Body composition of elite Olympic combat sport athletes

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Abstract

Physique traits of a range of elite athletes have been identified; however, few detailed investigations of Olympic combat sports (Judo, Wrestling, Taekwondo and Boxing) exist. This is surprising given the importance of body composition in weight category sports. We sought to develop a descriptive database of Olympic combat sport athletes, compare variables relative to weight division and examine differences within and between sports. Additionally, we investigated the appropriateness of athletes' self-selected weight classes compared to an internationally recognised classification system (the NCAA minimum wrestling weight scheme used to identify minimum 'safe' weight). Olympic combat sport athletes (56♂, 38♀) had body mass (BM), stretch stature and dual-energy X-ray absorptiometry derived body composition assessed within 7-21 days of competition. Most athletes were heavier than their weight division. Sport had an effect ($p<0.05$) on several physique traits, including; lean mass, lean mass distribution, stretch stature and BMI. BM was strongly positively correlated ($r>0.6$) with; fat free mass, fat mass and body fat percentage, however was not predictive of total mass/weight division. The Olympic combat sports differ in competitive format and physiological requirements, which is partly reflected in athletes' physique traits. We provide reference ranges for lean and fat mass across a range of BM. Lighter athletes likely must utilise acute weight loss in order to make weight, whereas heavier athletes can potentially reduce fat mass.

Introduction

Previous research has identified unique physique traits of elite performers in a variety of sports (Siders, Lukaski, & Bolonchuk, 1993; Olds, 2001). Morphological optimization (i.e. the idea specific physique traits are associated with optimised performance) differs between events; e.g. low body mass (BM) and body mass index (BMI) have been associated with success in distance running, with researchers hypothesizing improved running economy mediating the link (Larsen, 2003). In sports requiring strength and power, muscle mass is associated with performance outcomes (Olds, 2001; Siders et al., 1993). In 'complex' sports involving increased tactical and strategic elements and wider ranges of potential movement patterns however, the association between physique traits and success is largely unknown (O'Connor et al., 2007).

One group of sports which has received relatively little investigation is Olympic combat sports, including boxing, taekwondo, judo and wrestling. This is surprising given these sports have specified weight divisions, established to 'even the playing field' by matching athletes of similar size. It's common practice for athletes to reduce BM to compete in lower weight categories, via a combination of acute and chronic weight loss strategies, presumably to obtain a size or leverage advantage over smaller opponents. Chronic weight loss strategies include various forms of dietary restriction (targeting total energy or specific macronutrients) alongside increased exercise, whereas acute strategies commonly take the form of intentional dehydration (Reale, Cox, Slater, & Burke, 2016c). Data exists suggesting heavier athletes are more successful within a specified weight category (Reale, Cox, Slater, & Burke, 2016a; Wroble & Moxley, 1998); however, this remains contentious and may vary across sports and competition level (Horswill, Scott, Dick, & Hayes, 1994; Kazemi, Rahman, & De Ciantis, 2011; Reale, Cox, Slater, & Burke, 2016b; Wroble & Moxley, 1998). Often grouped together, Olympic combat sports can be separated into striking (boxing and taekwondo) and grappling (judo and wrestling). In striking sports, athletes utilise movement and distance, attempting to land blows with their hands (i.e. boxing), or with their feet/legs, the predominant scoring strikes in taekwondo. In grappling sports, competitors attempt to manipulate the opponent's BM throwing them to the ground, pinning or forcing the opponent to submit. These differences likely alter the physique characteristics associated with success. Understanding the differences in morphological optimisation between combat sports is important for talent identification and transfer initiatives. Further, this information may provide insight into potential benchmarks for athletes, assisting in the identification of ideal weight divisions or the manipulation of body composition within a division.

Acute weight loss strategies employed by combat sport athletes to 'make weight' have been shown to have adverse health and/or performance implications (Fogelholm, 1994; Franchini, Brito & Artioli, 2012; Reale, Slater, & Burke, 2016c). Recognising this, recommendations have been proposed by academics, practitioner body's and sporting organisations in attempts to reduce the prevalence and severity of acute weight loss. Such recommendations include: the introduction of additional weight classes, creation of policies relating to weight regain allowances following weigh-in, scheduling weigh-ins closer to competition, and targeted education (Artioli, et al., 2010a; Crighton, Close, & Morton, 2015; Turocy et al., 2011). For example, the National Collegiate Athletic Association (NCAA) have implemented such strategies in wrestling, identifying an annual minimum weight category in which an athlete can compete, based on their presenting body composition (setting minimum weight at a value corresponding with 5 and 12% body fat in males and females, respectively; and requiring euhydration at weigh-in). Specific aims of initiatives such as this are to reduce the prevalence of prolonged low energy diets/fasting, as well as acute intentional dehydration. Research suggests this initiative is changing BM management practices (Oppliger, Utter, Scott, Dick, & Klossner, 2006); however, the implications of applying similar strategies to other combat sports are unknown.

Accordingly, the aim of this study was to examine elite Olympic combat sport athletes' body composition profiles and build a descriptive database. Additionally, we sought to examine the appropriateness of athletes' self-selected weight classes compared against an internationally recognised classification system (the NCAA minimum 'safe' weight scheme).

Materials and Methods

Overview

Olympic combat sport athletes participated in a cross-sectional observational study examining body composition (estimated via dual energy x-ray absorptiometry (DXA)) in relation to competitive weight division within and between Olympic combat sports. DXA scans were performed within 7-21 days of competition thus representing close to 'competition body composition' yet presumably before acute weight loss had begun. The Higher Research Ethics Committee of the Australian Institute of Sport (AIS), Canberra, Australia approved the study. Subjects provided written informed consent.

Participants

Male and female Judo, Boxing, Wrestling and Taekwondo athletes attending various training camps at the AIS volunteered for this study. Subjects were either members of the Australian national team or visiting overseas national teams (Thailand, Egypt, Philippines, Brazil, Japan, Ireland & New Zealand).

Body composition measurements

Subjects underwent BM, stretch stature and DXA derived body composition measurements. Stretch stature was measured with a stadiometer (Harpenden, Holtain Limited, Crymych, United Kingdom) to the nearest 0.1cm. BM was measured on a calibrated scale to the nearest 0.01kg (Tanita, Japan, BWB800S). DXA scans were performed accordance to a previously developed protocol emphasizing; standardized participant presentation and positioning, and scanner quality assurance processes (Nana, Slater, Stewart, & Burke, 2015). Scans were performed in whole body mode on a fan beam scanner (Lunar Prodigy, GE Healthcare, Madison, WI) with analysis performed using the GE enCORE 2015 software (GE Healthcare) and the Geelong reference database. Subjects race/ethnicity was selected from available options within the software according to which each individual identified best described their ancestry. Standard thickness mode was utilised, determined via the auto scan feature then analysed automatically by the Encore software, with regions of interest reconfirmed by the technician.

Data analysis

Descriptive statistics were reported for subjects; BM (kg), stature (m), bone mass (g and %), lean mass (kg and %), fat mass (kg and %), BMI (kg/m^2), fat mass index (FMI) (kg/m^2) and fat free mass index (FFMI) (kg/m^2) for each sport by sex. Athletes competing in divisions with no upper weight limit were excluded from analyses examining relationships relative to weight division.

For between-sport within sex comparisons, Levene's test of homogeneity was conducted followed by one-way ANOVA with Tukey post-hoc tests. Between-sport and sex comparisons were made of total and lean mass relative to weight division (expressed as percentage of weight division upper limit), plus lean mass distribution (lower body and peripheral lean mass relative to total lean mass); this involved Levene's test of homogeneity, followed by two-way ANOVA with Sidak post-hoc tests. Analysis was completed using PRISM v6.0 (GraphPad Software, San Diego, California, USA). Subjects were grouped by sex and simple linear regressions calculated to predict: total mass/weight division, lean mass/weight division, body fat percentage, BMI, FFMI and FMI based on BM.

Identification of each individual athletes' recommended 'safe weight' was completed in-line with the NCAA minimum wrestling weight procedure and utilizing body fat cut-offs advocated by the NATA position statement (Turocy et al., 2011). Turocy et al (2011) suggest athletes should not compete below a weight at which they would need to achieve body fat of around <5% in males, or <12% in females. This was calculated by taking each athletes DXA derived FFM, and then adding FFM x 0.5 (i.e. a male athlete with 75 kg FFM, minimum safe weight would be 75 kg + 3.75kg = 78.75 kg).

Significance was set as $p<0.05$. Additionally, effect sizes (ES) and 95% confidence intervals (CI95%) are reported when appropriate. The magnitudes of ES were classified as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large (≥0.80) when examining differences between means and as trivial (0–0.09), small (0.10–0.29), medium (0.30–0.49) and large (≥0.50) when examining correlation coefficients using the scale advocated by Cohen (4). All data are expressed as mean ±SD, unless otherwise specified.

Results

Subject characteristics

Ninety-four athletes met inclusion criteria for the study. Two males (one boxer and judoka) and two female taekwondo athletes competed in weight divisions with no upper weight limit, thus were excluded from analysis relative to weight division. BM, stretch stature and body composition compartments expressed in absolute and relative terms are displayed for males and females in Table 1.

Significant differences were found between sports in: males for BM (F (3,52) = 3.272, p=0.0283), total bone mass (F (3, 52) = 4.893, p=0.0045), lean mass percentage (F (3, 52) = 5.112, p=0.0036), total fat mass (F (3, 52) = 4.403, p=0.0078), fat mass percentage (F (3, 52) = 4.620, p=0.0061), BMI (F (3, 52) = 9.642, p<0.0001), FMI (F (3, 52) = 5.302, p=0.0029) and FFMI (F (3, 52) = 6.161, p=0.0012); and between female athletes for FFMI (F (3, 34) = 4.419, p=0.0100). Post hoc test results of specific differences between groups are displayed in table 1. Of note, boxers and taekwondo athletes differed similarly from judoka across several measures. Large effect sizes (not displayed in table 1.) were found between: male taekwondo athletes and all other athletes for differences in FFMI (ES=1.05 CI95%[0.17, 1.86], ES=1.67 CI95%[0.73, 2.51], ES=1.20 CI95%[0.28, 2.03] for boxers, judoka and wrestlers respectively) and BMI (ES=1.02 CI95%[0.14, 1.84], ES=1.86 CI95%[0.89, 2.72], ES=1.54 CI95% [0.57, 2.40] for boxers, judoka and wrestlers respectively); and between female taekwondo and all other athletes for differences in FFMI (ES=0.80 CI95%[0.07, 1.59], ES=1.52 CI95%[0.33, 2.55], ES=1.50 CI95%[0.19, 2.61] for boxers, judoka and wrestlers respectively); and in BMI between female taekwondo athletes and wrestlers (ES=1.06 CI95%[0.17, 2.14]), and female taekwondo athletes and judoka (ES=1.02 CI95%[0.08, 2.00]).

**INSERT TABLE 1.

Total and lean mass relative to weight division

Differences between sports and sexes for total and lean mass relative to weight division are displayed in Figure 1 (A & B). One female taekwondo athlete was lighter than the weight division upper limit (<73kg division). Eight males were lighter than the upper limit of their weight divisions; three wrestlers (one <74kg and two <86kg athletes), three judoka (one <60kg and two <100kg athletes) and two boxers (one <54kg and <91kg athlete).

No significant effect of sport or sex was observed for total mass relative to weight division, although large effect sizes were found between: female boxers and all other athletes (ES=1.24 CI95%[0.2, 2.19], ES=0.99 CI95%[0.08, 1.84], ES=0.85 CI95%[0.21, 1.85] for judoka, taekwondo athletes and wrestlers respectively. Medium effect sizes (not displayed in figure) were found between: male boxers and taekwondo athletes (ES=0.52 CI95%[0.32, 1.32]), and male wrestlers and taekwondo athletes (ES=0.62 CI95%[0.23, 1.43]).

Regarding lean mass relative to weight division, significant effects were found for sex ($F(1, 82) = 35.65$, $p=<0.0001$) but not for sport, and no interaction was found between sex and sport. Large effect sizes were found between: males and females (ES=1.39 CI95% [0.91,1.85]); male taekwondo athletes and wrestlers (ES=1.09 CI95% [0.18, 1.91]); male taekwondo athletes and judoka (ES=1.21 CI95% [0.32, 2.03]); and male boxers and judoka (ES=0.82 CI95% [0.06, 1.55]).

Lean mass distribution

Differences between sports and sexes in lean mass distribution are displayed in Figure 1 (C&D). Sex had a significant effect on peripheral/trunk lean mass distribution ($F(1, 86) = 12.31$, $p=0.0007$), however neither an effect for sport nor an interaction between these variables was evident. A large effect size was found between males and females (ES=0.90 CI95% [0.46, 1.32]).

Sport had a significant effect on lower/upper lean mass distribution ($F(3, 86) = 9.996$, $p<0.0001$); however, no effect of sex and no significant interaction was revealed. Post-hoc test results of specific differences are displayed in Figure 1. Medium effect sizes (not displayed in figures) were found between male boxers and judoka (ES=0.79 CI95%[0.04, 1.49]); male judoka and wrestlers (ES=0.79 CI95%[0.03, 1.50]); male judoka and taekwondo athletes (ES=0.64 CI95%[0.18, 1.41]); and female wrestlers and judoka (ES=0.79 CI95%[0.42, 1.91]).

Comparison of selected weight division to NCAA minimum 'safe' weight recommendations

Across sports, two female athletes competed in divisions below the NCAA minimum safe weight. Both were wrestlers competing in the <48kg and <58kg divisions with identified minimum safe weights of 54kg and 68kg, respectively. In the male cohort; one boxer, taekwondo and wrestler competed in the <49kg, <58kg and <74kg divisions with identified minimum safe weights of 50kg, 61kg, 75kg, respectively.

****INSERT FIGURE 1.**

Relationships between body mass and body composition

Simple linear regressions with 95% confidence bands are displayed in Figures 2 and 3. No significant relationship was found between BM and total mass/weight division. However lean mass/weight division, body fat percentage, BMI, FFMI and FMI were strongly correlated with BM in males and females.

****INSERT FIGURE 2.**

****INSERT FIGURE 3.**

Discussion

This is the first investigation to present DXA-derived body composition data across elite Olympic combat sport athletes, reporting on absolute physique traits as well as traits relative to weight division. The primary findings were; 1) the majority of athletes were heavier than their competitive weight division 7-21 days before competition, yet few were outside of accepted weight division guidance classification; 2) total BM was predictive of multiple physique traits; and 3) certain physique traits were unique to individual sports.

Detailed body composition data on combat sport athletes is scarce. Most research has investigated physique traits superficially, utilising indirect indices of composition, such as subcutaneous skinfold measurements and associated estimates of body composition derived from regression equations (Bridge, Ferreira da Silva Santos, Chaabène, Pieter, & Franchini, 2014; Chaabène et al., 2014; Franchini, Del Vecchio, Matsushigue, & Artioli, 2011; Horswill, 1992) or bioelectrical impedance which may not be valid to assess body composition in individuals and/or combat sport athletes (Loenneke et al., 2012). DXA is recognised as the preferred choice for physique assessment of athletes, notably for athletes in weight sensitive sports (Meyer et al., 2013). DXA quantifies whole body and regional bone, fat and fat free mass and when validated against a reference four compartment model, accurately measures fat mass within 1% across a range of diverse athletes (Prior et al., 1997). Despite this, few DXA investigations have examined combat sport athletes, and those doing so have failed to report their findings in a context relevant to combat sports (Nasri et al., 2015; Santos et al., 2014; Ubeda et al., 2010), including relationships to weight division or regional mass distribution.

In this study, mean BM of the athletes was 4.3±3.9% greater than competitive division; similar to the magnitude of acute weight loss commonly reported; ~5% (Artioli et al., 2010b; Franchini et al., 2012). Female boxers in our sample tended to be closer to their weight division than other athletes. This finding is of no surprise given the rules of amateur boxing which schedule weigh-ins on the morning of competition, providing minimal time for athletes to recover from acute weight loss unlike other combat sports. This pattern was not as pronounced in males; taekwondo athletes displayed greater BM relative to their weight division in comparison to boxing and wrestling athletes (evidenced by medium effect sizes) yet no differences were observed between boxers, judokas and wrestlers.

Our findings support earlier survey data (Artioli et al., 2010b; Reale, Slater & Burke 2018; Franchini et al., 2012) and studies using other indirect indices of acute BM management (Horswill et al., 1994; Kazemi et al., 2011; Reale, Cox, et al., 2016a; Wroble & Moxley, 1998) which collectively suggest most combat sport athletes utilise acute weight loss prior to weigh-in. Acute weight loss of ~5% is known to impact performance measures with limited recovery time (Hall & Lane, 2001), however with ≥4 hours following weigh-in, alongside appropriate nutrition interventions, performance can be restored (Artioli, R. T. Iglesias, et al., 2010). In our study, we observed low body fat levels amongst many (but not all) athletes, which suggests significant fat loss was either unlikely or not possible (given the short time frame available) during the pre-competition period to make weight. Indeed, losses in fat mass towards weigh-in goals in combat athletes may be as little as 0.5kg per week with the rate slowing as athletes become leaner (Morton, Robertson, Sutton, & MacLaren, 2010). As athletes were significantly above their weight division, it's likely they would be engaging in acute weight loss to achieve their weight division. While modest acute weight loss (˜≤3%BM) may be achievable using benign strategies such as low fibre diets and/or a moderate reduction in muscle glycogen stores, greater degress of acute weight loss will need to be derived from losses in body water and may impact performance (Reale, Cox, Slater, & Burke 2016c). Although few athletes in our study were competing below 'minimum safe weight', if resorting to acute weight loss strategies these athletes would likely violate NCAA guidelines prohibiting dehydration at weigh-in; demonstrating the multi-pronged approach required for interventions aimed at reducing acute weight loss practices.

While acute weight manipulation before competition is a (commonly perceived) key part of a combat sport athlete's preparation (Oppliger, Landry, Foster, & Lambrecht, 1993), research on weight making strategies and the effect on success is mixed. Some studies utilise BM re-gain post weigh-in as a surrogate for the magnitude of acute weight loss pre-weigh-in (Kazemi et al., 2011; Horswill et al., 1994; Reale et al., 2016a & 2016b; Wroble & Moxley, 1998). Such studies have reported correlations between BM re-gain and success in judo (Reale, et al., 2016a) and wrestling (Wroble & Moxley, 1998), however this may depend on competition level (Horswill et al., 1994). By contrast, this relationship has not been observed in boxing (Reale, et al., 2016b) or taekwondo (Kazemi et al., 2011). Similar inconsistencies have been reported with other parameters: trends (albeit not statistically significant) for higher stature and lower BMI correlating with success have been suggested to be evident in taekwondo (Kazemi, De Ciantis, & Rahman 2013) but not in boxing, judo or wrestling (Guidetti, Musulin, & Baldari, 2002; Horswill, 1992; Lech, Sterkowicz, & Rukasz, 2007). In our study, significant differences and large effects sizes existed between taekwondo and the other sports for BMI, FFMI and FMI, underscoring the possible relationship between lighter built, taller athletes and success in taekwondo. The nature of the scoring system in taekwondo may explain the advantage afforded by height/reach as minimal contact is required to score relative to other combat sports and greater scores awarded for kicks compared to punches, favouring longer levers. These ascertions warrant further investigation.

Our results also revealed differences in lean mass distribution between sports. Taekwondo athletes possessed proportionally the most lower body lean mass, followed by judoka, then wrestlers, and lastly boxers. It is interesting to note sport had a larger effect on upper/lower body lean mass distribution than sex, since males typically possess higher relative upper body lean mass than females (Janssen, Heymsfield, Wang, & Ross, 2000). This finding likely reflects the individual demands of the sports and the unique effects of training stresses placed on athletes. As previously outlined, competition goals and scoring requirements differ between sports, thus specific physique traits may predispose athletes to competitive success.

In contrast to the differences observed between athletes across sports, similarities included the relationship between BM and several body composition/physique traits. We found strong correlations between BM and; BMI, FFMI, FMI as well as relative lean and fat mass. In general, these findings suggest athletes become more heavily built as BM increases. The correlation between percentage body fat and BM suggests lighter athletes are less able to make weight through body fat reduction alone, thus must rely on acute weight loss strategies (such as dehydration), whereas heavier athletes have greater capacity to decrease body fat to make weight. This may provide insight as to where education relating to fat loss strategies and managing dehydration is best targeted.

The results of this study extend previous findings focusing globally on combat sport athletes' body composition, which commonly collapse athletes across weight divisions. Previous comparisons between weight divisions have revealed trends of increasing body fat and endomorphy with BM (Franchini, et al., 2011; Horswill, 1992), however DXA measurements are scarce. Santos et al. did utilise DXA in estimating body fat percentages in grapplers (12.2% in males and 23.0% in females) and strikers (12.9% in males and 27.6% in females) (Santos et al., 2014), however failed to analyse these findings relative to weight division/BM. These earlier data are in line with our mean findings (11.7% in males and 22.7% in females). Linear regression analysis of our data allowed predictions of potential benchmarks (i.e. body fat percentage targets) across varying weights, and found regardless of BM, athletes all weighed a similar relative amount above their weight division. This suggests athletes plan for relative rather than absolute acute weight loss. This contrasts earlier reports that athletes in lighter weight divisions utilise larger acute weight manipulations (Horswill et al., 1994; Reale et al., 2016a; Wroble & Moxley, 1998).

Limitations in this study include; small sample sizes, the cross sectional design, lack of additional anthropometric measures (i.e. lever length, seated height etc.), and lack of additional information relating to dietary/weight loss practices of the subjects. Additionally the effect of race/ethnicity on body composition in the cohort was not able to be identified, due to the varied make up of the sample and difficulty in clear separations. Thus, it is difficult to draw robust conclusions on precise morphological optimization for combat sport athletes. Additionally, the comparison between wrestling athletes and others in this study is problematic, as the wrestlers were derived from Australian and New Zealand national teams; two countries not noted as top competitors at the world level, thus may not truly be reflective of the world's top competitors, whereas the remaining athletes were from countries who are competitive on the world stage in that particular sport. Lastly, although the time frame relative to competition at which measurements were taken is perhaps the most logical time to implement a standardized data collection plan for this investigation (minimizing the chances of capturing athletes body composition prior to substantial fat loss or during / post acute weight loss), we cannot rule out the possibility additional fat loss occurred following measurement prior to weigh-in, or that athletes had not begun engaging in acute weight loss strategies. We recommend further investigation of physique traits at elite competitions and the relationships to success in order to determine to what degree morphological optimisation exists. Additionally, examining high level performers, across sports, within a single race/ ethnicity will enable researchers to further tease out individual effects of sport, body mass, race/ethnicity etc. However, this body of work adds value to existing literature; highlighting differences between combat sport athletes, examining how

BM/weight division influences body composition targets and strengthening the case that low BMI, FMI and FFMI are favourable for performance in taekwondo.

Conclusion

Olympic combat sports differ in rules and regulations as well as physiological requirements, which is partly reflected in athletes' physique traits. While total BM relative to weight division during the pre-competition period is similar across weight divisions (at least in this sample), differences exist in body composition across athletes of varying BM, with heavier athletes possessing greater lean and fat mass relative to height. We provide reference ranges for lean and fat mass across a range of weight divisions which provides a guide for combat sport athletes' in their chronic BM management efforts and in identifying a suitable weight division. As lighter athletes are leaner, these athletes likely rely heavily on acute weight making strategies during the pre-competition period to make weight compared to athletes in heavier weight divisions. These athletes were shown to have greater body fat levels and thus greater potential to lose body fat during the pre-competition period to make weight. Lean mass distribution differs between sports with taekwondo athletes possesing the greatest relative lower body lean mass, followed by judoka, wrestlers and boxers who possess the greatest relative upper body lean mass. In taekwondo, lower BMI, body fat, and lean mass for height, and a propensity for lower body lean mass relative to upper body lean mass appears beneficial (at least relative to judo, boxing and wrestling).

Disclosure statement

This study did not receive any funding. All the authors declare that they have no conflict of interest derived from the outcomes of this study.

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Tables

Table 1. Subject characteristics (mean ±SD). Data are collapsed across weight divisions, and analysed within sex and between sports

	Boxing		Judo		Taekwondo		Wrestling		Mean	
	Males (n=15)	**Females (n=17)**	**Males (n=17)**	**Females (n=7)**	**Males (n=10)**	**Females (n=9)**	**Males (n=14)**	**Females (n=5)**	**Males (n=56)**	**Females (n=38)**
Body mass (kg)	67.6±16.2[a,*]	60.6±10.8	80.7±14.9	68.1±11.4	68.1±8.5	59.9±9.8	76.2±11.0	65.6±8.0	73.2±12.7	62.5±10.5
Stature (m)	1.71±0.13	1.64±0.05	1.76±0.09	1.66±0.05	1.80±0.06	1.68±0.07	1.77±0.05	1.63±0.03	1.75±0.09	1.65±0.06
Bone mass (g)	3352±782[a,*]	2826±447	4114±731	3102±549	3259±455[a,*]	2736±386	3721±576	2987±301	3659±737	2877±441
Bone mass (%)#	5.0±0.4	4.7±0.3	5.1±0.4	4.6±0.4	4.8±0.3	4.6±0.5	4.9±0.4	4.6±0.4	5.0 ±0.4	4.6±0.4
Lean mass (kg)	57.8±12.2	43.9±4.9	64.4±9.3	47.4±4.0	58.8±7.3	43.0±4.8	62.2±7.8	47.8±7.2	61.1±9.7	44.8±5.2
Lean mass (%)#	85.9±4.3[a,*]	73.3±6.1	80.4±5.5	70.6±7.5	86.4±1.5[a,*]	72.3±5.2	81.9±6.1	73.8±14.0	83.3±5.4	72.6±7.3
Fat mass (kg)	6.6±4.4[a,*]	13.9±6.3	12.3±6.7	17.6±7.9	5.9±1.5[a,*]	14.2±5.7	10.4±6.2	14.8±10.4	9.1±5.9	14.8±6.9
Fat mass (%)#	9.1±4.3[a,*]	22.0±6.2	14.5±5.7	24.9±7.6	8.8±1.7[a,*]	23.1±5.5	13.1±6.3	21.6±14.2	11.7±5.5	22.7±7.5
BMI (kg/m^2)	22.7±2.1[a,**]	22.5±3.2	26.1±3.4	24.5±3.2	20.7±1.7[a,****]	21.3±3.1	24.2±2.6[b,*]	24.7±3.4	23.7±3.2	22.9±3.3
FMI (kg/m^2)	2.1±1.1[a,*]	5.1±2.1	3.9±2.0	6.3±2.7	1.8±0.4[a,**]	5.0±1.9	3.3±1.9	5.6±4.1	2.9±1.8	5.4±2.4
FFMI (kg/m^2)	19.5±1.6	17.4±1.4	20.8±1.9	18.1±0.8	17.9±1.4[a,***]	16.3±1.4[c,**]	19.8±1.7[b,*]	19.0±2.4	19.7±1.9	17.5±1.6

Sport had a significant effect on BM, total bone mass, lean mass percentage, total fat mass, fat mass percentage, BMI, FMI and FFMI in males, and FFMI in females. Specific differences between groups are indicated as follows: a - difference to judo males, b - different to TKD males, c - different to wrestling females, *p≤0.05, **p≤0.01, ***p≤0.001, ****p≤0.0001, BMI = body mass index, FMI = fat mass index, FFMI = fat free mass index, # - percentage of total mass

Figure captions

Figure 1 - Total and lean mass relative to weight division, and lean mass distribution, mean values ±SD. Analysis of subjects by sex and sport for; total body mass relative to weight division (A), total lean mass relative to weight division (B), lower body lean mass relative to total lean mass (C), peripheral (arms + legs) lean mass relative to total lean mass (D). Two way-anovas revealed: an effect of sex on lean mass relative to weight division and peripheral/axial lean mass distibution; and an effect of sport on lower/upper body lean mass distrbution. Ù denotes within sex large effect size.

Figure 2 – Linear regression of all male and female athletes body mass compared to: total mass/weight division (A and B), lean mass/weight division (C and D) and body fat percentage (E and F). Dotted lines indicate 95% confidence bands.

Figure 3 – Linear regression of all male and female athletes body mass compared to: body mass index (A and B), fat free mass index (C and D) and fat mass index (E and F). Dotted lines indicate 95% confidence bands.

Table 1. Subject characteristics (mean ±SD). Data are collapsed across weight divisions, and analysed within sex and between sports

	Boxing		**Judo**		**Taekwondo**		**Wrestling**		**Mean**	
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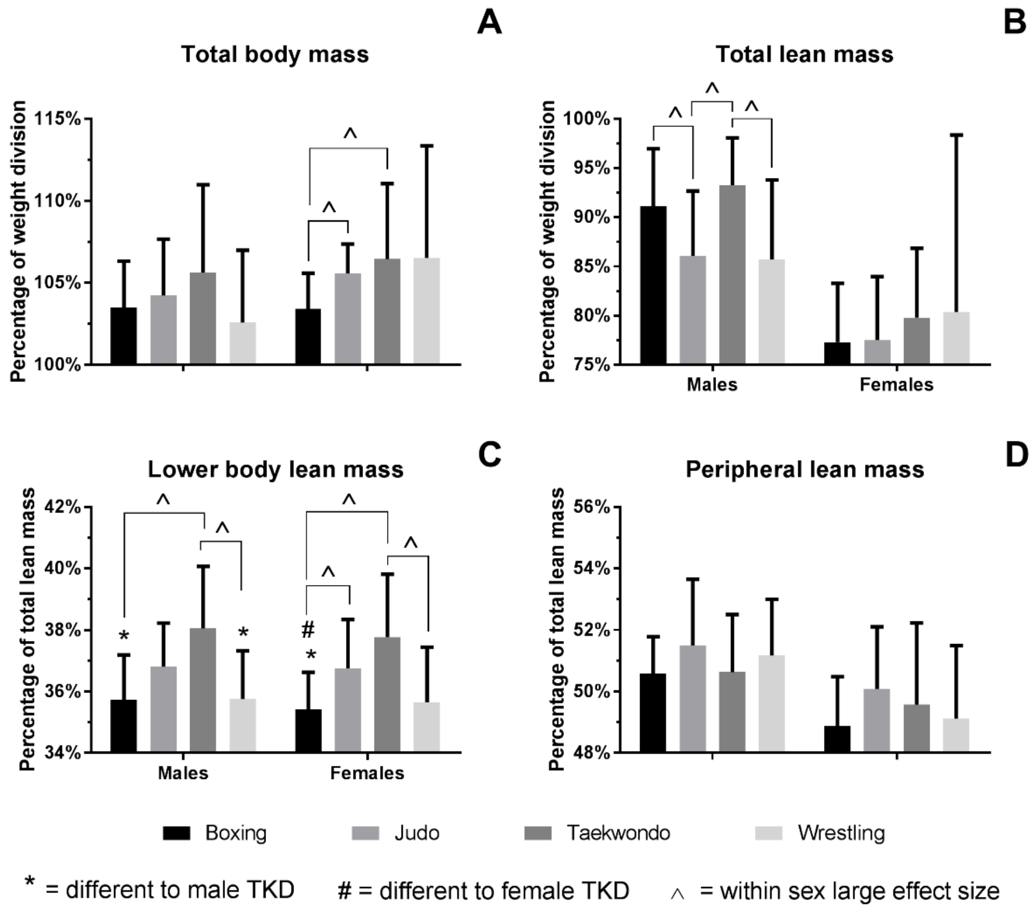
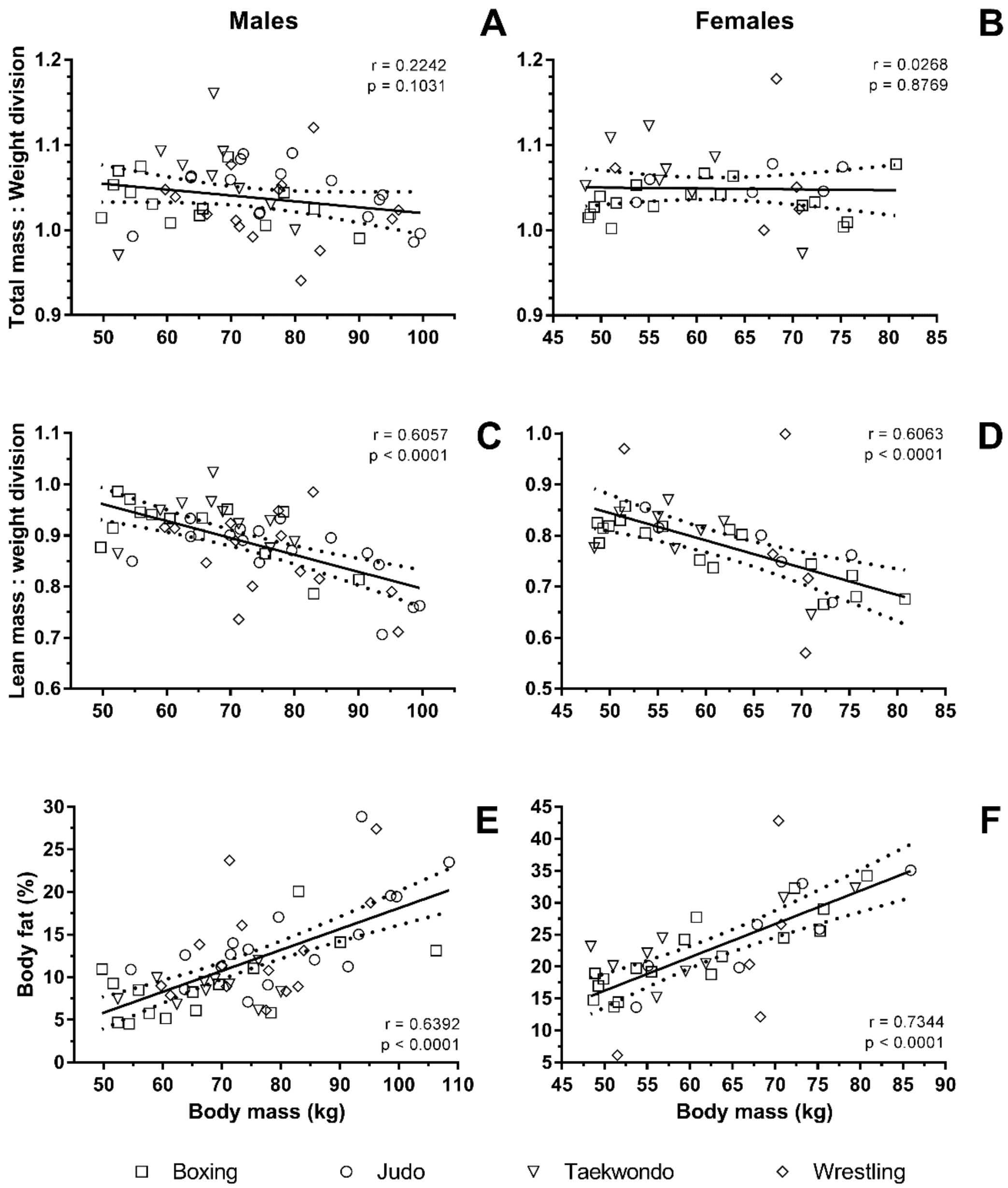
Stature (m)	1.71±0.13	1.64±0.05	1.76±0.09	1.66±0.05	1.80±0.06	1.68±0.07	1.77±0.05	1.63±0.03	1.75±0.09	1.65±0.06
Bone mass (g)	3352±782[a,*]	2826±447	4114±731	3102±549	3259±455[a,*]	2736±386	3721±576	2987±301	3659±737	2877±441
Bone mass (%)#	5.0±0.4	4.7±0.3	5.1±0.4	4.6±0.4	4.8±0.3	4.6±0.5	4.9±0.4	4.6±0.4	5.0±0.4	4.6±0.4
Lean mas	57.8±12.2	43.9±4.9	64.4±9.3	47.4±4.0	58.8±7.3	43.0±4.8	62.2±7.8	47.8±7.2	61.1±9.7	44.8±5.2

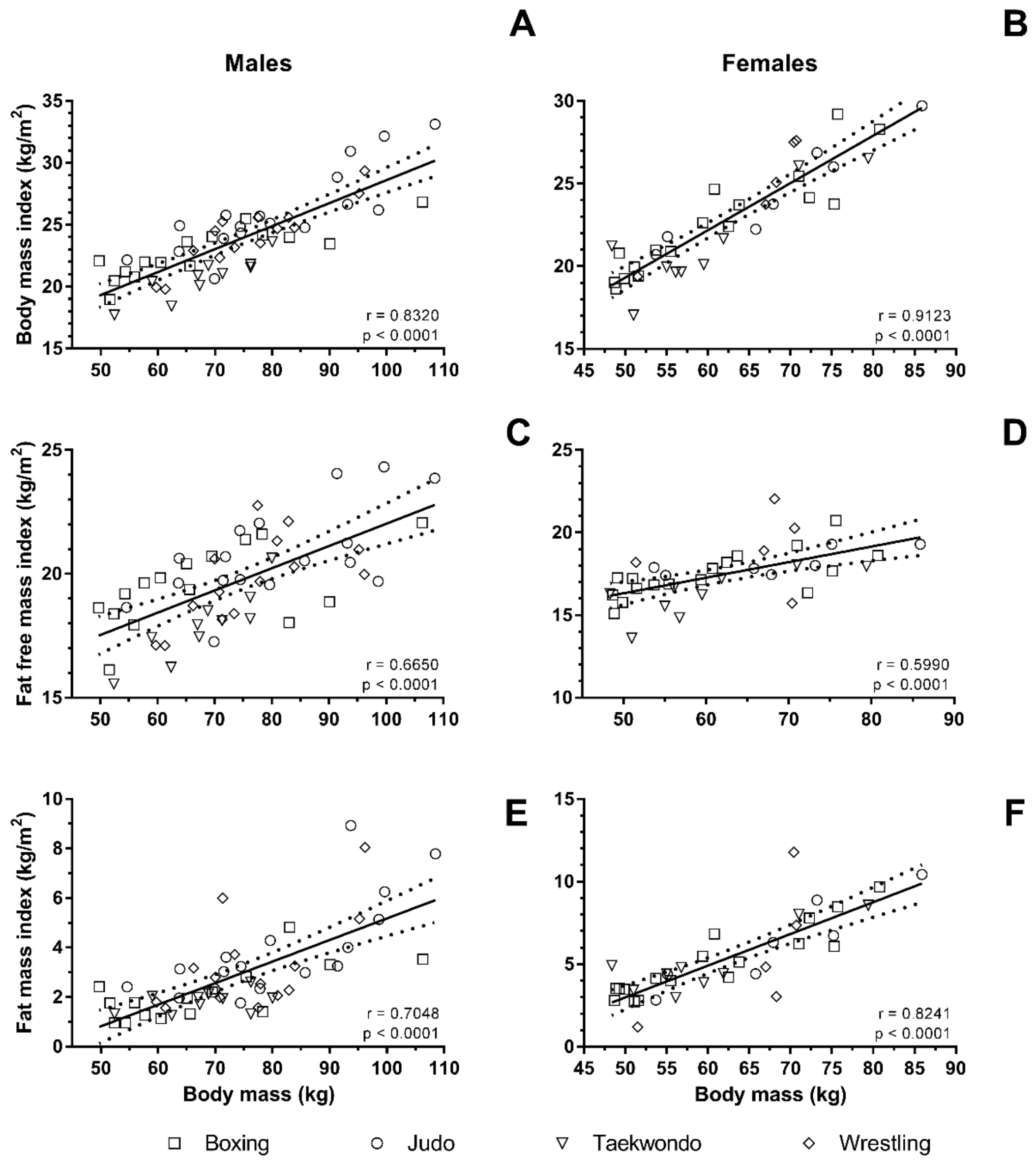
s (kg)										
Lean mass (%)#	85.9±4.3[a,*]	73.3±6.1	80.4±5.5	70.6±7.5	86.4±1.5[a,*]	72.3±5.2	81.9±6.1	73.8±14.0	83.3±5.4	72.6±7.3
Fat mass (kg)	6.6±4.4[a,*]	13.9±6.3	12.3±6.7	17.6±7.9	5.9±1.5[a,*]	14.2±5.7	10.4±6.2	14.8±10.4	9.1±5.9	14.8±6.9
Fat mass (%)#	9.1±4.3[a,*]	22.0±6.2	14.5±5.7	24.9±7.6	8.8±1.7[a,*]	23.1±5.5	13.1±6.3	21.6±14.2	11.7±5.5	22.7±7.5
BMI (kg/m^2)	22.7±2.1[a,**]	22.5±3.2	26.1±3.4	24.5±3.2	20.7±1.7[a,****]	21.3±3.1	24.2±2.6[b,*]	24.7±3.4	23.7±3.2	22.9±3.3
FMI (kg/m^2)	2.1±1.1[a,*]	5.1±2.1	3.9±2.0	6.3±2.7	1.8±0.4[a,**]	5.0±1.9	3.3±1.9	5.6±4.1	2.9±1.8	5.4±2.4
FFMI	19.5±1.6	17.4±1.4	20.8±1.9	18.1±0.8	17.9±1.4[a,***]	16.3±1.4[c,**]	19.8±1.7[b,*]	19.0±2.4	19.7±1.9	17.5±1.6

(kg/ m^2)

Sport had a significant effect on BM, total bone mass, lean mass percentage, total fat mass, fat mass percentage, BMI, FMI and FFMI in males, and FFMI in females. Specific differences between groups are indicated as follows: a - difference to judo males, b - different to TKD males, c - different to wrestling females, *p≤0.05, **p≤0.01, ***p≤0.001, ****p≤0.0001
BMI = body mass index, FMI = fat mass index, FFMI = fat free mass index
# - percentage of total mass


A
Total body mass
Percentage of weight division
115%
110%
105%
100%
B
Total lean mass
100%
95%
90%
85%
80%
75%
Males
Females
C
Lower body lean mass
Percentage of total lean mass
42%
40%
38%
36%
34%
Males
Females
D
Peripheral lean mass
56%
54%
52%
50%
48%
Boxing
Judo
Taekwondo
Wrestling
* = different to male TKD
# = different to female TKD
^ = within sex large effect size


Males
A
Females
B
Total mass : Weight division
r = 0.2242
p = 0.1031
r = 0.0268
p = 0.8769
C
D
Lean mass : weight division
r = 0.6057
p < 0.0001
r = 0.6063
p < 0.0001
E
F
Body fat (%)
r = 0.6392
p < 0.0001
r = 0.7344
p < 0.0001
Body mass (kg)
Body mass (kg)
Boxing
Judo
Taekwondo
Wrestling



A
B
Males
Females
Body mass index (kg/m2)
r = 0.8320
p < 0.0001
r = 0.9123
p < 0.0001
C
D
Fat free mass index (kg/m2)
r = 0.6650
p < 0.0001
r = 0.5990
p < 0.0001
E
F
Fat mass index (kg/m2)
r = 0.7048
p < 0.0001
r = 0.8241
p < 0.0001
Body mass (kg)
Body mass (kg)
Boxing
Judo
Taekwondo
Wrestling