusion criteria were as follows: (a) cross-sectional study, (b) able-bodied elite (national or international level or national team) karate athlete, (c) males and females ≥ 14 years old, (d) WKF kata and/or kumite specialization or WKF karate athlete (including approved karate styles), (e) athlete's physical and/or physiological profile was the primary aim of the study. The exclusion criteria were as follows: (a) article type different than a cross-sectional study, (b) athletes with disabilities or amateur karatekas, (c) high-performance WKF karate athletes < 13 years of age, (d) physical or physiological profile was not the primary aim of the study (e) elite karate athletes from styles not included in the World Karate Federation (WKF) or lack of data according to karate federation, (f) mixed kind of martial arts in a single study group, (g) athlete's physical profile included only anthropometric and/or morphological characteristics, (h) lack of numeric data according to the performed test, (i) no full-text available, (j) manuscript not in English language.

Literature search and study selection process

A search of electronic databases (PubMed, EBSCO, Scopus) was conducted by two authors (EG, MD) to identify all studies on physical and physiological profile in elite karate athletes from 1st January 2012 up to 30th of June 2024. January 2012 was selected as the primary year of the systematic screening in order to: (a) guarantee a sufficient update of the previous narrative review conducted by Chaabene et al. [23], and to (b) enable to screen all scientific data that addressed the analyzed issues after beginning the process of WKF competitive kata and kumite rules modifications. As a prerequisite, all studies were performed in healthy populations including males and females (≥ 14 years). Search terms were combined by Boolean logic (AND/OR) in PubMed, EBSCO and SCOPUS databases. The search was undertaken using the following 12 keyword combinations in English with the assumed hierarchy of their importance: karate, athlete, physical profile, physiological profile, physical fitness, strength, power, agility, speed, flexibility, endurance, coordination. The detailed search string, based on a selected database is available in the APPENDIX I. Moreover, two authors (EG, MD) with expertise in karate training and strength and conditioning reviewed the reference lists of the included studies and screened Google Scholar to find additional research. Furthermore, if a systematic/ scoping review or meta-analysis was identified the above mentioned authors (EG, MD) have screened the references list in each of the identified qualitative or quantitative analysis in order to define the missing research. Moreover, the corresponding authors of the selected publications were also contacted directly if the crucial data were not available in the original articles.

Data extraction process and data items

Following the Joanna Briggs Institute (JBI) Manual for Evidence Synthesis guidelines [25] a JBI Qualitative Data Extraction Tool for systematic reviews of qualitative evidence [25] was fulfilled by two authors (EG, MD) as part of an independent process, in order to determine which variables should be extracted. The above mentioned form included the following domains: (1) basic data (author, year of publication, journal, record number), (2) methodology (study design), (3) methods (that were used in the study), (4) phenomena of interest (aim of the study), (5) setting (clinical, community), (6) geographical (region, country), (7) cultural, (8) participants (sample size, participant's characteristics, age), (9) data analysis, (10) author's conclusions, (11) reviewer's comments. Furthermore, a third independent co-author (AZ) checked the data for accuracy and consistency.

Methodological quality of the included studies (risk of bias)

The quality of the included studies was assessed based on the Joanna Briggs Institute Critical Appraisal Checklist [26] for analytical and comparative cross-sectional studies. The JBI checklist is known to be the newest and the most preferred tool to assess the risk of bias in the above cited scientific research. The JBI checklist includes 8 items that are scored as follows: 'Yes,' 'No,' 'Unsure', 'Not applicable'. A 'Yes' was assigned to the assessed item, if the manuscript criterion was fulfilled, which simultaneously received a score of one. If the manuscript criterion was not fulfilled (including missing data) a 'No', 'Unsure' or 'Not applicable' was assigned to the evaluated item and a zero score was yielded. Each of the included articles were read and ranked by two independent investigators (EG, MD) with expertise in karate and strength and conditioning. Moreover, an independent co-author (AZ) was designated to resolve all discrepancies that could occur among study investigators during the evaluation. The methodological quality of the included studies was indicated by the total score (out of a possible 8 points), with the higher values representing better quality of the included research manuscripts.

Synthesis methods

The selected manuscripts were grouped into tables according to the main issues that were undertaken by the researchers of the included papers i.e., (a) muscular strength, (b) muscular power, (c) speed, (d) agility, (e) flexibility, (f) aerobic power and aerobic capacity, (g) anaerobic power and anaerobic capacity. Furthermore, they were summarized according to the following items: (1) author of the study, year of publication, (2) participant's characteristics, (3) region and country of origin, athlete's rank and specialization [kata/kumite], (4) kind of measurement, (5) research test, (6) testing protocol, (7) main findings of the study.

Results

Study selection and characteristics

The flow of the systematic review is presented in Fig. 1. Together 164 full-text articles were evaluated to determine eligibility, while 20 scientific studies met the assumed inclusion criteria and were subjected to detailed analysis, including the assessment of their methodological quality (Table 1).

Among twenty reports that had been evaluated for their methodological quality eight were considered to score 8/8 points of eligibility to be included in the qualitative analysis. Four articles were found to have 7/8 points of eligibility, one was scored as 6/8 points of eligibility and four were assessed as 5/8 points of eligibility, what was the minimum score to be included into the qualitative synthesis. Moreover, one article was scored 2/8 and two were evaluated with 1/8 points of eligibility, and therefore were excluded from the further analysis due to high incidence of the risk of bias. The initial agreement of the two independent investigators (EG, MD) was 90%. Furthermore, all discrepancies among the investigators were resolved by expert evaluation conducted by an independent co-author (AZ). Finally, 17 full-text articles were included in the qualitative analysis (Tables 2, 3, 4, 5, 6, 7 and 8).

Discussion

A careful examination of the current scientific data on the physical and psychological factors that influence high-performance in elite WKF karate athletes yielded partially inconsistent findings. However, this qualitative analysis found that among different motor abilities that were evaluated by the researchers, the force-velocity characteristics with the dominant effect of the velocity component seem to be crucial in regard to performance outcomes in WKF karate athletes. Moreover, elite-level WKF karatekas are generally characterized by high level



Fig. 1 PRISMA flow diagram detailing the study inclusion process

Number	Author	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Sum
1.	Scattone-Silva et al. [27]	Y	Y	Y	Y	Y	Y	Y	Y	8/8
2.	Tabben et al. [28]	U	Y	Y	Y	Υ	Y	Y	Y	7/8
3.	Sánchez-Puccini et al. [29]	U	Y	Y	Y	U	N/A	Y	Y	5/8
4.	Kotrljanovic et al. [30]	U	Y	Y	Y	Y	Y	U	Y	6/8
5.	Nikookheslat et al. [20]	Ν	Y	U	Y	Y	Y	U	Y	5/8
6.	Arazi et al. [31]	Ν	Y	U	Y	Y	Y	U	Y	5/8
7.	Ateş et al. [32]	U	Y	U	U	Ν	U	U	Y	2/8
8.	Spigolon et al. [33]	Y	Y	Y	Y	Y	Y	Y	Y	8/8
9.	Najmi et al. [34]	U	Y	Y	Y	Y	Y	Y	Y	7/8
10.	Güler et al. [35]	Ν	Y	Y	Y	Y	Y	Y	Y	7/8
11.	Rakita et al. [36]	Ν	Y	Y	Y	Ν	N/A	Y	Y	5/8
12.	Martínez de Quel et al. [37]	Y	Y	Y	Y	Y	Y	Y	Y	8/8
13.	Shalja et al. [38]	U	Ν	Ν	U	U	U	U	Y	1/8
14.	Przybylski et al. [39]	Y	Y	Y	Y	Y	Y	Y	Y	8/8
15.	Shalja et al. [40]	Ν	Ν	U	U	Ν	Ν	U	Y	1/8
16.	Martínez de Quel et al. [41]	U	Y	Y	Y	Y	Y	Y	Y	7/8
17.	Wąsik et al. [42]	Y	Y	Y	Y	Y	Y	Y	Y	8/8
18.	Ojeda-Aravena et al. [43]	Y	Y	Y	Y	Y	Y	Y	Y	8/8
19.	Smajla et al. [44]	Υ	Y	Y	Y	Υ	Y	Y	Υ	8/8
20.	Almeida-Neto et al. [45]	Y	Y	Y	Y	Y	Y	Y	Y	8/8

Table 1 The assessment of the methodological quality of the included studies (risk of bias) using the JBI method for cross-sectional studies

Q1- Were the criteria for inclusion in the sample clearly defined?; Q2- Were the study subjects and the setting described in detail?;Q3- Was the exposure measured in a valid and reliable way?; Q4- Were objective, standard criteria used for measurement of the condition?;Q5- Were confounding factors identified?;Q6- Were strategies to deal with confounding factors stated?;Q7- Were the outcomes measured in a valid and reliable way?;Q8- Was appropriate statistical analysis used?; Y-yes; N-no; U-unsure; NA-not applicable

of speed, agility and flexibility of the hamstring muscles, however flexibility level may differ between karate disciplines, what was not confirmed by the speed and agility profile. Furthermore, in WKF kumite athletes high level of both aerobic and anaerobic capacity seems to be significant for elite sport performance. Simultaneously, it is difficult to definitely confirm the influence of aerobic and anaerobic metabolism on kata performance in elite WKF karatekas, however both of them may contribute to the effectiveness of a kata bout.

Strength and power profile

A number of underlying factors can impact on athlete's performance, however only some of them can be manipulated with regular sports training [16]. Among these factors muscular strength has been shown to be a variable that can significantly impact successful sport performance, when it is combined with appropriate training periodization [16]. The presented data of the qualitative analysis indicated that five strength components can be related to high-performance in elite WKF kata and kumite athletes i.e. (a) hand grip strength [34, 39, 42], (b) strength endurance [20], (c) isometric strength [39], (d)

isokinetic strength [27, 30] and (e) maximum strength [28, 31, 39].

Numerous authors investigated relationship between isokinetic hand grip strength (assessed with a hand-held dynamometer) and effective WKF karate performance [34, 39, 42], however only Najmi et al. [34] indicated its contribution to performance enhancement in male kumite athletes. On the other hand, both Przybylski et al. [39] and Wąsik et al. [42] pointed to the significance of hand grip strength in Shotokan style karatekas, but at the same time the cited research indicated other components that can be crucial to achieve high-performance in a karate bout e.g. strength endurance [39] and dexterity [42]. The inconsistence in the results of the cited research can be related to the intrinsic differences that characterize discipline-specific karate performance.

Considering that, the current available scientific literature indicates that the majority (43.7%) of successful offensive actions during a kumite bout are scored by punches [46]. Similarly, in a kata bout both offensive and defensive techniques of the upper limbs are performed more frequently compared to various kinds of kicks what is related to the characteristic of kata's routine [47]. However, the neurophysiological mechanisms responsible for

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Table 2 The su

	rarticipants characteristic [kata/kumite]	Research test [unit]	Testing protocol	Main findings (mean ± SD)
Scattone-Silva et al. [27]	Elite Shotokan karate athletes $nM = 7/age = 24.5 \pm 4.8$ [years]; BH = 171.5 \pm 6.5 [cm]; BM = 76.0 \pm 17.7 [kg]	lsokinetic strength test [nM]	Warm up (upper limbs): 5-minutes on a cycle ergometer (no load) (Saratoga Cycle, Rand- Scot, Colorado, USA) Warm up (lower limbs): 5-minutes on a cycle ergometer (Ergo 167 Cycle, Ergo-Fit, Pir- masens, Germany), load 75 W, 20 km/h speed Testing for both upper and lower limbs: 5 rep- etitions at 600/s and 10 repetitions at 3600/s. Peak torque was normalized by body mass x 100 (%)	Knee extensor/flexor (peak torque) [nM]: 600/s (dominant limb): 267.24 ±47.02/139.81 ± 24.86 600/s (non-dominant limb): 262.26 ± 51.01/135.26 ± 23.10 3600/s (dominant limb): 124.69 ± 26.07/74.69 ± 16.71 3600/s (non-dominant limb): 123.80 ± 35.51/74.41 ± 19.40 5houlder extensor/flexor (peak torque) [nM]: 600/s (dominant limb): 600/s (dominant limb): 58.87 ± 15.43/79.33 ± 16.78 3600/s (dominant limb): 58.87 ± 15.43/79.33 ± 16.78 3600/s (dominant limb): 58.87 ± 15.43/79.33 ± 16.78 3600/s (dominant limb): 33.72 ± 11.46/37.47 ± 11.39
Tabben et al. [28]	Tunisian national karate team [M/D] nP = 19/age = 23.0 ± 2.9 [years]; BH = 178.3 ± 6.6 [cm]; BM = 74.2 ± 10.5 [kg]	1RM test [kg] in bench press, half squat and lying row	Warm up: 3 min of walking Specific warm up: set of 10 repetitions at a relatively light load Gradual increase of load up to 1RM based on self-perceived capacity (3–6 attempts, rest between attempts was set at 4 min). Testing exercises were performed as follows: bench press, half squat, lying row.	1 RM - bench press: 75.0 ± 13.0 [kg] 1 RM - half squat:190.0 ± N/A[kg] 1 RM - lying row:79.0 ± 12.0 [kg]
Kotrljanovic et al. [30]	Serbian national karate team [M/D] nP = 18; nM = 9/age = 24.1 ± 3.72 [years]; BH = 183.10 ± 5.70 [cm]; BM = 78.19 ± 9.73 [kg] nF = 9/age = 21.25 ± 2.76 [years]; BH = 167.63 ± 4.17 [cm]; BM = 63.05 ± 3.56 [kg]	lsokinetic strength test [nM]	A standardized warm-up followed by a famil- iarization session on an isokinetic dynamom- eter (Human Norm): a)Isokinetic strength of hamstring and quadri- ceps: Familiarization session 3 repetitions at individually perceived 50%, 70% of 90% of maximum extraction for a) hamstring and quadriceps. Testing protocol: 4 trials at 60%'s and 180%s, rest between trials was set at > 2 min. b)Muscle strength of the internal and external rotation of the shoulders rotations Familiarization session: M/D Testing protocol: M/D	Peak torque [nM] of: Quadriceps (180°/s, 60°/s) Right (males): 212.78±34.54, 137.11±20.27 Right (females): 135.22±32.92 87.67±20.16 Left (males): 137.24±27.13, 88.89±14.31 Hamstrings Right (females): 137.44±27.13, 88.89±14.31 Hamstrings Right (females): 145.67±22.65, 102.33±16.06 Right (females): 145.67±22.65, 102.33±16.06 Right (females): 143.44±37.102.44±23.31 Left (males): 143.44±34.27, 102.44±23.31 Left (females): 97.89±21.09, 70.00±12.94 Internal rotation (180°/s, 60°/s)

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Author, year	Participant's characteristic [kata/kumite]	Research test [unit]	Testing protocol	Main findings (mean ± SD)
				Right (males):44.11 ± 84.2, 37.33 ± 8.25 Right (females): 25.44 ± 5.43, 20.33 ± 4.09 Left (males): 44.00 ± 10.48, 37.56 ± 9.33 Left (females): 21.78 ± 3.31, 18.56 ± 9.33 Left (females): 21.78 ± 3.31, 18.56 ± 3.81 External rotation (180°5, 60°5) Right (males): 34.67 ± 5.83, 28.33 ± 3.84 Right (females): 19.67 ± 2.74, 20.11 ± 9.93 Left (males): 34.78 ± 6.59,28.56 ± 4.61 Left (females): 20.22 ± 3.31, 16.22 ± 3.15
Nikookheslat et al. [20]	Iranian national karate team [kumite] nM = 40/ age = 23.79 ± 3.06 [years]; BH = 177.86 ± 6.20 [cm]; BM = 72.76 ± 9.98 [kg]	Pull up test [repetitions]	Maximal repetitions of pull up (with palms facing the study participant)	Pull up test: 15.71 ± 8.37 [repetitions]
Arazi et al. [31]	Iranian national karate team [kumite] nM = 11/age = 23.27 ± 2.83 [years]; BH = 181.54 ± 4.71 [cm] ; BM = 82.78 ± 13.55 [kg]	1RM test [kg] in bench press half squat deadlift	Maximum of 8 repetitions in bench press/ squat/deadlift 1RM was calculated via Biebrzycki equalion: 1RM = 100 × load rep/(102.78–2.78 × rep)	1RM - bench press: 100.27 ± 15.61[kg] 1RM - half squat: 155.94 ± 19.49 [kg] 1RM - deadlift: 156.97 ± 21.38 [kg]
Najmi et al. [34]	National Malaysia karate team [kumite] nP = 16 males Senior group: $nM = 8/$ age $= 23.63 \pm 2.88$ [years]; BH $= 173.11 \pm 7.29$ [cm]; BM $= 66.29 \pm 10.5$ [kg] Junior group: $nM = 8/$ age $= 21.88 \pm 1.64$ [years]; nM = 8/age $= 21.04$ [years]; BH $= 171.01 \pm 6.49$ [cm]; BM $= 64.61 \pm 8.12$ [kg]	Hand-grip strength test [kg]	To squeeze the dynamometer with maximum isometric effort in a standing position without additional movements x 3 trials (rest between the trials was set from 10 up to 20 s). The best score was taken into analyses.	Handgrip strength test: Senior group: 47.41 ± 6.12 [kg] Junior group:35.71 ± 4.92 [kg]
Przybylski et al. [39]	Polish participants at World and European Championships and Olympic Games [M/D] nP = 32/ nF = 12/age = 20.92 ± 3.00 [years]; BH = 165.08 ± 6.11 [cm]; BM = 58.58 ± 5.52 [kg] nM = 20/age = 20.40 ± 4.16 [years]; BH = 176.25 ± 6.31 [cm]; BM = 70.35 ± 8.14 [kg]	a)Medicine ball throw test [cm] b)Hand grip strength test [kg] c)Bent arm hang test [s] d) IRM test (bench press) [kg]	 a)3 trials of a forward throw (both arms) with a swing of a 2 kg medicine ball while standing in front of a line. The best result was taken into analyses. b)3 trials of a maximal squeeze b)3 trials of a maximal squeeze b)3 trials of a maximal squeeze c) the dynamometer Lafayette 78010, Lafayette Instrument Company, Lafayette, IN, USA), with a 1 min rest between the attempts. The best result from the dominant hand was taken into analyses. c) To hold on the bar as long as possible (eyes on bar leve) d) The starting weight was determined individually by each atthet, and the progression of the barbell load was 2.5 kg. Two failed attempts excluded the athlete from the test. 	Medicine ball throw test: Males: 1147,00 \pm 201.50 [cm] Females:845.00 \pm 115.17 [cm] Hand grip strength test: Males:44.30 \pm 9.55 [kg] Females:29.00 \pm 3.62 [kg] Bent arm hang test: Males:46.60 \pm 9.35 [s] Females:30.42 \pm 14.43 [s] 1RM test in bench press: Males:65.50 \pm 15.89 [kg] Females:40.00 \pm 10.66 [kg]

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Author, year	Participant's characteristic [kata/kumite]	Research test [unit]	Testing protocol	Main findings (mean±SD)
Wąsik et al. [42]	Elite karate athletes (Shotokan style) [M/D] nP = 18/age = 23.3 ± 11.8 [years]; BM = 70.9 ± 14.2 [kg]	Hand-grip strength test [kg]	Hand grip strength test: 5 trials of maximal grip on a dynamometer (KERN MAP 130K1). 2 extreme results of each were rejected. andthe arithmetic mean was calculated from the remaining trials.	Hand grip strength test: Left grip: 59.3 ± 23.7 [kg] Right grip: 55.5 ± 24.7 [kg]

1RM One repetition maximum, BH Body heigth, BM - mody mass; M/D - missing data; nF - numer of females; nM - numer of males; nP - numer of study participants

Author, vear	Participant's characteristic	Research	Testing protocol	Main findings
	[kata/kumite]	test [unit]		(mean±SD)
Tabben et al. [28]	Tunisian national karate team [M/D] nP = 19/age = 23.0 ± 2.9 [years]; BH = 178.3 ± 6.6 [cm]; BM = 74.2 ± 10.5 [kg]	a)5 J test [m] b)5J test [cm] c)CMJ test [cm]	 a) 5 consecutive strides, the last foot print after the landing was the measure- ment point b-c) 3 trails on a force platform (Quattro Jump (Kistler, Amherst, NY) with 2 min of rest-between trials. 	5 J test: 11.8 ± 1.1 [m] SJ test: 47.2 ± 6.2 [cm] CMJ test: 50.0 ± 5.7 [cm]
Sánchez-Puccini et al. [29]	Columbian national karate team [M/D] nM = 19/ age = 31.6±8.8 [years]; BH = 167.4±9.3 [cm]; BM = 65.4±12.0 [kg]	Standing broad jump test [cm]	Q/W	Standing broad jump test: 221.5 ± 14.8 [cm]
Nikookheslat et al. [20]	Iranian national karate team [kumite] n n = 40/ age = 23.79 \pm 3.06 [years]; BH = 177.86 \pm 6.20 [cm]; BM = 72.76 \pm 9.98 [kg]	Sargent jump test [cm] Standing broad jump test [cm]	A single jump x 3 trials The best of 3 attempts was recorded.	Sargent jump test: 56.60 ± 8.14 [cm] Standing broad jump test: 151.07 ± 13.90 [cm]
Arazi et al. [31]	Iranian national karate team [kumite] nM = 11/age = 23.27 ± 2.83 [years]; BH = 181.54 ± 4.71 [cm] ; BM = 82.78 ± 13.55 [kg]	Long jump test (lower body) [m] Medicine ball (2 kg) throw test (upper body) [m]	3 repeated trials of the long jump/medi- cine ball throw. The best result was taken into statistical analyses.	Long jump test: 2.49 ± 0.16 [m] Medicine ball throw test: 10.46 ± 1.48 [m]
Spigolon et al. [33]	Top 3 males and females of the state ranking in each weight category [kumite] nP=51/ age 19 ± 5 [years]; BH=1.7 \pm0.3 [cm]; BM=67.0 \pm 13.0	SJ test [cm] CMJ test [cm]	For both tests 3 attempts were per- formed on Ergo Jump platform with 15 s rest between trials. Interval break between SJ and CMJ test was 3 min.	SJ test: 32.2 ±6.9 [cm] CMJ test: 37.1 ±7.8 [cm]
Najmi et al. [34]	National Malaysia karate team [kumite] nP = 16 males Senior group: nM = 8/ age = 23.63 \pm 2.88 [years]: BH = 173.11 \pm 7.29 [cm]; BM = 66.29 \pm 10.5 [kg] Junior group: nM = 8/age = 21.88 \pm 1.64 [years]; BH = 171.01 \pm 6.49 [cm]; BM = 64.61 \pm 8.12 [kg]	CMJ test [cm]	3 trials of CMJ performed on a Force Platform. 5 s was given to perform the trial. Rest between trials was set at 1 min. The best score was taken into analyses.	CMJ test: Senior group:37.88±2.47 [cm] Junior group: 31.5±4.34 [cm]
Martínez de Quel et al. [37]	Spanish national karate team [kumite, kata] nP = 81;nKU = 53; nKA = 28/ age = 16–17 [years] nKU/BH = 161.5 \pm 7.2; BM = 55.68 \pm 7.2; nKA/BH = 156.1 \pm 4.9; BM = 52.68 \pm 6.3	EUROFIT test (4th trial) - standing long jump [cm] Two-handed overhead medicine ball (3 kg) throw test	a)A standardized EUROFIT testing proto- col i.e., 2 trials of a standing long Jump – the better result was taken into analyses M/D according to the two-handed over- head medicine ball throw test	Standing long jump test: Kumite athletes:186.3 \pm 17 [cm] Kata athletes:185.6 \pm 17 [cm] Two-handed overhead medicine ball throw test: Kumite athletes:5.38 \pm 0.7 Kata athletes:5.20 \pm 0.7

(continued)
Table 3

Author, year	Participant's characteristic [kata/kumite]	Research test [unit]	Testing protocol	Main findings (mean±SD)
Przybylski et al. [39]	Polish participants at World and European Championships and Olympic Games [M/D] $P=32/nF=12/age=20.92\pm3.00$ [years]; BH=165.08\pm6.11 [cm]; BM=58.58\pm5.52 [kg] nM=20/age=20.40\pm4.16 [years]; BH=176.25\pm6.31 [cm]; BM=70.35\pm8.14 [kg]	a)Long jump test [cm] b)HJ test [cm]	a) 3 trials of maximal long jump from a standing position, b) 3 trials - the best result was taken into analyses.	Long jump test: Males:254.85 ± 20.18 [cm] Females:215.08 ± 15.01 [cm] HJ test: Males:55.75 ± 8.83 [cm] Females:42.17 ± 6.39 [cm]
Martinez de Quel et al. [41]	Spanish National Karate Team [M/D] P = 676; nM = 434; nF = 242 $nM (cadets) = 157/age = 15.26 \pm 0.63$ $years); BH = 168.59 \pm 7.97 [cm];$ $BM = 59.71 \pm 9.55 [kg]$ $nM (junors) = 163/age = 16.98 \pm 0.47$ years); BH = 172.394.6.78 [cm]; $BM = 65.38 \pm 8.91 [kg]$ $nM (U21) = 114/age = 19.47 \pm 0.74 [years];$ $BH = 174.33 \pm 8.12 [cm]; BM = 70.35 \pm 9.64$ [kg] $nf (cadets) = 81/age = 19.47 \pm 0.74 [years];$ $BH = 174.33 \pm 8.12 [cm]; BM = 70.35 \pm 9.64$ [kg] $nf (cadets) = 81/age = 19.47 \pm 0.74 [years];$ $BH = 174.33 \pm 8.12 [cm]; BM = 70.35 \pm 9.64$ [kg] $nf (cadets) = 81/age = 19.47 \pm 0.74 [years];$ $BM = 52.45 \pm 6.01 [kg]$ $nf (unors) = 98/age = 17.05 \pm 0.47$ $[years]; BH = 159.97 \pm 5.88 [cm];$ $BM = 52.45 \pm 6.09 [kg]$ $nf (junors) = 98/age = 17.05 \pm 0.47$ $[years]; BH = 163.18 \pm 7.30 [cm]; BM = 58.64 \pm 9.05$ [kg]	a)EUROFIT test (4th trial) - standing long jump [cm] b)Two-handed overhead medicine ball (3 kg) throw test [m]	a) a standardized EUROFIT testing proto- col i.e., 2 trials of a standing long jump – the better result was taken into analyses b) M/D	Cadets (males/females): Standing long jump: 218.6±16.0 / 180.3±18.8 [cm] Overhead medicine ball throw (3 kg): 6.98±1.08 / 4.98±0.75 [m] Juniors: Standing long jump: 228.2±15.8 / 186.1±17.0 [cm] Overhead medicine ball throw (3 kg)?744±1.02 / 5.33±0.74 [m] U21: Standing long jump: 235.1±16.5 / 189.2±18.2 [cm] Overhead medicine ball throw (3 kg): 8.69±1.10 / 5.85±0.89 [m]
Ojeda-Aravena et al. [43]	Chilian national karate team [kumite] $nP=18$; $nM=10/age = 17.0 \pm 2$ [years]; $BH=168.0 \pm 5.0$ [cm]; $BM=67.4 \pm 13.0$ [kg] $nF=8/age = 14.0 \pm 2.0$ [years]; $BH=153.0 \pm 7.0$ [cm]; $BM=50.0 \pm 9.0$ [kg]	Squat jump test [cm] CMJ test [cm]	3 trials with a 30 s rest between attempts	SJ test: Females:21.8±4.0 [cm] Males:31.4±6.2 [cm] CMJ test: Females:23.9±4.9 [cm] Males:33.7±6.6 [cm]

'ticipant's characteristic ta/kumite]	Research test [unit]	Testing protocol	Main findings (mean±SD)
strian national karate team [kumite] = 39; nM = 22; nF = 17/age = 19.3 ±4.1 ars]; BH = 173.2 ±8.2 [cm]; = 65.4 ± 10.6 [kg]	a)CMJ test [N/A] b)Flywheel squat test [N/A]	a) different loads (0 kg, followed by 20 kg uploaded consequently until the ath- lete was able to jump 10 cm high) x 3 trials on each load with 1 min of recovery between the attempts of a CMIs on a bilateral force plate (model9260AA6, Kistler, Winthertur, Switzerland). The rest between different loads was set at 2 min. b) 2 sets of 5–10 repetitions of fly- wheen squat on a bilateral force plate system (type 9260AA, Kistler, Winterhur, Switzerland) followed by 2 sets of 10 repetition of different loads. The rest between the load was set at 2 min.	CMJ test / Flywheel squat test: Theoretical maximal force: 299±4.3/27.0±4.3 [Nkg - 1] Maximal unloaded velocity: 4.7±1.5/2.0±0.4 [ms - 1] Theoretical maximal power: 345±7.4/13.3±2.1 [(Wkg - 1] Regression line of force-velocity relation- ship: -6.9±2.3/-14.3±4.7 [Ns - 1mkg - 1]
	ta/kumiteJ strian national karate team [kumite] = 39, nM = 22; nF = 17/age = 19.3 ± 4.1 ars]; BH = 173.2 ± 8.2 [cm]; 1= 65.4 ± 10.6 [kg]	ta/kumitej test [unit] strian national karate team [kumite] a)CMJ test [N/A] = 39; nM = 22; nF = 17/age = 19.3 ± 4.1 b)FJywheel squat test [N/A] ars]; BH = 173.2 ± 8.2 [cm]; I= 65.4 ± 10.6 [kg]	tax/kumitej test lunitj a) Kumitej a) CMJ test [N/A] a) Stinan national karate team [kumite] a) CMJ test [N/A] a) Si fiferent loads (0 kg, followed by 20 kg uploaded consequently until the ath- lete was able to jump 10 cm high) ars]; BH = 173.2 ± 8.2 [cm]; x 3 trials on each load with 1 min of recovery between the attempts of recovery between the attempts of a CMJs on a bilateral force plate (model920A46, Kistler, Winthertur, Switzerland). The rest between different loads was set at 2 min. b) 2 sets of 5-10 repetitions of fly- wheen squat on a bilateral force plate system (type 9260AA, Kistler, Winthertur, Switzerland) followed by 2 sets of 10 repetition of different loads. The rest between the load was set at 2 min.

Table 3 (continued)

51 Five jump, BH body height [cm], BM Body mass [kg], CMJ Countermovement jump, HJ High jump, M/D Missing data, N/A Not applicable, nF number of females, nM number of males, nP number of participants, SJ Squat jump

Table 4 The summary o	of the studies from 2012–2024 evaluati	ng speed in elite WKF karate athletes		
Author, year	Participant's characteristic [kata/kumite]	Research test [unit]	Testing protocol	Main findings (mean±SD)
Tabben et al. [28]	Tunisian national karate team [M/D] nP = 19/age = 23.0 ± 2.9 [years]; BH= 178.3 ± 6.6 [cm]; BM = 74.2 ± 10.5 [kg]	30 m sprint test [s]	20 min of an individual warm up 3 × 30 m sprints with lap timing at 10 m and 20 m. Recovery time between the trials was set at 3 min, the best sprint time was taken into analyses.	10 m: 1.84 ± 0.12 [s] 20 m: 3.17 ± 0.14 [s] 30 m: 4.41 ± 0.17 [s]
Nikookheslat et al. [20]	Iranian national karate team [kumite] nM = 40/ age = 23.79 ± 3.06 [years]; BH = 177.86 ± 6.20 [cm]; BM = 72.76 ± 9.98 [kg]	40-yard dash test [s] Visual reaction time test [ms]	a)A single maximum sprint over 40 yards b) M/D	a) 40-yard dash test :4.99 \pm 0.16 [s] b) Visual reaction time:378.78 \pm 63.82 [ms]
Arazi et al. [31]	Iranian national karate team [kumite] nM = 11/age = 23.27 ± 2.83 [years]; BH = 181.54 ± 4.71 [cm] ; BM = 82.78 ± 13.55 [kg]	40-yard dash test [s]	Q/W	40-yard dash test :5.1 ± 0.16 [s]
Martínez de Quel et al. [37]	Spanish national karate team [kumite, kata] nP = 81;nKU = 53; nKA = 28/ age = 16-17 [years] nKU/BH = 161.5 \pm 7.2; BM = 55.68 \pm 7.2 nKA/BH = 156.1 \pm 4.9; BM = 52.68 \pm 6.3	EUROFIT test (2nd trial) – plate tapping test [s]	A standardized EUROFIT testing pro- tocol i.e., 2 trails of plate tapping x25 for each of the plates – the better result was taken into analyses	Plate tapping test: Kumite athletes:9.30±0.8 [s] Kata athletes:9.33±1.0 [s]
Przybylski et al. [39]	Polish participants at World and European Championships and Olympic Games [M/D] $nP = 32$ / $nF = 12/age = 20.92 \pm 3.00$ (years], BH = 165.08 ± 6.11 [cm]; $BM = 58.58 \pm 5.52$ [kg] $nM = 20/age = 20.40 \pm 4.16$ [years]; $BH = 176.25 \pm 6.31$ [cm]; $BM = 70.35 \pm 8.14$ [kg]	a)Disk tapping test [s] b) Chocu-Euki test [number of punches] c) Optical stimulation test (1, 2) [s] d) Optical stimulation test [s] and acoustic (1, 2) stimulation test [s]	 a)2 trials of 25 movements back and forth (a total of 50 touches of a disk). The better score was recorded. b) Maximum number of straight hand punches performed in 10 s of straight hand punches performed in 10 s of straight hand punches performed in 10 s of straight the pedal attached to a special platform on the ground 2) hand-held handle with a thumb. The arithmetic mean was taken into analyses. d) Complex reaction time test: 1)to react as quickly as possible to 15 concess. d) Complex reaction time test: 1)to react as quickly as possible to 15 concest. d) Complex reaction time test: 1)to react as quickly as possible to 15 concorded to a respective light impulses by pressning the buttons on hand-held handles with the thumbs. Each hand correst of the arched to a respective color. 	Disk tapping test: Males:93.30 \pm 6.22 [s] Females:95.00 \pm 11.78 [s] Chocu-tsuki test: Males:77.10 \pm 10.15 [n] Females:77.10 \pm 10.15 [n] Females:77.100 \pm 12.55 [n] Simple reaction time [males/female]: Simple reaction time [males/female]: Hands (optical simula- tion):0.23 \pm 0.01/0.23 \pm 0.02 [s] Hands (acoustic stimula- tion):0.15 \pm 0.02/0.16 \pm 0.02 [s] Complex reaction time: Hands 0.31 \pm 0.04/0.30 \pm 0.03 [s] Hands 0.31 \pm 0.04/0.30 \pm 0.03 [s] Imbs:0.39 \pm 0.05/0.41 \pm 0.09 [s]

sneed in elite WKF karate athletes studies from 2012-2024 evaluation of tho 20 8 Ş

Author, year	Participant's characteristic [kata/kumite]	Research test [unit]	Testing protocol	Main findings (mean±SD)
Martínez de Quel et al. [41]	Spanish National Karate Team [M/D] mP e576;nM = 434; nF = 242 nM (cadets) = 157/agge = 15.26 \pm 0.63 (years); BH = 168.59 ± 7.77 [cm]; BM = 59.71 \pm 9.55 [kg] nM (uniors) = 163/agge = 16.98 \pm 0.47 (years]; BH = 173.39 \pm 6.78 [cm]; BM = 5.33 \pm 8.91 [kg] nM (U21) = 114/agge = 19.47 \pm 0.74 [years]; BH = 174.33 \pm 8.12 [cm]; BM = 70.35 \pm 9.64 [kg] nf (cadets) = 81/agge = 19.47 \pm 0.74 [years]; BH = 174.33 \pm 8.12 [cm]; BM = 70.35 \pm 9.64 [kg] nf (cadets) = 81/agge = 15.35 \pm 0.47 [years]; BH = 159.97 \pm 5.88 [cm]; BM = 52.45 \pm 6.01 [kg] nf (uniors) = 98.agge = 17.05 \pm 0.47 [years]; BH = 159.97 \pm 5.88 [cm]; BM = 54.65 \pm 6.09 [kg] nf (U221) = 63/agge = 19.45 \pm 0.78 [years]; BH = 163.18 \pm 7.30 [cm]; BM = 58.64 \pm 9.05 [kg]	EUROFIT test (2nd trial) – plate tapping test [s]	 O react as quickly as possible to 10 consecutive light and sound impulses, pressing the thumbs on the buttons on hand-held handles, and the feet on the pedals mounted on a special platform on the ground. Each limb was assigned only one type of pulse. A standardized EUROFIT testing protocol i.e., 2 trails of plates – the better result was taken into analyses 	Cadets (males/females): 9.58 ± 1.01 / 9.64 ± 0.81 [5] Juniors (males/females): 9.21 ± 0.88 / 9.32 ± 0.86 [5] U21 (mles/females): 9.13 ± 1.08 / 9.50 ± 1.22 [5]
Wąsik et al. [42]	Elite karate athletes (Shotokan style) [M/D] nP = 18/age = 23.3 ± 11.8 [years]; BM = 70.9 ± 14.2 [kg]	Ditrich's method [cm]	5 trials of grasping the stick as fast as possible. 2 extreme results of each were rejected. and the arithmetic mean was calculated from the remaining trials.	Left hand: 14.8 ± 4.5 [cm] Right hand: 13.7 ± 6.4 [cm]
Ojeda-Aravena et al. [4 3]	Chilian national karate team [kumite] $nP = 18$; $nM = 10/age = 17.0 \pm 2$ [years]; $BH = 168.0 \pm 5.0$ [cm]; $BM = 67.4 \pm 13.0$ [kg] $nF = 8/age = 14.0 \pm 2.0$ [years]; $BH = 153.0 \pm 7.0$ [cm]; $BM = 50.0 \pm 9.0$ [kg]	5 m test [m s – 1]	2 trials of 2 min of passive rest, the best score was taken into analyses.	5 m test: Feamles:1.22 ± 0.07[m s – 1] Males:1.07 ± 0.04[m s – 1]
BH Body height [cm], BM Body	· mass [kg], <i>M/D</i> Missing data, <i>nF</i> Number of fem	ales, <i>nM</i> Number of males, <i>nP</i> Number of study	r participants	

Table 4 (continued)

Author, year	Participant's characteristic [kata/kumite]	Research test [unit]	Testing protocol	Main findings (mean±SD)
Nikookheslat et al. [20]	Iranian national karate team [kumite] nM = 40/ age = 23.79 ± 3.06 [years]; BH = 177.86 ± 6.20 [cm]; BM = 72.76 ± 9.98 [kg]	Shuttle run test [s]	4×9 m of shuttle run x 2 testing trials The best trial was taken into analyses	Shuttle run test: 8.38±0.28 [s]
Arazi et al. [31]	Iranian national karate team [kumite] nM=11/age=23.27±2.83 [years]; BH=181.54±4.71 [cm] ; BM=82.78±13.55 [kg]	Shuttle run test [s]	A shuttle run of 4×9 m	Shuttle run test: 8.85±0.41 [s]
Najmi et al. [34]	National Malaysia karate team [kumite] nP = 16 males Senior group: nM = 8/ age = 23.63 ± 2.88 [years]; BH = 173.11 ± 7.29 [cm]; BM = 66.29 ± 10.5 [kg] Junior group: nM = 8/age = 21.88 ± 1.64 [years]; BH = 171.01 ± 6.49 [cm]; BM = 64.61 ± 8.12 [kg]	T-test [s]	To run as fast as possible: 1) a forward sprint (10 m) 2) side shuffle to the left (5 m) 3) side shuffle to the right (10 m) 3 trials were performed, the best result was taken into analyses.	T-test: Senior group:10.76±0.34 [s] Junior group:11.98±0.53 [s]
Martínez de Quel et al. [37]	Spanish national karate team [kumite, kata] nP = 81;nKU = 53; nKA = 28/ age = 16-17 [years] nKU/BH = 161.5 ± 7.2; BM = 55.68 ± 7.2 nKA/BH = 156.1 ± 4.9; BM = 52.68 ± 6.3	EUROFIT test (8th trial) – shuttle run test [s]	A shuttle run of 10×5 m	Shuttle run test: Kumite athletes:19.27±1.5 [s] Kata athletes:19.2±1.6 [s]
Martínez de Quel et al. [41]	Spanish national karate team [kumite, kata] nP = 676; nM = 434; nF = 242 nM (cadets) = 157/ $age = 15.26 \pm 0.63$ [years]; $BH = 168.59 \pm 7.97$ [cm]; $BM = 59.71 \pm 9.55$ [kg] nM (juniors) = 163/ $age = 16.98 \pm 0.47$ [years]; $BH = 172.39 \pm 6.78$ [cm]; $BM = 65.38 \pm 8.91$ [kg] $nM (U21) = 114/age = 19.47 \pm 0.74$ [years]; $BH = 174.33 \pm 8.12$ [cm]; $BM = 70.35 \pm 9.64$ [kg] nF (cadets) = 81/ $age = 15.35 \pm 0.47$ [years]; $BH = 159.97 \pm 5.88$ [cm]; $BM = 52.45 \pm 6.01$ [kg] nF (juniors) = 98/ $age = 17.05 \pm 0.47$ [years]; $BH = 159.54 \pm 6.97$ [cm]; $BM = 54.65 \pm 6.99$ [kg] $nF (U21) = 63/age = 19.45 \pm 0.78$ [years]; $BH = 163.18 \pm 7.30$ [cm]; $BM = 58.64 \pm 9.05$ [kg]	EUROFIT test (8th trial) – shuttle run test [s]	A shuttle run of 10×5 m	Cadets (males/females): 17.42±1.74/19.18±1.82 [s] Juniors (males/females):16.84±1.55/ 19.25±1.53 [s] U21 (males/females):17.25±1.15/ 18.68±1.52 [s]
Ojeda-Aravena et al. [43]	Chilian national karate team [kumite] $nP = 18; nM = 10/age = 17.0 \pm 2$ [years]; BH = 168.0 \pm 5.0 [cm]; BM = 67.4 \pm 13.0 [kg] $nF = 8/age = 14.0 \pm 2.0$ [years]; BH = 153.0 \pm 7.0 [cm]; BM = 50.0 \pm 9.0 [kg]	T-test (40 m) [s]	T-test protocol: 2 trails of completing a 40-m run between 4 cones (T), with 2 min rest between the attempts, the best score was taken into analyses	T-test: Females:13.64±1.06 [s] Males:11.8±0.69 [s]

Table 5 The summary of the studies from 2012–2024 evaluating agility in elite WKF karate athletes

BH Body height [cm], BM Body mass [kg], M/D Missing data, nF number of females, nKA number of kata athletesn, KU Number of kumite athletes, nM number of males, nP number of study participants

Author, year	Participant's characteristic [kata/kumite]	Research test [unit]	Testing protocol	Main findings (mean±SD)
Nikookheslat et al. [20]	Iranian national karate team [kumite] nM=40/ age=23.79±3.06 [years]; BH=177.86±6.20 [cm]; BM=72.76±9.98 [kg]	Sit-and-reach test on a box [cm]	M/D	Sit-and-reach test on a box: 38.73±5.71 [cm]
Arazi et al. [31]	Iranian national karate team [kumite] nM=11/age=23.27±2.83 [years]; BH=181.54±4.71 [cm] ; BM=82.78±13.55 [kg]	Sit-and-reach test [cm]	3 attempts, the highest value was used	Sit-and-reach test: 37.63 ± 10.73 [cm]
Najmi et al. [34]	National Malaysia karate team [kumite] nP = 16 males Senior group: $nM = 8/$ $age = 23.63 \pm 2.88$ (years]; $BH = 173.11 \pm 7.29$ [cm]; $BM = 66.29 \pm 10.5$ [kg] Junior group: $nM = 8/age = 21.88 \pm 1.64$ [years]; $BH = 171.01 \pm 6.49$ [cm]; $BM = 64.61 \pm 8.12$ [kg]	Sit-and-reach test on a box [cm]	3 trials of a maximal trunk flexion (2 s hold) while sitting on a flex- ion box were performed. The best result was taken into analyses.	Sit-and-reach test on a box: Senior group: 41.56±4.78 Junior group: 38.56±7.94
Martínez de Quel et al. [37]	Spanish national karate team [kumite, kata] nP=81;nKU=53; nKA=28/age=16-17 [years] $nKU/BH=161.5\pm7.2;$ $BM=55.68\pm7.2$ $nKA/BH=156.1\pm4.9;$ $BM=52.68\pm6.3$	EUROFIT test (3rd trial) – sit- and – reach test on a box [cm]	2 trials, the best result was taken into analyses	Sit-and-reach test on a box: Kumite athletes:28.24±7.00 [cm] Kata athletes:29.07±5.6 [cm]
Przybylski et al. [39]	Polish participants at World and European Championships and Olympic Games [M/D] nP = 32/ nF = 12/ age = 20.92 ± 3.00 [years]; BH = 165.08 ± 6.11 [cm]; BM = 58.58 ± 5.52 [kg] nM = 20/age = 20.40 ± 4.16 [years]; BH = 176.25 ± 6.31 [cm]; BM = 70.35 ± 8.14 [kg]	a)Attainable flexure test [cm] b) Yoko-geri test [cm]	a)Maximum number of repeti- tions in 30 s. In a supine position on the mat- tress, the participant touched the mat with their back and then returned to the supine position, with their elbows touching the knees. b) A side kick up to maximal height	Attainable flexure test: Males:21.20 \pm 4.80 [cm] Females:17.08 \pm 6.47 [cm] Yoko-geri test: Males:175.52 \pm 11.50 [cm] Females:159.17 \pm 12.45 [cm] Cross-sectional stride: Males:22.60 \pm 11.45 [cm] Females:13.92 \pm 7.59 [cm]
Martínez de Quel et al. [41]	Spanish National Karate Team [M/D] nP = 676; nM = 434; nF = 242 nM (cadets) = 157/ $age = 15.26 \pm 0.63$ [years]; $BH = 168.59 \pm 7.97$ [cm]; $BM = 59.71 \pm 9.55$ [kg] nM (juniors) = 163/ $age = 16.98 \pm 0.47$ [years]; $BH = 172.39 \pm 6.78$ [cm]; $BM = 65.38 \pm 8.91$ [kg] nM (U21) = 114/age = 19.47 \pm 0.74 [years]; $BH = 174.33 \pm 8.12$ [cm]; $BM = 70.35 \pm 9.64$ [kg] nF (cadets) = 81/ $age = 15.35 \pm 0.47$ [years]; $BH = 159.97 \pm 5.88$ [cm]; $BM = 52.45 \pm 6.01$ [kg] nF (juniors) = 98/ $age = 17.05 \pm 0.47$ [years]; $BH = 159.54 \pm 6.97$ [cm]; $BM = 54.65 \pm 6.99$ [kg] $nF(U21) = 63/age = 19.45 \pm 0.78$ [years]; $BH = 163.18 \pm 7.30$ [cm]; $BM = 58.64 \pm 9.05$ [kg]	EUROFIT test (3rd trial) -sit and reach test [cm]	2 trials, the best result was taken into analyses	Sit-and-reach test: Cadets: Males: 25.02 ± 6.24 [cm] Females: 28.38 ± 5.96 [cm] Juniors: Males: 27.54 ± 7.00 [cm] Females: 28.51 ± 6.54 [cm] U21: Males: 28.07 ± 6.86 [cm] Females: 26.35 ± 8.06 [cm]

Table 6 The summary of the studies from 2012–2024 evaluating flexibility in elite WKF karate athletes

BH Body height [cm], BM Body mass [kg], M/D Missing data, nF number of females, nM number of males, nP number of study participants

Table 7 The summary c	of the studies from 2012–2024 evaluati	ng aerobic power and capacity in elit	e WKF karate athletes	
Author, year	Participant's characteristic [kumite/kata]	Research test [unit]	Testing protocol	Main findings (mean±SD)
Tabben et al. [28]	Tunisian national karate team [M/D] nP= 19/age = 23.0 ± 2.9 [years]; BH= 178.3 ± 6.6 [cm]; BM= 74.2 ± 10.5 [kg]	Treadmill run test (up to exhaustion) [mL.kg-1.min-1]	To run on a flat treadmill Ergo XELG 90(Woodway, Weil, Germany): 3 min at 9 km/h followed by an increased speed by 1 km/h every minute until exhaustion.	Aerobic capacity: 51.0; 58.0 [mL.kg-1.min-1]
Sánchez-Puccini et al. [29]	Columbian national karate team [M/D] nM= 19/ age = 31.6 ± 8.8 [years]; BH = 167.4 ± 9.3 [cm]; BM = 65.4 ± 12.0 [kg]	Modified Astrand-Ryming test [W, ml-kg-1 •min–1]	M/D, testing protocol was performed on a Monark 818E cycle ergometer (Monark AB, Varberg, Sweden)	Aerobic power:223.6 ± 48.2 [W] Aerobic capacity:44.8 ± 7.1 [ml-kg– 1-min–1]
Arazi et al. [31]	Iranian national karate team [kumite] nM= 11/age = 23.27 ± 2.83 [years]; BH= 181.54 ± 4.71 [cm] ; BM = 82.78 ± 13.55 [kg]	One-mile run test [M/D]	The time spend to complete one mile was entered into equation VO2max = 108.94 - (8.41 × time) + (0.34 × time2) + (0.21 × age × gender) - (0.84 × BMI), where male = 1, female = 0	Aerobic power:51.58±3.39 [ml · kg–1 · min–1]:
Najmi et al. [34]	National Malaysia karate team [kumite] nP = 16 males Senior group: nM = 8/ age = 23.63 ± 2.88 [years]; BH = 173.11 ± 7.29 [cm]; BM = 66.29 ± 10.5 [kg] Junior group: nM = 8/age = 21.88 ± 1.64 [years]; BH = 171.01 ± 6.49 [cm]; BM = 64.61 ± 8.12 [kg]	20 m shuttle run test [min]	A single run in 20 m apart with increas- ing intensity according to the sound signal played on a CD. VOZmax was calculated based on the last level and shuttle at which study participant finished the test.	20-m shuttle run test: Senior group:56.65 ± 4.17 [ml/kg/min] Junior group:44.27 ± 4.31 [ml/kg/min]
Güler et al. [35]	Turkish national karate team [kumite] nM= 16/age = 23.31 ± 4.27 [years]; BH= 173.4.91 [cm]; BM=68.8 ± 8.17 [kg]	SKPT [min]	General warm up followed by 5 sets of 3 min simulated karate competition bouts with consecutive increasing num- ber of attacks and decreased number of rest in each of the following sets.	SKPT test: VO2max [mi-in-1-kg-1] Start: 746 ± 1,86 1st set: 33,66 ± 5,70 2nd set: 39,46 ± 5,58 3rd set: 41,69 ± 4,82 4th set: 41,46 ± 4,57 5th set: 40,91 ± 6,63 1-minute rest: 37,28 ± 7,19 3-minute rest: 3-minute rest: 5-minute rest: 9,577+1,67

kata] nP=81;nKU=53; nKA=28/ age=16-17 [years] nKU/BH=161.5±7.2; BM=55.68±7.2 nKA/BH=156.1±4.9; BM=52.68±6.3

EUROFIT test (9th trial) – 20-m shuttle run test [min]

Martínez de Quel et al. [37] Spanish national karate team [kumite,

A standardized EUROFIT protocol for the 20-m shuttle run i.e., a single

run with increasing intensity according to the sound signal

20-m shuttle run test: Kumite athletes: 6.99±1.3 [min] Kata athletes:6.01±1.2 [min]

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Author, year	Participant's characteristic [kumite/kata]	Research test [unit]	Testing protocol	Main findings (mean ±SD)
Przybylski et al. [39]	Polish participants at World and Euro- pean Championships and Olympic Games [M/D] nP = 32/ nF = 12/age = 20.92 ± 3.00 [years]; BH = 165.08 ± 6.11 [cm]; BM = 58.58 ± 5.52 [kg] nM = 20/age = 20.40 ± 4.16 [years]; BH = 176.25 ± 6.31 [cm]; BM = 70.35 ± 8.14 [kg]	Beep test [M/D]	To complete a number of 20 m runs from one line to another according to time intervals defined by successive sound signals.	Beep test: Males:58.28±6.25 [M/D] Females:49.90±9.53 [M/D]
Martinez de Quel et al. [41]	Spanish National Karate Team [M/D] nP = 676;nM = 434; nF = 242 nM (cadets) = 157/age = 15.26 \pm 0.63 (years); BH = 168.59 ± 7.97 [cm]; BM = 59.71 ± 9.55 [kg] nM (junics) = 163/age = 16.98 ± 0.47 (years); BH = 172.39 ± 6.78 [cm]; BM = 65.38 ± 8.91 [kg] nM (U21) = 114/age = 19.47 ± 0.74 [years]; BH = 174.33 ± 8.12 [cm]; BM = 70.35 ± 9.64 [kg] n (Cadets) = 81/age = 19.47 ± 0.74 [years]; BH = 174.33 ± 8.12 [cm]; BM = 70.35 ± 9.64 [kg] n f (cadets) = 81/age = 19.47 ± 0.74 [years]; BM = 52.45 ± 6.01 [kg] n f (cadets) = 81/age = 19.55 ± 0.47 [years]; BH = 159.97 ± 5.88 [cm]; BM = 52.45 ± 6.01 [kg] n f (uniors) = 998/age = 17.05 ± 0.47 [years]; BH = 159.54 ± 6.97 [cm]; BM = 54.65 ± 6.99 [kg] n f(U21) = 63/age = 19.45 ± 0.78 [years]; BH = 163.18 ± 7.30 [cm]; BM = 58.64 \pm 9.05 [kg]	EUROFIT test (9th trial) – 20-m shuttle run test [min]	A standardized EUROFIT protocol for the 20-m shuttle run i.e., a single run with increasing intensity according to the sound signal	20-m shuttle run test: Cadets: Males:9.05 ± 1.33[min] Females:6.47 ± 1.23 [min] Juniors: Males:9.26 ± 1.42 [min] Females:6.69 ± 1.36 [min] U21: Males: 9.85 ± 1.26 [min] Females: 7.18 ± 1.25 [min]
Almeida-Neto et al. [45]	Brazilian national karate team/ state athletes [kumite] nM (state a thletes) = $12/$ age = 34.0 ± 8.8 [years]/ BH = 170.0 ± 4.60 [cm]; BM = 75.3 ± 2.21 [kg] nM (national team) = $12/$ age = 27.1 ± 3.95 [years]; BH = 172.1 ± 6.71 [cm]; BM = 72.4 ± 3.06 [kg]	Queen College Step test [ml/kg/min]	Going up and down on a 41.3 [cm] plat- form for 3 min according to the rhythm of a mechanical metronome (Crown [®] , Buenos Aires, Argentina) i.e., movement tempo: 24 steps/minute VO2max was estimated based on the following formula: VO2max (ml/ kg/min) = 111.33 - (0.42 * Heart rate post test)	Queen College Step test: State kumite athletes:47.9±2.71 National kumite athletes: 55.0±2.45
BH Body height [cm], BM Body	r mass [kg], <i>M/D</i> Missing data, <i>nF</i> number of fem	ales, <i>nKA</i> Number of kata athletes, <i>nKU</i> numbe	er of kumite athletes, <i>nM</i> number of males, <i>nP</i> nu	mber of study participants, <i>SKPT</i> Simulated

Author, year	Participant's characteristic [kata/kumite]	Research test [unit]	Testing protocol	Main findings (mean±SD)
Sánchez-Puccini et al. [29]	Columbian national karate team [M/D] $nM = 19/ age = 31.6 \pm 8.8$ [years]; BH = 167.4 ± 9.3 [cm]; BM = 65.4 ± 12.0 [kg]	a)Wingate test [W] b) Sargent jump test [cm]	a)30 s, 7.5% of resistance based on BM on a Monark ergometer (Monark AB, Varberg, Sweden) b) Vertical jump height was converted by Lewis nomogram to anaerobic power [kg•s–1]	a) Anaerobic peak power: 591.9±91.0 [W] Anaerobic capacity: 5748.7±1477.5 [W] b)Anaerobic power: 90.1±22.7 [kg•s–1]
Nikookheslat et al. [20]	Iranian national karate team [kumite] nM=40/ age=23.79±3.06 [years]; BH=177.86±6.20 [cm]; BM=72.76±9.98 [kg]	Wingate test [W, W/kg]	30 s of leg cycling	Anaerobic peak power: 957.47±164.11 [W], 13.15±1.79 [W/kg] Anaerobic mean peak power: 539.94±81.11 [W], 7.42±0.87 [W/kg]
Arazi et al. [31]	Iranian national karate team [kumite] nM=11/age=23.27±2.83 [years]; BH=181.54±4.71 [cm] ; BM=82.78±13.55 [kg]	15 s vertical jump test [W · kg−1]	Repetitive jumps on Ergo- Jump with maximal flight time and minimal landing time consequently for 15 s	Anaerobic power [W · kg−1]: 45.45±4.39
Rakita et al. [36]	Serbian high performed karate athletes [kata, kumite] $nM=25/age=15.32\pm0.22$ [years]; BH=174.92 \pm 7.16 [cm]; BM=63.25 \pm 9.18 [cm]	a) Kizami-zuki test [numer of punches] b) Gyaku-zuki test[numer of punches] c) Oi-zuki test [numer of punches] d) Mawashi-geri test [num- ber of kicks] e) Mae-geri test [number of kicks]	To perform maximum technically correct strikes during 10 s. Only correct strikes were taken into analyses.	Kizami zuki: 9.24±0.93 [n] Gyaku-zuki:9.20±0.76 [n] Oi-zuki:9.24±1.23 [n] Mawashi-geri:10.00±0.96 [n] Mae-geri:11.32±1.28 [n]
Przybylski et al. [39]	Polish participants at World and European Champion- ships and Olympic Games [M/D] $nP=32/nF=12/age=20.92\pm3.00$ [years]; BH=165.08±6.11 [cm]; BM=58.58±5.52 [kg] $nM=20/age=20.40\pm4.16$ [years]; BH=176.25\pm6.31 [cm]; BM=70.35\pm8.14 [kg]	a) Uraken-uchi + gyaku-zuki test (upper limbs) [number of punches] b)Mawashi- geri test (lower limbs) [number of kicks)	a)Uraken-uchi + gyaku-zuki in 30 s b) Maximum number of mawashi-geri kicks in 30 s	Uraken-uchi + gyaku-zuki test Males:74.60 \pm 8.95 [n] Females:64.00 \pm 9.15 [n] Mawashi-geri kick test: Males:55.90 \pm 5.26 [n] Females:46.25 \pm 7.14 [n]

Table 8 The summary of the studies from 2012–2024 evaluating anaerobic power and capacity in elite WKF karate athletes

BH Body height [cm], BM Body mass [kg]; M/D Missing data, nF number of females, nM = number of males, nP number of study participants

muscle contractions are diverse in both karate disciplines. This is mainly because during kata's routine athlete perform multiple short isometric contractions in the upper body (*kime*) at the end of each offensive or defensive action that are combined with longer isometric contractions in the lower limbs performed in order to maintain proper kata stances [5]. On the contrary, in a kumite bout an athlete has to be able to perform multiple short isotonic contractions in the lower limbs while moving during the bout (*jumping*), that are combined with explosive striking actions when an athlete performs a punch or a kick to the opponent's body, excluding short time-periods when two opponents stand in a clinch [6]. In this light, it would seem logical that hand grip strength can be related to the effectiveness of karate performance both in kata and kumite, however simultaneously it seems that its impact is not primary significant for striking sports such as WKF karate. This was also confirmed by Przybylski et al. [39] who found that high-performance in male Shotokan style karate athletes is mainly determined not by hand-grip strength, but by general strength- endurance defined as an ability to resist fatigue, what enables to adequately hit opponent's scoring areas. Nevertheless, future studies should investigate the above mentioned issue in order to draw definitive conclusions.

Another important component that seems to determine karate performance includes isokinetic strength. Scattone-Silva et al. [27] and Kotrljanovic et al. [30] suggest that elite level WKF karate athletes should be characterized by the ability to quickly recruit adequate

muscle fibers in maximal effort what is simultaneously related to the level of multiple isokinetic variables such as acceleration, peak torgue or time to peak torgue. However, even though karate is a complex sport both kata and kumite bouts are characterized by asymmetrical movement patterns [48], that result mainly from lateralization of the fighting side (left/right) and domination of strikes from the front lower limb, especially in kumite. Therefore, in order to decrease the risk of overload or acute injuries that are frequent in this population [49] it would seem justified to indicate that elite-level WKF karate athletes should be characterized by symmetrical isokinetic strength level in agonist-antagonist muscles. This thesis was confirmed in the research conducted by Kotrljanovic et al. [30], who found that the majority of elite-level karatekas presented adequate or even higher conventional concentric strength ratio than recommended, however these results differed between genders. Nevertheless, Scattone-Silva et al. [27] suggested that karate training can contribute to agonist-antagonist strength asymmetry, thus it seems logical to conclude that in order to maintain a high level of performance, WKF karate athletes should decrease possible muscular asymmetries, especially in hip flexors and extensors [27].

Another major strength component that was frequently investigated by several researchers [28, 31, 39] was the level of maximum strength assessed by one repetition maximum (1RM) tests. However, only Arazi et al. [31] indicated a relationship between values of 1RM in the bench press, half squat and deadlift and high-performance in male kumite athletes. On the contrary, the analysis conducted by Przybylski et al. [39] did not find any statistically significant relationships between the level of maximal strength of the upper body assessed by 1RM in the bench press and karate performance. Similar conclusions were presented by Tabben et al. [28], who simultaneously pointed to the significance of power of the lower limbs as a variable that determines elite-level WKF karate performance. This was also confirmed by Arazi et al. [31] who, beyond indicating the contribution of maximal strength to kumite performance, pointed to the dominance of lower-body explosive power in elite karatekas. Based on the above, it should be indicated that there are intrinsic relationships between strength and power [18]. As indicated by Cormie et al. [50] an athlete is unable to generate adequate muscular power without a relevant level of muscular strength. Moreover, it should be noted, that the greater absolute muscular strength, the greater abilities of development of the velocity-related variables [18]. Therefore, considering the issue of performance enhancement and high-performance profile a force-time characteristics such as rate of force development and external mechanical power [16] should be indicated.

The majority of the studies included in this systematic review investigated the power performance in elite WKF karate athletes [20, 28, 29, 31, 33, 34, 37, 39, 41, 43, 44]. The analyzed studies indicate different ways of assessment of power performance, however the following three methods were indicated as the most frequent i.e. (a) medicine ball throw (upper limbs), (b) countermovement jump and squat jump on a force plate (lower limbs), and (c) standing long jump (lower limbs). As it was found in the considered studies, regardless of age and gender elite-level WKF karate athletes were characterized by a high level of muscular power both in upper and lower limbs, that increased with age category [41], however greater power production was observed in males. Also interesting and partly surprising was that out of eleven cited articles only two studies [31, 37] assessed power of both upper and lower limbs, while the majority of the above mentioned authors focused on evaluating power profile in kumite athletes including only the lower limbs. This may suggest that power performance of the lower limbs can be significant for high-performance in WKF karate, mainly because both kumite and kata athletes have to primary generate adequate power of the lower extremities in order to displace and accelerate their body mass. Additionally, it should be noted that to generate power in a chosen technical movement an athlete always has to use some level of muscular strength, however greater acceleration will always contribute to higher values of power [51]. This phenomenon can be confirmed by the study conducted by Smajla et al. [44], who investigated the forcevelocity profile in elite WKF karatekas and indicated that both high force and power production are crucial variables that determine elite karate performance. Thus it seems logical to conclude that explosive and ballistic movements which characterize WKF [14, 15], the dominance of the velocity component would be the primary source of power production. Therefore, according to strength and conditioning, WKF karate athletes should use in training both, high external loads and high velocities in different zones of the force-velocity curve [52], however adequate percentage of 1RM (%1RM) should be implemented in order to optimize the above mentioned force-velocity curve.

Speed and agility profile

As indicated by Chaabène et al. [23] high-level performance in sports that are based on explosive techniques, such as karate, is dependent on speed (in terms of the synthetic concept) and reaction time (in terms of the analytical concept). Similarly, Katic et al. [53] demonstrated that among muscular power both speed and agility can significantly determine efficiency of a WKF karate bout. Considering that, during a karate bout, an athlete has to execute strikes and blocks at maximum speed in order to ensure that athlete's hand or foot reaches its target before opponent has any chance to defend themselves or to respond with an attack or counterattack [54]. Based on that, it seems reasonable to conclude that a high level of both speed, reaction time and agility can contribute to high-performance in WKF karate. As it was indicated by numerous research.

[20, 28, 31, 37, 39, 41, 42] WKF karate athletes were generally characterized by high speed and agility variables, however simultaneously some inconsistency between several authors were noted. For instance, Przybylski et al. [39] suggested that female WKF karate athletes are characterized by higher hand speed profile compared to male athletes, but at the same time they were assessed with lower specific karate speed and slower results in simple and complex reaction time. These findings are in contrary to the study conducted by Martinez de Quel et al. [41] who demonstrated that male WKF kumite athletes, regardless of the age group, were generally characterized with higher hand reaction speed profile, that increased with the age category (cadet, junior, U21). On the other hand, Martinez de Quel et al. [41] and Ojeda-Aravena et al. [43] found that male WKF karate athletes needed a shorter time to fulfill the assigned agility test compared to female athletes. Additionally, also surprising is that junior male athletes were characterized with the shortest time needed to successfully complete the agility test accordioning to other sex-related age categories (cadets, junior, U21) [41]. Partly similar findings were presented according to females, in which cadet female WKF karate athletes represented a higher agility profile compared to the junior category, however females from the U21 category were characterized by the best agility score.

Given the above, it can be concluded that the intrinsic differences in both genders according to the speed and agility profile may be related mainly to (a) natural phases of human's development that differ between males and females, (b) the impact of human's developmental phase on physical profile (especially on muscular strength), and (c) the applied testing protocol (Tables 4 and 5). Additionally, it seems that WKF karate disciplines do not differentiate speed and agility profile in elite karatekas. Based on the findings proposed by Martinez de Quel et al. [37] it seems that karate disciplines (kumite, kata) do not effect hand speed, as similar speed results in kumite $(9.30\pm0.8s)$ and kata $(9.33\pm1.0s)$ athletes were observed. Similarly, the above mentioned groups did not significantly differ according to agility results of the shuttle run test i.e., kumite $(19.27 \pm 1.5s)$ and kata $(19.2 \pm 1.6s)$. Considering that, it should be noted that the level of speed and agility is primarily determined by muscular strength. Accordioning to Suchomel [16] muscular strength can enhance both, General Sport Skills such as jumping, sprinting or the change of direction and Specific Sport Skills, regardless of whether the sports discipline has a strength-speed or endurance character. Besides, it is generally known that the level of muscular strength is strongly correlated with enhancement of the synaptic potentiation [16], what impacts speed and agility performance. Therefore, among golden periods of development of age-specific motor abilities, the level of muscular strength may strongly contribute to the results achieved in both speed and agility testing.

Flexibility profile

Undoubtedly, force-velocity variables can significantly impact karate athlete's performance, however even a high level of power can't be transferred into effective offensive striking techniques without adequate level of flexibility. As indicated by Chaabène et al. [23] according to karate, flexibility is crucial in order to perform successful technical actions during kumite and kata bouts such as high kicks. Moreover, Roschel et al. [55] suggested that adequate level of flexibility is necessary to perform full-range movements at high speeds in karate athletes. This was also confirmed by several biomechanical analyses [56, 57], which found that flexibility of both upper and lower limbs affects the efficiency of basic karate strikes such as *kizami-zuki* punch or *mawashi-geri* kick.

Interestingly, according to the presented systematic review, almost all scientific studies that assessed flexibility profile applied a similar testing protocol i.e., sit-and-reach test, that is known to be a standardized research test to evaluate flexibility of the hamstring and lower back muscles [58]. On the other hand, only a single study conducted by Przybylski et al. [39] used karate side kick (yogo-geri) in order to evaluate karate-specific flexibility of the lower limbs. In addition, to the best of the author's knowledge it is difficult to find a single study that investigated flexibility profile in WKF karate athletes within the focus on upper limbs or trunk muscles. Thus, the above mentioned findings of the qualitative analysis directly indicate that elite-level karatekas are characterized by high flexibility profile of the hamstring muscles, that is generally improved with age and training experience (cadets, juniors, U21, seniors) [34, 41]. Nevertheless, even though females are believed to be intrinsically more flexible than males [59], this systematic review indicated that the level of flexibility can be diverse between both genders [39, 41]. This phenomenon can be associated with karate disciplines as the study by Martinez de Quel et al. [37] found slightly better results in the sit-and-reach test in kata athletes $(29.07 \pm 5.6 \text{ cm})$ compared to kumite

 $(28.24\pm7.00$ cm) athletes. However, to fully investigate the above mentioned phenomenon future studies are needed.

Aerobic and anaerobic profile

Among different motor abilities that were evaluated by researchers in the presented systematic review several studies investigated aerobic and anaerobic metabolism, however the oxidative system was evaluated more frequently (Tables 7 and 8). Nevertheless, this qualitative analysis demonstrated that in kumite athletes high efficiency of both aerobic and anaerobic metabolism is significant to represent high-performance, what was partly confirmed in case of kata athletes [37].

Arazi et al. [31] suggested that the consistency of kumite performance is mainly determined by athlete's ability to maintain the intensity of assumed technical and tactical activities during the bout, followed by fast recovery between successive rounds. These results were also confirmed by Najmi et al. [34] and Martinez de Quel et al. [41] who reported that high level of the VO2_{max} contributes to high-performance in karate bouts. Additionally, the cited research confirms the significance of anaerobic metabolism to perform blocks or kicks in a kumite bout [34]. However, on the contrary Martinez de Quel et al. [37] concluded that the level of cardiorespiratory fitness is not the variable that differentiates performance in WKF karate athletes. The ambiguous results of the presented reports can be explained mainly by differences in (a) testing protocols that were used to assess athlete's physiological profile, (b) age, (c) gender, and (d) kind of WKF karate discipline.

Among different aerobic capacity protocols, the 20-m shuttle run test was implemented most frequently [34, 37, 39, 41], while the 30s Wingate test was applied the most often in order to evaluate anaerobic power and anaerobic capacity [20, 29]. Apart from the above mentioned testing protocols some authors also implemented karate specific tests in order to produce physiological strain similar to WKF karate competition [35, 36, 39].

The presented data found that the level of aerobic capacity was increased within older age categories (cadets, juniors, U21, seniors), however lower values of the $VO2_{max}$ were observed in females [41]. Partly similar findings were observed in the study by Przybylski et al. [39], who indicated that Shotokan style male karate athletes had higher sport specific endurance assessed by the number of karate punches and kicks during 30s than female athletes. Based on the above, it seems that male karate athletes tend to have higher level of aerobic and anaerobic fitness compared to females.

Considering the above, Martinez de Quel et al. [37] found that kumite athletes were characterized by higher

VO2_{max} compared to kata athletes, what may suggest that aerobic metabolism is a dominant energy source followed by the contribution of ATP-PCr during short periods of kumite bouts while performing offensive and defensive techniques. Similar conclusions were found in the study conducted by Güler et al. [35] who demonstrated that high aerobic capacity is necessary in order to prevent fatigue and to enable fast recovery during intermittent kumite actions and breaks between successive rounds. Additionally, a kumite bout consists of multiple rapid plyometric phases, thus high lactate concentrations may cause a decline in performance [35], what simultaneously indicates, that high-performance in kumite athletes incorporates various intensities to activate both aerobic and anaerobic energy systems.

Surprisingly, the majority of the presented research (Tables 7 and 8) that evaluated the physiological profile of WKF karate athletes included mostly male kumite athletes. Therefore, it is difficult to discuss the predominant exercise metabolism in kata athletes. Nevertheless, given the above it can be speculated that based on the general characteristics of kata performance and the findings presented by Martinez de Quel et al. [37], as well as Przybylski et al. [39] it is justified to conclude that high efficiency of both aerobic and anaerobic metabolism can contribute to high-performance in kata athletes. Nevertheless, to fully understand this phenomenon future studies should implement assessment of the aerobic and anaerobic capacity and aerobic and anaerobic power within participation of both genders and athletes from kata and kumite specialization.

Limitations and strengths of the study

While this qualitative analysis contributes to the current body of literature, there are some limitations that need to be addressed. The main limitation of the present study is a small number of studies that have investigated kata athletes, which did not allow to fully compare physical and physiological profile between different WKF karate disciplines. Moreover, the current available scientific studies did not provide sufficient data to conduct a meta-analysis that would allow for general interference. Furthermore, the presented research was conducted with various numbers of study participants, different age groups and a small number of females. Therefore the presented findings may not fully contribute to performance enhancement in female WKF karate athletes. In addition, various testing protocols that were implemented to assess the physical and physiological profile make generalization impossible. Given that, future research is needed to fully understand the complexity of physical and physiological requirements that characterize high-performance of elite WKF karate athletes, that should be focused on

expending knowledge on adequate testing protocols that can be implemented accordingly to WKF karate disciplines. Lastly, the presented qualitative analysis included only cross-sectional studies, thus there can be also some experimental research that could contribute to the issue of physical and physiological profile in elite WKF karatekas.

The main strength of the present study is the systematic review of the latest reports (2012-2024) that have examined the physical and physiological profile in elite WKF karate athletes. Additionally, the majority of the included scientific studies were evaluated to be perfectly eligible for the presented analysis. To the best of author's knowledge this is the first systematic review performed according to the PRISMA standards that evaluated the above mentioned issues in WKF karatekas. Simultaneously, the authors believe that the novelty of the presented research issue and undertaking the hitherto unexplored aspects in scientific studies will enable a better understanding of the performance enhancement of combat sport athletes. It may also contribute to optimize karate athlete's strength and conditioning programs by focusing on the crucial variables that determine high-performance in WKF karate.

Conclusions

The presented qualitative analysis of the results of the published scientific literature provides evidence that the force-velocity characteristics with the dominant effect of the velocity component seem to be crucial in regard to performance outcomes in elite WKF karatekas. Moreover, it was found that a high level of flexibility of the hamstring muscles and well developed speed and agility abilities may significantly contribute to performance enhancement in WKF karate. Simultaneously, the efficiency of both aerobic and anaerobic metabolism is significant for high-performance in elite WKF kumite athletes, however aerobic capacity may be crucial for elite-level performance in kumite competition. Nevertheless, to date it is difficult to confirm the impact of the above mentioned energy systems on kata performance in elite WKF karatekas, however both aerobic and anaerobic metabolism contribute significantly to the effectiveness of a kata bout. Furthermore, athlete's age category (cadet, junior, U21, senior) and sex-related variables may intrinsically affect the level of the analyzed motor abilities.

At the same time, this systematic review showed that numerous testing protocols have been implemented to evaluate physical and physiological profile of WKF karate athletes, among which the following can be recommended as frequent forms of assessment of motor abilities in WKF karate athletes: (1) 1RM test (maximal strength) (2) medicine ball throw test (muscular power of the upper limbs), (3) CMJ/SJ/long jump test (muscular power of the lower limbs) (4) plate tapping test (hand speed), (5) 40 m dash test (speed) (6) shuttle-run test (agility), (7) 20 m shuttle run test (aerobic capacity), and (8) 30s Wingate test (anaerobic capacity).

Abbreviations

WKF	World Karate Federation
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
JBI	Joanna Briggs Institute
VO2 _{max}	Maximal oxygen uptake
ATP PCr	Adenosine triphosphate - phosphocreatine

Supplementary Information

The online version contains supplementary material available at https://doi. org/10.1186/s13102-024-01047-5.

Supplementary Material 1.	
Supplementary Material 2.	

Authors' contributions

Conceptualization: EG and AZ; methodology: EG; investigation: EG and MD; data curation: EG; formal analysis: EG and AZ; validation: EG, AZ and MD; preparing tables and figure: EG, writing – original draft preparation: EG; writing – review and editing: EG; funding acquisition (Open Access): AZ; supervision: AZ. All authors have read and approved the final version of the manuscript.

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Data availability

The data collected and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent of participate

Not applicable.

Consent for publication Not applicable.

Competing interests

The authors declare no competing interests.

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References

- Adamczyk JG, Safranow K, Gajewski AK, Boguszewski D, Sozański H, Sołtyszewski I, Pepłońska B, Cięszczyk P, Siewierski M, Żekanowski C. The second-to-fourth digit (2D:4D) ratio of male combat athletes is Associated with the choice of Sport. J Hum Kinet. 2021;78:59–66. https://doi. org/10.2478/hukin-2020-0083.
- Koropanovski N, Berjan B, Bozic PR, Pazin N, Sanader A, Jovanovic S, Jaric S. Anthropometric and physical performance profiles of elite karate kumite and kata competitors. J Hum Kinet. 2011;30:107–14. https://doi. org/10.2478/v10078-011-0078-x.
- De Oliveira MA, Lopes JC, Sonoda-Nunes RJ, Figueiredo A. The sportivization process of a martial art: the karate. RAMA. 2019;14(2s):59–60.
- 4. Piepiora P, Witkowski K. Quo vadis, karate. Arch Budo. 2023;19:129-35.

- Doria C, Veicsteinas A, Limonta E, Maggioni MA, Aschieri P, Eusebi F, Fanò G, Pietrangelo T. Energetics of karate (kata and kumite techniques) in top-level athletes. Eur J Appl Physiol. 2009;107(5):603–10. https://doi.org/ 10.1007/s00421-009-1154-y.
- https://www.wkf.net/pdf/WKF_Kumite_Competition_Rules_2024.pdf. Accessed 1 June 2024.
- Chaabène H, Franchini E, Sterkowicz S, Tabben M, Hachana Y, Chamari K. Physiological responses to karate specific activities. Sci Sports. 2015;30(4):179–87. https://doi.org/10.1016/j.scispo.2015.03.002.
- Chaabène H, Franchini E, Miarka B, Selmi MA, Mkaouer B, Chamari K. Time–motion analysis and physiological responses to karate official combat sessions: is there a difference between winners and defeated karatekas? Int J Sports Physiol Perform. 2014;9(2):302–8. https://doi.org/ 10.1123/ijspp.2012-0353.
- Beneke R, Beyer T, Jachner C, Erasmus J, Hütler M. Energetics of karate kumite. Eur J Appl Physiol. 2004;92(4–5):518–23. https://doi.org/10.1007/ s00421-004-1073-x.
- Tabben M, Conte D, Haddad M, Chamari K. Technical and tactical discriminatory factors between winners and defeated elite karate athletes. Int J Sports Physiol Perform. 2019;14(5):563–8. https://doi.org/10.1123/ijspp. 2018-0478.
- https://www.wkf.net/pdf/WKF_Kata_Competition_Rules_2024.pdf. Accessed 1 June 2024.
- Bussweiler J, Hartmann U. Energetics of basic karate kata. Eur J Appl Physiol. 2012;112(12):3991–6. https://doi.org/10.1007/s00421-012-2383-z.
- Davide F, Antonino B, Daniele Z, Paoli A, Antonio P. Is karate effective in improving postural control? Arch Budo. 2012;8(4):191–4.
- Rinaldi M, Nasr Y, Atef G, Bini F, Varrecchia T, Conte C, Chini G, Ranavolo A, Draicchio F, Pierelli F, Amin M, Marinozzi F, Serrao M. Biomechanical characterization of the Junzuki karate punch: indexes of performance. Eur J Sport Sci. 2018;18(6):796–805. https://doi.org/10.1080/17461391.2018. 1455899.
- Hariri S, Sadeghi H. Biomechanical analysis of mawashi-geri technique in karate. Int j Sport Stud Health. 2018;1(4):7–14. https://doi.org/10.5812/ intjssh.84349.
- Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. Sports Med. 2016;46(10):1419–49. https://doi.org/10.1007/s40279-016-0486-0.
- Lahti J. In: Sports analysis, training considerations and applied methods for mixed martial arts. Coaching seminar LBIA028 p.31, 2016. Available from: https://jyx.jyu.fi/bitstream/handle/123456789/49013/Lahti%20Johan.pdf [last access: 15 June, 2024].
- Taber C, Bellon C, Abbott H, Bingham G. Roles of maximal strength and rate of Force Development in maximizing muscular power. Strength Cond J. 2016;38(1):71–8. https://doi.org/10.1519/SSC.000000000000193.
- Srianto W, Siswantoyo S, Biomotor. Analysis of Speed and Flexibility in the Karate Talented Athletes Coaching in the Special Region of Yogyakarta. In: Conference on Interdisciplinary Approach in Sports in conjunction with the 4th Yogyakarta International Seminar on Health, Physical Education, and Sport Science (COIS-YISHPESS 2021) pp. 153–156;2022. Atlantis Press.
- Nikookheslat SD, Faraji H, Fatollahi S, Alizadeh M. Physical and physiological profile of elite Iranian karate athletes. Int J Appl Exerc Physiol 2016;5(4):35–44.
- Ioannides C, Apostolidis A, Hadjicharalambous M, Zaras N. Effect of a 6-week plyometric training on power, muscle strength, and rate of force development in young competitive karate athletes. J Phys Educ Sport. 2020;20(4):1740–6. https://doi.org/10.7752/jpes.2020.04236.
- Pojskic H, Zombra Ž, Washif JA, Pagaduan J. Acute effects of loaded and unloaded whole-body vibration on Vertical Jump performance in Karate athletes. J Hum Kinet. 2023;92:203–12. https://doi.org/10.5114/jhk/ 172637. PMID: 38736596; PMCID: PMC11079925.
- Chaabène H, Hachana Y, Franchini E, Mkaouer B, Chamari K. Physical and physiological profile of elite karate athletes. Sports Med. 2012;42(10):829– 43. https://doi.org/10.1007/BF03262297.
- Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Syst Rev. 2021;10(1):89. https://doi.org/10.1186/ s13643-021-01626-4.

- Aromataris E, Lockwood C, Porritt K, Pilla B, Jordan Z. JBI Manual for Evidence Synthesis. JBI; 2024, ISBN: 978-0-6488488-0-6. Available from: https://synthesismanual.jbi.global [last access: 01.06.2024].
- Ma LL, Wang YY, Yang ZH, Huang D, Weng H, Zeng XT. Methodological quality (risk of bias) assessment tools for primary and secondary medical studies: what are they and which is better? Mil Med Res. 2020;29(1):7. https://doi.org/10.1186/s40779-020-00238-8.
- Scattone-Silva R, Lessi GC, Lobato DFM, Serrão FV. Acceleration time, peak torque and time to peak torque in elite karate athletes. Sci Sports. 2012;27(4):e31–7. https://doi.org/10.1016/j.scispo.2011.08.005.
- Tabben M, Chaouachi A, Mahfoudhi M, Aloui A, Habacha H, Tourny C, Franchini EP. Physical and physiological characteristics of high-level combat sport athletes. J Combat Sports Martial Arts. 2014;5(1):1–5. https://doi. org/10.5604/20815735.1127445.
- Sánchez-Puccini MB, Argothy-Bucheli RE, Meneses-Echávez JF, López-Albán CA, Ramírez-Vélez R. Anthropometric and physical fitness characterization of male elite karate athletes. Int J Morphol. 2014;32(3):1026–31. https://doi.org/10.4067/S0717-95022014000300045.
- Kotrljanovic A, Atanasov D, Veljovic1 D, Drid P. An isokinetic profile in senior female and male karate athletes national team level. Arch Budo Sci Martial Arts Extrem Sports. 2016;12:203–10.
- Arazi H, Izadi M. Physical and physiological profile of Iranian world-class karate athletes. Biomed. 2017;9(1):115–23. https://doi.org/10.1515/ bhk-2017-0017.
- 32. Ateş O. (2018). Investigating the anaerobic performance of national and young national karate athletes. Young, 2018; 2,0–04.
- Spigolon D, Hartz CS, Junqueira CM, Ariel R, Vitor FH. The correlation of anthropometric variables and jump power performance in elite karate athletes. J Exerc Physiol. 2018;21(1):139–48.
- Najmi N, Abdullah MR, Juahir H, Maliki ABHM, Musa RM, Mat-Rasid SM, Adnan A, Kosni NA, Eswaramoorthi V, Alias N. Comparison of body fat percentage and physical performance of male national senior and junior karate athletes. Mal J Fund Appl Sci. 2018;10(1S):485–511. https://doi.org/ 10.4314/jfas.v10i1s.3.
- Güler M, Ramazanoglu N. Evaluation of physiological performance parameters of Elite Karate-Kumite athletes by the simulated Karate Performance Test. Univers J Educ Res. 2018;6(10):2238–43. https://doi.org/10. 13189/ujer.2018.061022.
- Rakita D, Rakonjac D, Jurisic M, Obradovic J. The influence of morphological characteristics on the specific motor skills of junior-age karate athletes. EQOL J. 2018;10:43–9. https://doi.org/10.31382/eqol.180605.
- Martínez de Quel Ó, Ara I, Izquierdo M, Ayán C. Does Physical Fitness Predict Future Karate Success? A study in Young Female Karatekas. Int J Sports Physiol Perform. 2020;15(6):868–73. https://doi.org/10.1123/ijspp. 2019-0435.
- Shalja S, Stankovska Z, Kostovski Z, Ganiu V. Changes in the maximum oxygen consumption in karate athletes in the preparatory and precompetitive period. Sport Sci Pract Asp. 2020;17(1):61–7.
- Przybylski P, Janiak A, Szewczyk P, Wieliński D, Domaszewska K. Morphological and motor fitness determinants of Shotokan Karate performance. Int J Environ Res Public Health. 2021;18(9):4423. https://doi.org/10.3390/ ijerph18094423.
- Shalja S, Stankovska Z, Mikić B, Kostovska Petkovska V, Kostovski Ž. Changes in the situational motor abilities of karate athletes in the preparatory and pre-competition period. Kinesiol. 2021;14(2):63–71 ISSN: 18403662.
- Martinez-de-Quel O, Alegre LM, Castillo-García A, Ayán C. Anthropometric and fitness normative values for young karatekas. Biol Sport. 2021;38(3):351–7. https://doi.org/10.5114/biolsport.2021.99324.
- Wąsik J, Bajkowski D, Shan G, Podstawski R, Cynarski WJ. The influence of the practiced karate style on the dexterity and strength of the hand. J Appl Sci. 2022;12(8):3811. https://doi.org/10.3390/app12083811.
- Ojeda-Aravena A, Herrera-Valenzuela T, Valdés-Badilla P, Azocar-Gallardo J, Campos-Uribe V, García-García JM. Relationship between explosive strength characteristics with change of direction speed in junior and cadet karate athletes. Isokinet Exerc Sci. 2022;30(1):29–38. https://doi.org/ 10.3233/IES-210114.
- 44. Smajla D, Spudić D, Kozinc Ž, Šarabon N. Differences in Force-Velocity profiles during Countermovement Jump and Flywheel squats and associations with a different change of direction tests in Elite Karatekas. Front Physiol. 2022;13:828394. https://doi.org/10.3389/fphys.2022.828394.

- 45. Almeida-Neto PF, Bulhoes-Correia A, de Matos DG, de Cesario M, das
- Neves T, Mousinho ES, Dantas GC, Cabral P, Kinands DG, de Cesalio M, das Neves T, Mousinho ES, Dantas GC, Cabral P. Kinanthropometric Profile and Maximum Oxygen Consumption in male Karate athletes at different competitive levels. J Martial Arts Anthrop. 2023;23(3):1–9. https://doi.org/ 10.14589/ido.23.3.1.
- Frigout J, Tasseel-Ponche S, Delafontaine A. Strategy and decision making in karate. Front Psychol. 2020;10:3025. http://doi.org/10.3389/ fpsyg.2019.03025
- 47. Nakayama M. Best Karate Bassai, Kanku (1st edition). Japan: Kodansha International Ltd.; 1979. pp. 12–66. ISBN: 0-87011-383-6.
- Molinaro L, Taborri J, Montecchiani M, Rossi S. Assessing the effects of Kata and Kumite techniques on physical performance in Elite Karatekas. Sens (Basel). 2020;20(11):3186. https://doi.org/10.3390/s20113186.
- Thomas RE, Ornstein J. Injuries in karate: systematic review. Phys Sportsmed. 2018;46(3), 279–303. https://doi.org/10.1080/00913847.2018.1472510.
- Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: part 2 - training considerations for improving maximal power production. Sports Med. 2011;1(2):125–46. https://doi.org/10.2165/11538 500-00000000-00000.
- 51. Thibaudeau C. The Black Book of Trasecretsecenhancedhanced Edition CreateSpace. Indep Publishing Platf. 2014;ISBN:1499766505.
- https://www.scienceforsport.com/force-velocity-curve/#toggle-id-1 [last access: 01.05.2024].
- Katic R, Jukic J, Cavala M, Vucic D, Blazevic S. Motor determinants of fighting efficacy in Croatian youth karateka. Coll Antropol. 2013;37(Suppl 2):1–8.
- Domaszewska K, Laurentowska M, Michalak E, Kryściak J, Rakowski P. The metabolism of purines and circulation-respiratory reaction to physical effort in karate. Pol J Sports Med. 2008;24:73–80.
- Roschel H, Batista M, Monteiro R, Bertuzzi RC, Barroso R, Loturco I, Ugrinowitsch C, Tricoli V, Franchini E. Association between neuromuscular tests and kumite performance on the Brazilian karate national team. J Sports Sci Med. 2009;8(CSSI3):20–4.
- Udara EGDN, Chandana A. Biomechanics of Roundhouse (Mawashi–Geri) Kicking in Karate: A Review. Academia Accelerafing the World's Research. 2021:1–13. https://www.researchgate.net/profile/Egoda-Gedarage-Udara/publication/362645905_BIOMECHANICS_IN_ROUNDHOUSE_ KICK_MAWASHI-GERI_IN_KARATE_A_REVIEW/links/62f60d5ab8dc8b4 403d912b7/BIOMECHANICS-IN-ROUNDHOUSE-KICK-MAWASHI-GERI-IN-KARATE-A-REVIEW.pdf. Accessed 1 June 2024.
- Almas KZ, Lismadiana L, Tomoliyus T, Hariono A, Danardono D, Prabowo TA, Hikmah N. Contribution of coordination, balance, flexibility, arm muscle strength to the 'kizami-gyaku zuki' punch: analysis of female karate athletes. Eur J Sport Sci. 2023;10(4). https://doi.org/10.46827/ejpe.v10i4. 5097.
- López-Miñarro PA, Andújar PS, Rodrñguez-Garcña PL. A comparison of the sit-and-reach test and the back-saver sit-and-reach test in university students. J Sports Sci Med. 2009;1(1):116–22.
- Tomkinson GR, Carver KD, Atkinson F, Daniell ND, Lewis LK, Fitzgerald JS, Lang JJ, Ortega FB. European normative values for physical fitness in children and adolescents aged 9–17 years: results from 2 779 165 eurofit performances representing 30 countries. Br J Sports Med. 2018;52(22):1445–14563. https://doi.org/10.1136/bjsports-2017-098253.

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