Anthropological Review • Vol. 79 (2), 201–210 (2016)

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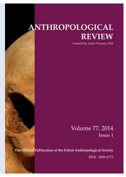
ANTHROPOLOGICAL REVIEW
Available online at: https://doi.org/10.1515/anre-2016-0015



Morphological optimization of female combat sports athletes as seen by the anthropologists

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ABSTRACT: Body build and proportions are key determinants of athletic success. The effects of the athlete selection process and discipline-specific training are differentiated body dimensions. The aim of the study was to examine the physical characteristics of female combat athletes. The results of anthropometric measurements of 154 females aged 21.2±1.79 years competing in judo, jiu-jitsu, karate, taekwondo, and fencing for 7.5±3.43 years.

Significant differences were observed between the judo and karate, taekwondo and fencing practitioners in chest, hip, arm and forearm girths. More variance was observed in body proportions. Fencers had the slimmest body shape, a more massive body size in the judokas. Longer upper extremities relative to lower extremity length were found in the jiu-jitsu group. Relative to body height, a larger torso and greater girths were observed in the judokas compared with the fencing, karate, and taekwondo practitioners. The groups did not differ in the level of endomorphy. Mesomorphy was highest in judokas and the lowest in fencers, although ectomorphy was most dominant in the latter group.

Females practitioners of combat sports exhibit differences in physical characteristics as an effect of optimizing body type and build via the training and athlete selection process of a given discipline. The anthropometric measures could play a role in talent identification programmes for martial arts and help the trainers to optimize the motoric effectiveness of athletes.

KEY WORDS: females, body build, combat sports, morphological characteristics

Introduction

Martial arts and combat sports are based on self-defense and combat practices that combine contact-based competition with mental and spiritual development. In recent times, more modern variants of these sports have grown in popularity and now see widespread practice on a global scale. However, the lower participation rates of females in types of one-on-one combat have been associated with various factors, such as the increased risk of injury (Lystad et al. 2009, Pocecco et al 2013). The low involvement of women is also reflected in the relatively limited number of studies involving female combat athletes.

Body build and proportions are key determinants of athletic success (Claes-

Original Article Received: February 15, 2016; Accepted for publication: May 21, 2016
DOI: 10.1515/anre-2016-0015

sens et al. 1994; Keogh et al. 2007; Ridge et al. 2007). Differences in the physical characteristics of athletes involved in different disciplines are the effect of a conscious process of optimizing the human body (Norton et al. 1996). The characteristic body proportions and body shapes of practitioners of a given sport are a consequence of vying for optimal performance by selecting the most physically-suited athletes and via training (Malousaris et al. 2008). Moreover, they influence the released strength and the choice of an appropriate technique, guaranteeing the optimal effectiveness of the move (Buckeridge et al. 2015).

Body build is also considered an important criterion when selecting potential candidates in the realm of combat sports (Pieter 2008). The effects of targeted combat-training programs have been readily observed in the somatotypes of young athletes in different developmental stages. The literature shows that despite the specific energy demands of different combat disciplines (Bouhlel et al. 2006), young male and female combat athletes present greater ectomorphy than their older peers, who are instead characterized with the endomorph somatotype (Pieter 1991; 2010). The characteristics of body build – type, size, and composition – are also subject to changes within the training cycle, as evidenced in a sample of advanced male and female karateka (Gloc et al. 2012).

While morphological body build is a key determinant of athletic success, it is not a sufficient predictor of performance. In a sample of male taekwondo practitioners, Pieter et al. (2002) indicated that competitive results are strongly associated with other prognostic determinants besides the mesomorph component, such as training level and competitive experience. Among women, competitive results were correlated with body height and competitive experience. Another study on highly-ranked female judokas found a relationship between low values of body height and fat mass with better performance in a physical fitness test battery (Smulski et al. 2011). An analysis of the anthropometric determinants of physical fitness in female jiu-jitsu competitors showed a relationship between body composition and weight class – the heavier weight classes had higher body fat percentage (Sterkowicz-Przybycień et al. 2014). This study also found that physical fitness test results depended on age. When considering sex differences, research found that the differences in body dimensions between male and female combat athletes are similar to those observed in the general population: females are shorter, weigh less, and have a greater percentage of fat than males, who show more lean body mass (Aiwa and Pieter 2007).

Differences between the combat sport disciplines lie primarily in the types of movements that have evolved and the strategies that are permitted. Judo mainly consists of throws and takedowns as well as joint locks, chokes, and holds. Besides the above techniques, jiu-jitsu also allows strikes and thrusts. Karate and taekwondo, in turn, favor kicks and strikes. The body build of athletes involved in these martial arts was also found to differentiate the type of preferred fighting styles. Judokas with higher levels of mesomorphy and endomorphy were more likely to use hand techniques or throws (Lech et al. 2007). Slimmer competitors, with a larger component of ectomorphy, tended to use foot techniques more frequently. Furthermore, it was found that judokas who predominately relied on foot techniques were not only relatively taller and thinner but also had longer lower limbs than those who preferred hand-based techniques. Other studies drew attention to the fact that shorter martial artists, with a relatively low center of gravity and larger body size and mass (concentrated particularly around the upper torso) are more effective when fighting with throwing techniques (Sertić et al. 2007).

Compared with the abovementioned combat sports, performance in fencing is more dependent on coordination skills due to the importance of tactics. This is linked to choosing the most opportune offensive and defensive techniques so as to take an opponent by surprise. However, research has found that fencers also adapt their strategy in light of their physical abilities and characteristics (Roi and Bianchedi 2008). While taller fencers use their body height to cover a larger distance in a single step, shorter fencers were found to expend more energy due to performing faster movements in which accuracy was more dependent on skill.

The majority of studies that have attempted to define the body build of athletes by somatotyping (via Heath and Carter's method) do so without considering other anthropometric measures, such as the dimensions of individual body segments, which also play a crucial role in determining biomechanical effectiveness. For example Green and Gabriel (2012) showed that anthropometric variables such as body weight, forearm length and elbow circumference play an important role in predicting of elbow flexion strength in males and females. Hence, the aim of the present study was to investigate differences in the anthropometry of female combat athletes by also considering various body proportions in addition to somatotype.

Material and methods

The study involved 154 combat athletes aged 21.2 ± 1.81 years competing at the university-level in judo (n = 35), jiu-jitsu (n = 26), karate (n = 33), taekwondo (n = 30), and fencing (n = 30). The sample had on average 7.5 ± 3.43 years of athletics experience. Significant differences between the groups (p = 0.000) were found – the judokas had been practicing the longest (8.8 ± 2.54 years) whereas the jiu-jitsu practitioners the least (5.7 ± 3.11 years). The experience of the fencing, karate, and taekwondo practitioners was 8.4 ± 3.28, 8.2 ± 3.89, and 6.1 ± 2.69 years, respectively. The athletes trained 7 to 10 times (10–15 hours) a week. Among the participants were individuals who had claimed multiple Polish national titles. The measurements were taken directly before the beginning of competition season.

The study was approved by the Ethics Committee of the University School of Physical Education in Wrocław, Poland, and conducted according to the requirements stipulated in the Declaration of Helsinki. Written informed consent was obtained from all participants. All anthropometric measurements were performed by the authors, qualified biological anthropologists, using GPM anthropological instruments (Siber Hegner Machinery, UK) in the morning hours. Anthropometry data in this work correspond to international standards (Stewart et al. 2011). Each anthropometrist took the same measurements and was assisted by a recorder. All bilateral measurements were obtained from the right side of the body.

Measures included: body mass (BM), body height (BH), sitting height (SH), lower extremity length measured from base to the trochanterion (LEL), upper extremity length (UEL), mesosternal chest girth at the end of normal expiration (CHG), hip girth (HG), relaxed arm girth (AG), maximal forearm girth (FAG), maximal thigh girth (TG), and maximal calf girth (CG). Upper and lower skeletal breadths included the sum of elbow and wrist breadths (UEB) and the sum of knee and ankle breadths (LEB). The former was measured at the biepicondylar humerus and bistyloid, the latter as the biepicondylar femoral breadth and the distance between the medial and lateral malleolus. Moreover, four skinfolds (triceps, subscapular, supraspinale, medial calf) as well as arm flexed and tensed girth were measured to calculate the anthropometric somatotype and body fat percentage.

The absolute variables were used to calculate body mass index (BH/BM2; kg/m^2) and the following body proportions: the ratios of sitting height/body height (SH/BH), upper extremity length/lower extremity length (UEL/LEL), chest girth/body height (CHG/BH), hip girth/body height (HG/BH), upper (UEB/BH) and lower (LEB/BH) skeletal breadths relative to body height, and arm (AG/UEL), forearm (FAG/UEL), thigh (TG/LEL), and calf (CG/LEL) girths relative to respective extremity length.

Body type was assessed by determining the average somatotype of the groups by calculating the level of endomorphy, mesomorphy, and ectomorphy according to (Carter and Heath, 1990). Skinfolds at the subscapular and iliac crest sites were taken and included in a regression model together with biepicondylar humerus breadth and thigh girth to determine body fat percentage (Brozek et al. 1963; Katch and McArdle 1973).

Data analysis was executed using Statistica 10.0 (Statsoft, USA). Levene's test was used to analyze the equality of variances. Differences between the groups were assessed by analysis of variance (ANOVA) and Tukey's test post hoc to control for unequal sample sizes. The average somatotype of the groups is presented on a somatotype chart using Somatotype Calculation and Analysis software (Goulding 2002). Differences between the somatotypes of the groups were examined using Somatotype Analysis of Variance (SANOVA).

Results

The anthropometric measures, body proportions, and somatotypes of the combat sport athletes are presented in Table 1. The judo group exhibited the largest body mass – this difference was statistically significant when compared with the karate and fencing practitioners. No between-group differences were identified in body height, sitting height, and extremity length. The judo and jiu-jitsu athletes had significantly larger chest, hip, arm, and forearm girths than the other groups. No significant differences were observed in thigh girth, whereas calf girths were significantly smaller in fencers compared with the jiu-jitsu athletes. In addition, the sum of elbow and wrist breadths were significantly smaller in fencers than judokas.

The relative body proportions differentiated the groups of combat athletes to a greater extent than the absolute anthropometric measures. Overall, body size was the largest among the judokas compared with the karate, taekwondo, and fencing practitioners. BMI, in turn, was the lowest in the fencing group. The ratio of sitting height and body height was similar in all groups as was the ratio of upper extremity length to lower extremity length. However, a significant difference was found with the larger up-

Table 1. Anthropometric measures and body proportions across the combat sport disciplines (mean ± s).

Group	Judo	Jiu-jitsu	Karate	Taekwondo	Fencing	p
			Variables			
BM [kg]	65.4 (11.22)	59.6 (5.48)	60.4 (5.78)[a]	59.0 (9.54)	57.8 (8.01)[a]	0.025
BH [cm]	165.0 (6.83)	165.7 (6.08)	167.4 (4.30)	166.7 (5.12)	166.7 (5.24)	0.407
SH [cm]	87.8 (3.68)	88.3 (2.91)	88.5 (3.00)	87.9 (2.67)	87.7 (2.53)	0.481
UEL [cm]	71.5 (2.90)	71.2 (3.62)	71.3 (2.48)	71.9 (3.49)	71.9 (3.02)	0.900
LEL [cm]	87.1 (4.79)	87.2 (3.79)	88.5 (3.44)	87.9 (3.33)	87.9 (3.41)	0.392
CHG [cm]	90.5 (6.31)	86.1 (3.41)	86.2 (4.20)[a]	84.8 (6.00)[a]	83.3 (5.63)[ab]	0.000
HG [cm]	99.2 (7.75)	95.4 (4.47)	95.4 (4.73)	94.7 (8.48)	93.4 (6.35)[a]	0.021
AG [cm]	29.0 (2.70)	26.4 (1.81)	26.2 (1.86)[a]	25.7 (4.47)[a]	25.0 (2.86)[ab]	0.000
FAG [cm]	25.0 (1.61)	24.3 (1.49)	23.2 (1.36)[a]	23.7 (1.21)[a]	23.3 (1.97)[a]	0.000
TG [cm]	58.5 (5.00)	58.1 (5.33)	56.4 (3.19)	56.0 (3.21)	56.1 (4.40)	0.101
CG [cm]	36.7 (2.79)	37.3 (3.88)	35.6 (2.36)	36.0 (1.98)	34.8 (2.20)[b]	0.025
UEB [cm]	11.5 (0.57)	11.3 (0.81)	11.0 (0.62)[a]	11.1 (0.54)	11.0 (0.55)	0.021
LEB [cm]	16.0 (0.71)	16.0 (0.74)	15.8 (0.74)	15.5 (0.76)	15.5 (0.79)	0.106
			Ratios			
BH/BM^2	23.93 (2.92)	22.52 (2.14)	21.74 (1.94)[a]	21.52 (1.81)[a]	20.76 (2.00)[a]	0.000
SH/BH	53.23 (1.16)	53.35 (1.18)	53.32 (1.27)	52.87 (1.32)	52.62 (1.60)	0.309
UEL/LEL	82.18 (3.06)	82.98 (3.53)	81.71 (2.32)	80.68 (2.58)[b]	81.75 (2.49)	0.080
CHG/BH	54.89 (3.29)	52.77 (2.37)[a]	52.02 (2.62)[a]	51.48 (2.23)[a]	49.96 (2.76)[ab]	0.000
HG/BH	60.15 (3.90)	58.81 (3.56)	57.62 (3.14)[a]	57.01 (2.84)[a]	56.05 (3.19)[a]	0.001
AG/UEL	40.60 (3.78)	38.94 (3.32)	37.14 (3.39)[a]	36.79 (2.87)[a]	34.77 (3.56)[ab]	0.000
FAG/UEL	34.94 (2.06)	33.70 (1.37)	32.67 (2.41)[a]	33.26 (1.92)[a]	32.43 (2.57)[a]	0.000
TG/LEL	67.20 (5.07)	66.89 (5.11)	64.83 (4.50)	63.36 (4.70)[a]	63.92 (5.02)	0.012
CG/UEL	42.19 (3.08)	43.03 (4.13)	40.87 (3.28)	40.71 (2.64)	39.62 (2.68)[b]	0.005
UEB/BH	6.94 (0.25)	6.74 (0.45)	6.59 (0.31)[a]	6.66 (0.32)[a]	6.62 (0.31)[a]	0.000
LEB/BH	9.71 (0.41)	9.57 (0.58)	9.48 (0.39)	9.29 (0.40)[a]	9.33 (0.45)	0.002

[a] significantly different from the judo group ($p < 0.05$)
[b] significantly different from the jiu-jitsu group ($p < 0.05$)
Table legend: body mass (BM), body height (BH), sitting height (SH), lower extremity length (LEL), upper extremity length (UEL), chest girth (CHG), hip girth (HG), relaxed arm girth (AG), maximal forearm girth (FAG), maximal thigh girth (TG), maximal calf girth (CG), sum of elbow and wrist breadths (UEB), sum of knee and ankle breadths (LEB).

Table 2. Body components across the combat sport disciplines (mean ± s).

Group	Judo	Jiu-jitsu	Karate	Taekwondo	Fencing	p
Endomorphy	3.54 (1.08)	3.63 (1.42)	3.53 (0.81)	3.10 (0.87)	3.07 (1.38)	0.179
Mesomorphy	5.19 (0.94)	4.53 (1.34)	4.03 (1.00)[a]	3.87 (1.03)[a]	3.37 (1.06)[ab]	0.000
Ectomorphy	1.65 (0.95)	2.36 (0.89)	2.54 (1.01)[a]	2.70 (0.95)[a]	3.10 (0.96)[a]	0.000
% fat	12.38 (2.28)	12.61 (2.03)	11.78 (2.44)	11.59 (2.13)	11.81 (2.20)	0.339

[a] significantly different from the judo group ($p < 0.05$)
[b] significantly different from the jiu-jitsu group ($p < 0.05$)

per extremity length relative to lower extremity length of the jiu-jitsu group compared with the taekwondo practitioners.

Examining the judokas in greater detail, this group was characterized by significantly larger upper body proportions than the other groups of combat athletes. Relative hip, arm, and forearm girths were statistically smaller in the groups of karate, taekwondo, and fencing athletes. Relative thigh girth was slightly larger in the judo group when compared with the taekwondo group. In contrast, relative calf girth was significantly lower in the fencing group than the jiu-jitsu practitioners.

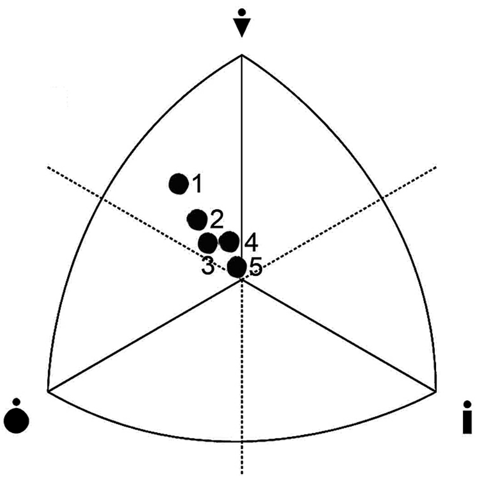

Fig. 1. The average somatotypes of the female combat athletes (1 – judo, 2 – jiu-jitsu, 3 – karate, 4 – taekwondo, 5 – fencing).

No significant differences were observed in body fat percentage (Table 2). However, the combat athletes could be categorized into two groups: judo and jiu-jitsu practitioners showed higher levels of body fat while lower values were found in the karate, taekwondo, and fencing groups.

When comparing somatotypes, no significant differences were observed for endomorphy. The judo, jiu-jitsu, and karate practitioners shared similar values whereas the taekwondo and fencing groups were found with a slightly lower level of endomorphy. Significant differences were detected for the mesomorph and ectomorph components. The highest value of mesomorphy w observed in the judokas, which was superior compared with the karate, taekwondo, and fencing practitioners. Statistically significant differences were also observed in the mesomorph component between the fencing and jiu-jitsu groups. For ectomorphy, the judokas showed the lowest values for this component, whereas the highest were exhibited by the fencers.

The average somatotypes for the groups of combat athletes are presented in Figure 1. Analysis of variance detected significant between-group differences ($F = 7.06$, $p = 0.001$). The endomorphic mesomorph somatotype was most endemic in the judo (3.62–5.21–1.65) and jiu-jitsu (3.72–4.64–2.30) groups. Comparable is the karate group, albeit with a lower level of mesomorphy (3.60–4.06–2.53). A more uniform level of mesomorphy is presented in the taekwondo practitioners, who could be considered a balanced mesomorph (3.15–3.94–2.71). However, the most balanced somatotype was observed in the group of fencers (3.22-3.49-3.06).

Discussion

Athletes are different from the age-matched general population as a result of the selection process and training effects. Within the realm of competitive physical activities, physical fitness and performance are largely dependent on body type, size, and composition.

In examining the literature (Sterkowicz-Przybycień and Almansba 2011) we found the present sample of judokas to show lower body height and weight values than Polish national team members (169.3 cm and 74.87 kg). Practitioners of jiu-jitsu in our sample were taller and heavier than highly skilled Polish national team members (165.1 cm and 58.69 kg) examined by Sterkowicz-Przybycień et al. (2014). In turn, the karate group was comparable in terms of body height and weight to top Polish competitors (166.39 cm and 58.75 kg) according to research results of Sterkowicz-Przybycień (2013). The taekwondo practitioners were minimally shorter than their national team peers although they shared similar body weight values (169.7 cm and 60.6 kg) (Kalinowska and Przybyłowicz 2010). The university-level fencers in our study were significantly shorter and lighter than elite Polish epeeists (169.9 cm and 62.31 kg), foilists (168.4 cm and 58.82 kg), and sabreurs (173.0 cm and 63.32 kg) (Sterkowicz-Przybycień and Franchini 2013).

Significant differences in the anthropometry of combat athletes were observed. When considering body build, the taekwondo group was the tallest and slimmest and had a relatively short body and relatively long legs. The structure of the trunk was also compact, as evidenced by the low chest and hip girth values. A similar situation was observed in the girths of the extremities. The resulting body proportions of this sample may be considered preferential, as kicks and strikes to the head and trunk of an opponent play a significant role in taekwondo (Kazemi et al. 2005; Preuschl et al. 2016).

In terms of body size, the karate group was similar to their taekwondo peers. However, they were distinguished by a relatively longer trunk and relatively shorter lower limbs. These two physical characteristics are associated with lowering the body's center of gravity and therefore allowing for a more balanced position while also aiding blocking moves and counterattacks involving strikes and kicks (Jukić et al. 2013).

Judo is a wrestling-oriented combat sport that develops speed, agility, endurance, and strength in addition to self-control, courage, resiliency, concentration, and perseverance. The large body size with large trunk and extremity girths in this group is similar to what was observed by other authors (Jagiello et al. 2007).

Although the jiu-jitsu group was slimmer than the judokas, they presented relatively longer upper limbs and narrower hips. To some extent, the body proportions of this group underscore the specificity of the discipline in that it uniquely combines karate and judo techniques (Pieter and Bercades 2009).

Fencing, compared with the above martial arts, is an aerobic- and anaerobic-based tactical discipline that involves mastering a wide gamut of techniques in order to take an opponent by surprise via speed and effective swordplay. The body build of the fencers, characterized by a slim body shape with elongated lower limbs, is similar to the findings of other studies (Ochoa et al. 2013).

It should be noted that the lack of substantial differences in the anthropometry of the present sample of combat athletes active in university sports clubs and elite national-level competitors is indicative of the significant effect that physiological, technical, and tactical factors have on achieving competitive success (Tsolakis and Vagenas 2010).

The specific exertional characteristics of each combat sport are also evident in the somatotypes of practicing athletes. While our sample of judo practitioners was high in mesomorphy (3.41–5.05–1.78), which was even higher than in Polish national team members (4.04–4.89–1.55) (Sterkowicz-Przybycień and Almansba 2011), a lower level of endomorphy was observed. This difference in the combination of somatotypes may have been due to our larger sample size of athletes in lower weight classes, which are known to show lower levels of body fat (Jagiello et al. 2007).

The jiu-jitsu sample presented an endomorphic mesomorph somatotype (3.78–4.28–2.30), although the mesomorph component was at a lower value than in the judo group. The practitioners of karate were observed with lower, albeit equal, levels of mesomorphy and endomorphy and greater ectomorphy (3.54–3.80–2.44). A similar finding was reported for Philippine national team members (3.05–3.68–2.38) (Pieter and Bercades, 2009), although top karate competitors from Botswania were described with greater endomorphy and mesomorphy and less ectomorphy (Amusa and Onyewadume 2001).

Our sample of taekwondo practitioners could also be characterized as endomorphic mesomorphs (3.18–3.71–2.50), although they presented the lowest values of endomorphy and mesomorphy. When compared with the present group of Polish taekwondo athletes, a slimmer body shape was found in an American sample that presented a mesomorphic ectomorph somatotype (2.47–3.08–3.47) (Pieter 1991). In turn, the sample of fencers showed the lowest mesomorphy and highest ectomorphy than the other combat sport athletes. Compared with Philippine karate seniors (3.69–4.84–1.32), the Polish sample had less fat, a more muscled physique, and higher ectomorphy (Pieter and Bercades 2009).

Conclusions

Our findings indicate that the sample of combat athletes, competing for university sports clubs and not at the professional level, present characteristics of morphological optimization. We found that classifying body type via the Heath-Carter method of somatotyping does not fully represent the anthropometric variability of athletes competing in sports that share many similar techniques, tactics, and strategies. The specificity of each discipline is better observed and with greater precision in the body proportions of athletes. Such a broadened anthropometric assessment can not only aid specialists in determining appropriate selection criteria for a given discipline but also serve as the basis in choosing the most optimal fighting technique and style based on athlete's body type and build. There exist specific differences in body proportions in the female practitioners of combat sports, caused by the fight principles and the used techniques and better diagnosis of biomechanical relationships between body segments provides coaches and athletes with information helping to optimize the motoric effectiveness. It can help to minimize the injury risk.

Acknowledgement

This work was supported by the Ministry of Science and Higher Education under Grant [number NRSA1 001551].

Authors' contributions

AB study conception and design, acquisition of funding, analysis and interpretation of data, drafting of manuscript and an author of the final version of the manuscript. JP acquisition of data, literature search, critical revision. JA acquisition of data, literature search, co-author of the draft version of the manuscript. AS acquisition of data, literature search, co-author of the draft version of the manuscript.

Conflict of interest

The authors have no conflict of interests to declare.

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