©Journal of Sports Science and Medicine (2006) **CSSI,** 13-20
http://www.jssm.org

Combat Sports Special Issue

Research article

COMPARISON OF NORMALIZED MAXIMUM AEROBIC CAPACITY AND BODY COMPOSITION OF SUMO WRESTLERS TO ATHLETES IN COMBAT AND OTHER SPORTS

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Published (online): 01 July 2006

ABSTRACT
Sumo wrestling is unique in combat sport, and in all of sport. We examined the maximum aerobic capacity and body composition of sumo wrestlers and compared them to untrained controls. We also compared "aerobic muscle quality", meaning VO_{2max} normalized to predicted skeletal muscle mass (SMM) (VO_{2max} /SMM), between sumo wrestlers and controls and among previously published data for male athletes from combat, aerobic, and power sports. Sumo wrestlers, compared to untrained controls, had greater ($p < 0.05$) body mass (mean ± SD; 117.0 ± 4.9 vs. 56.1 ± 9.8 kg), percent fat (24.0 ± 1.4 vs. 13.3 ± 4.5), fat-free mass (88.9 ± 4.2 vs. 48.4 ± 6.8 kg), predicted SMM (48.2 ± 2.9 vs. 20.6 ± 4.7 kg) and absolute VO_{2max} (3.6 ± 1.3 vs. 2.5 ± 0.7 $L \cdot min^{-1}$). Mean VO_{2max} /SMM ($ml \cdot kg\ SMM^{-1} \cdot min^{-1}$) was significantly different ($p < 0.05$) among aerobic athletes (164.8 ± 18.3), combat athletes (which was not different from untrained controls; 131.4 ± 9.3 and 128.6 ± 13.6, respectively), power athletes (96.5 ± 5.3), and sumo wrestlers (71.4 ± 5.3). There was a strong negative correlation ($r = - 0.75$) between percent body fat and VO_{2max} /SMM ($p < 0.05$). We conclude that sumo wrestlers have some of the largest percent body fat and fat-free mass and the lowest "aerobic muscle quality" (VO_{2max} /SMM), both in combat sport and compared to aerobic and power sport athletes. Additionally, it appears from analysis of the relationship between SMM and absolute VO_{2max} for all sports that there is a "ceiling" at which increases in SMM do not result in additional increases in absolute VO_{2max}.

KEY WORDS: Oxygen uptake, skeletal muscle mass, fat-free mass, fat mass.

INTRODUCTION

Combat sports arguably contain unique characteristics in comparison to other sports: one must directly attack and conquer an opponent. Most combat sports require (in the physical realm) a mix of technique, strength, aerobic fitness, power, and speed. Thus, usually no one performance characteristic dominates in combat sports, like in (for instance) the shot put, where size, strength and power dominate, or marathon running, where ability to maintain continuous aerobic output dominates (Bassett and Howley, 2000).

One of the most unique combat sports is that of Sumo wrestling. To win in sumo, one must push one's opponent out of the ring, or cause the opponent to touch the ground with any part of the body except the soles of the feet. Although this sounds deceptively simple, sumo is an extremely complex sport requiring a combination of strength (Kanehisa, et al., 1997; 1998), massive size (very large fat free and fat mass; Hattori, et al., 1999; Kondo, et al., 1994), and probably some combination of anaerobic and aerobic capacity. The characteristics needed to participate at an elite level in this sport are held only by a select group of athletes. Interestingly, we could find no published study on the anaerobic or aerobic characteristics of sumo wrestlers.

The purpose of this study is to compare and contrast the maximum aerobic capacity and body composition of sumo wrestlers with untrained controls, and to previously published data from participants in other combative, aerobic, and power sports. Untrained controls were used to indicate where on the aerobic capacity continuum that sumo wrestlers fall.

METHODS

Participants

Eight untrained college undergraduates (22.2 ± 1.0 yrs; all data presented as mean ± SD) and eight highly trained, championship-level college sumo wrestlers (21.1 ± 1.0 yrs) volunteered to participate in this study. The sumo wrestlers were members of Japan's number one collegiate team, and included a champion of the Japan Amateur Championship. Sumo wrestlers had been competitively training for a minimum of four years (5.5 ± 2.6 years). Controls had not participated in recreational sports for at least two years prior to testing. The department's ethical commission approved the study. All participants received a verbal and written description of the study and gave informed consent prior to testing. We also compared the results from the sumo wrestlers and untrained controls with previously published data from combative (including Judo, karate, boxing, wrestling, and Kendo), aerobic (including marathon, long and middle distance running, rowers, and cross country skiing), and power sports (including U.S. football, discus throw, shot put, and basketball; see Table 1). Weighted means of these groups from previously published results were calculated for comparison purposes.

Measurement of VO_2 max

Maximal oxygen uptake (VO_2max) was assessed by graded work on a cycle ergometer (Aerobike 400, COMBI Co., Ltd.). The participants started to exercise at 30 W for 2 min, and the load was increased by 15 W every minute until exhaustion. The exercise was terminated when the participants failed to maintain the prescribed pedaling frequency of 60 rpm. Respiratory gas was collected with an automated breath-by-breath mass spectrometry system (Aeromonitor AE-280S, Minato Medical Science Co., Ltd.) and gas exchange was computed every 60 s. Heart rate was monitored by a Polar Heart Rate Monitor (Vantage XL, Polar, USA). The following criteria were used to establish maximum effort: oxygen consumption appearing to plateau with increasing workload (< 150 $ml·min^{-1}$), maximum heart rate within ± 11 bpm of the age-predicted maximum (220-age), and a maximum respiratory exchange ratio above 1.15.

Measurement of body composition

Fat-free mass (FFM) was estimated from body density using the subcutaneous fat measurements from ultrasound (Body density = 1.090 - 0.00050 [sum 9 sites of AT thickness]; Abe, et al., 1994). We have previously reported that the standard error of the estimate (SEE) of body density using ultrasound equations is approximately 0.006 $g·ml^{-1}$ (~ 2.5% body fat) in the normal Japanese population (Abe, et al., 1994). However, extracellular fluid content tends to increase in obese participants (Waki, et al., 1991) and may be higher in sumo wrestlers. If so, this could affect the estimation of body composition in sumo, but to what extent is unclear. Our unpublished observations show a significant strong correlation between under water weighing-measured body density and ultrasound estimated body density for sumo wrestlers ($n = 45$, $r = 0.919$, $p < 0.001$). However, after calculation of body fat percentage, these unpublished results suggested an overestimation of body fat by ~ 4%. Thus, our present results may overestimate body fat percentage in sumo wrestlers by ~ 4%. Body fat percentage was calculated from body density using the equation of Brozek, et al. (1963). FFM was derived by subtracting fat mass from total body mass.

Prediction of skeletal muscle mass

For all Participants and previously collected data, skeletal muscle mass (SMM) was predicted from FFM using the equation SMM = 1.47 x FFM + 18.1 (Abe et al., 2003).

Statistical analysis

Comparisons of body mass, FFM, percent body fat,

Table 1. Anatomic and maximal aerobic characteristics of male sumo wrestlers and untrained male controls from the current study, and combat, aerobic, and power sport male athletes from previous studies. Notes: Ht = height, Wt = weight, FFM = fat-free mass, pre. SMM = predicted skeletal muscle mass. Country indicates nationality of the athletes. Method indicates modality of VO_{2max} test. Level indicates the competitive status attained by the participants tested.

Sport	Country	n	Height (cm)	Weight (kg)	% fat	FFM (kg)	Pre. SMM (kg)	VO_{2max} L/min	VO_{2max} ml/kg BM	VO_{2max} ml/kg SMM	Method	Level	Reference
Sumo wrestling	Japan	8	176.6	117.0	24.0	88.9	48.2	3.60	31.1	74.8	CE	College	present study
Untrained	Japan	8	171.5	56.1	13.3	48.4	20.6	2.50	44.6	121.4	CE	College	present study
Judo	Canada	19	175.1	80.2	12.3	70.3	35.5	4.61	57.5	129.8	TM	National	Taylor and Brassard, 1981
Judo	Canada	22	174.2	75.4	9.3	68.4	34.2	4.49	59.2	131.2	TM	National	Thomas et al., 1989
Karate	Japan	7	172.9	66.3	10.7	59.2	28.0	3.81	57.5	136.4	TM	College	Imamura et al., 1998
Karate	Japan	9	169.5	60.1	12.6	52.5	23.4	3.44	57.2	146.9	TM	College	Imamura et al., 1998
Boxers	Italy	8	177.1	77.4	14.5	66.1	32.6	4.45	57.5	136.3	TM	Elite amateur	Guidetti et al., 2002
Wrestling	US	25	173.3	80.6	8.4	73.8	37.9	4.49	55.7	118.5	TM	Junior World	Silva et al., 1981
Wrestling	US	2	177.0	81.1	9.8	73.2	37.5	5.10	64.0	136.1	CE	NCAA champ	Fahey et al.,1975
Kendo	Japan	7	171.0	71.2	12.8	62.1	29.9	3.91	54.9	130.6	TM	College	Hayashi, 1994
Football (Def. line)	US	32	192.4	117.0	17.9	96.0	53.0	5.30	45.3	100.0	TM	Professional	Wilmore et al., 1976
Discus throw	US	7	186.1	104.7	16.4	87.5	47.2	4.90	46.8	103.8	CE	World champ	Fahey et al., 1975
Shot put	US	5	188.2	113.0	16.8	94.0	51.6	4.80	42.5	93.0	CE	World champ	Fahey et al., 1975
Basketball	US	15	200.6	96.9	9.0	86.6	46.6	4.50	46.4	96.6	TM	Professional	Parr et al., 1978
Marathon	US	8	176.7	61.9	5.3	58.6	27.6	4.58	74.0	166.2	TM	Elite amateur	Pollock, 1977
Long dist. running	Finland	8	177.0	66.2	8.4	60.6	28.9	5.19	78.4	179.4	TM	National	Rusko et al., 1978
Rowing	Australia	9	189.7	88.7	7.3	82.2	43.6	5.51	62.5	126.3	TM	Olympic	Novak et al., 1978
CC skiing	Finland	17	174.0	69.3	10.2	62.2	30.0	5.42	78.3	180.6	TM	National	Rusko et al., 1978
MD running	Canadian	7	176.7	67.0	7.8	61.8	29.7	5.09	76.0	171.3	TM	National	Ready, 1984

CE = cycle ergometer, TM = treadmill, CC = cross country, MD = middle distance.

and VO_2max were made between sumo and controls using a t-test. Comparisons of the means of VO_2max /SMM were made between sumo wrestlers, untrained controls, combat athletes, aerobic athletes, and power athletes via an ANOVA with Tukey's post-hoc test. Linear regression was used to assess relationships between FFM and VO_2max, and percent body fat and VO_2max /SMM. Statistical significance was set at $p< 0.05$.

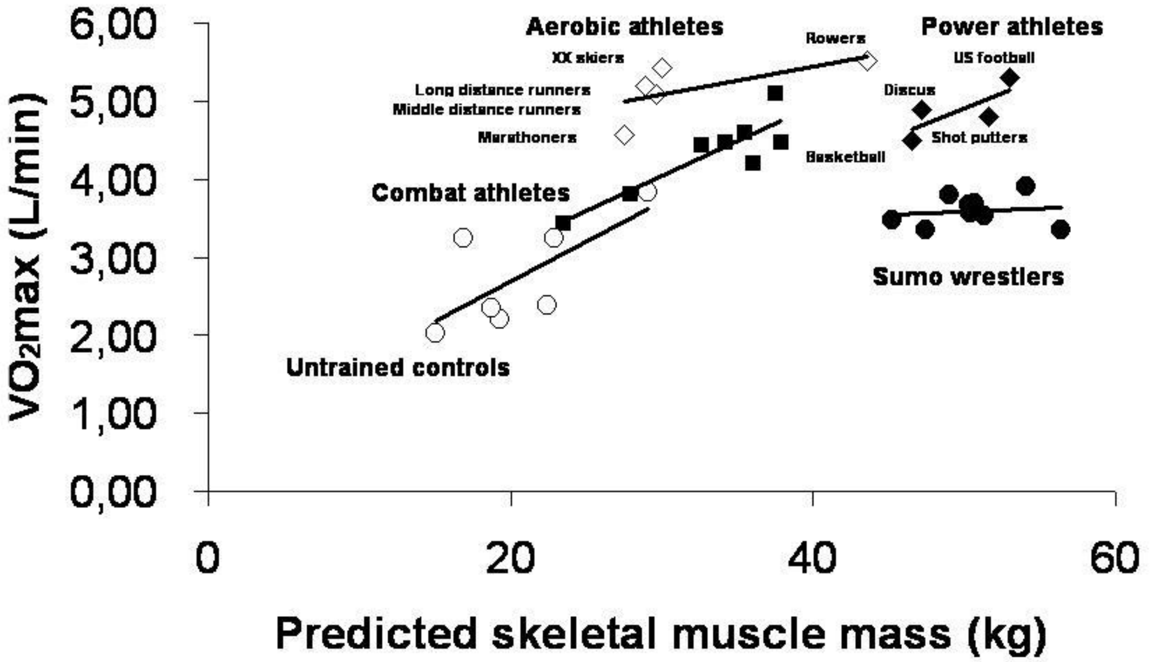

Figure 1. Relationship between skeletal muscle mass (SMM) and absolute VO_{2max} in sumo wrestlers (filled circles), untrained controls (unfilled circles), and combat (filled squares), aerobic (unfilled diamonds), and power sport athletes (filled diamonds). Equation and correlation results: aerobic athletes, y = 0.0416x + 3.8116, R = 0.70, power athletes, y = 0.0885x + 0.4407, R = 0.69, sumo wrestlers, y = 0.0078x + 3.2051, R = 0.14, untrained controls, y = 0.1022x + 0.6564, R = 0.70, combat athletes, y = 0.089x + 1.3745, R = 0.88. Sources: sumo wrestlers and untrained controls, current study; all others from previous results listed in Table 1 and grouped as listed in Methods.

RESULTS

Data are presented as means ± SD unless otherwise noted. Results of data collected in this study (sumo wrestlers and untrained controls) are shown at the top of Table 1, and are compared with previous results collected from combat, aerobic, and power sport participants. Sumo wrestlers, compared to untrained controls, were taller (1.77 ± 0.03 vs. 1.72 ± 0.03 m; $p < 0.05$), and had larger ($p < 0.05$) body mass (117.0 ± 4.9 vs. 56.1 ± 9.8 kg), percent fat (24.0 ± 1.4 vs. 13.3 ± 4.5), fat-free mass (88.9 ± 4.2 vs. 48.4 ± 6.8 kg), predicted SMM (48.2 ± 2.9 vs. 20.6 ± 4.7 kg) and VO_2max (3.6 ± 1.3 vs. 2.5 ± 0.7 $L{\cdot}min^{-1}$). Heart rate at maximum was not different between sumo wrestlers and controls (189 ± 8 vs. 192 ± 7 bpm, respectively; $p > 0.05$). Relative VO_2max to body mass, however, was significantly lower in sumo wrestlers compared to untrained controls (31.1 ± 1.3 vs. 44.6 ± 9.1 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, respectively; $p < 0.05$).

The predicted SMM and VO_2max/SMM results are in reasonable agreement with previous results using MRI to quantify SMM (Sanada et al., 2005). Mean VO_2max/SMM was significantly different ($p < 0.05$) among aerobic athletes (164.8 ± 18.3 $ml{\cdot}kgSMM^{-1}{\cdot}min^{-1}$), combat athletes (which was not different from untrained controls; 131.4 ± 9.3 and 128.6 ± 13.6 $ml{\cdot}kgSMM^{-1}{\cdot}min^{-1}$, respectively), power athletes (96.5 ± 5.3 $ml{\cdot}kgSMM^{-1}{\cdot}min^{-1}$), and sumo wrestlers (71.4 ± 5.3 $ml{\cdot}kgSMM^{-1}{\cdot}min^{-1}$).

Figure 1 was created by using previous data (weighted mean results) from combat, aerobic, and power sport participants (from Table 1), and data collected from sumo wrestlers and untrained controls in the current study, and shows the relationship between SMM and absolute VO_2max for these participants. There appears to be an overall positive relationship between SMM and absolute VO_2max until ~ 45 kg of predicted SMM; the relationship appears to weaken after this point.

Figure 2 is a plot of the relationship between percent fat and VO_2max/SMM from sumo and untrained controls, and previously collected data (weighted mean results) from combat, aerobic, and power athletes. There is a strong negative correlation between these variables ($r = -0.75$; $p < 0.05$).

DISCUSSION

To our knowledge, this is the first time that VO_2max results have been reported for sumo wrestlers. However, in order to make better comparisons of VO_2max among participants of varying fat and body mass, we divided VO_2max by the amount of

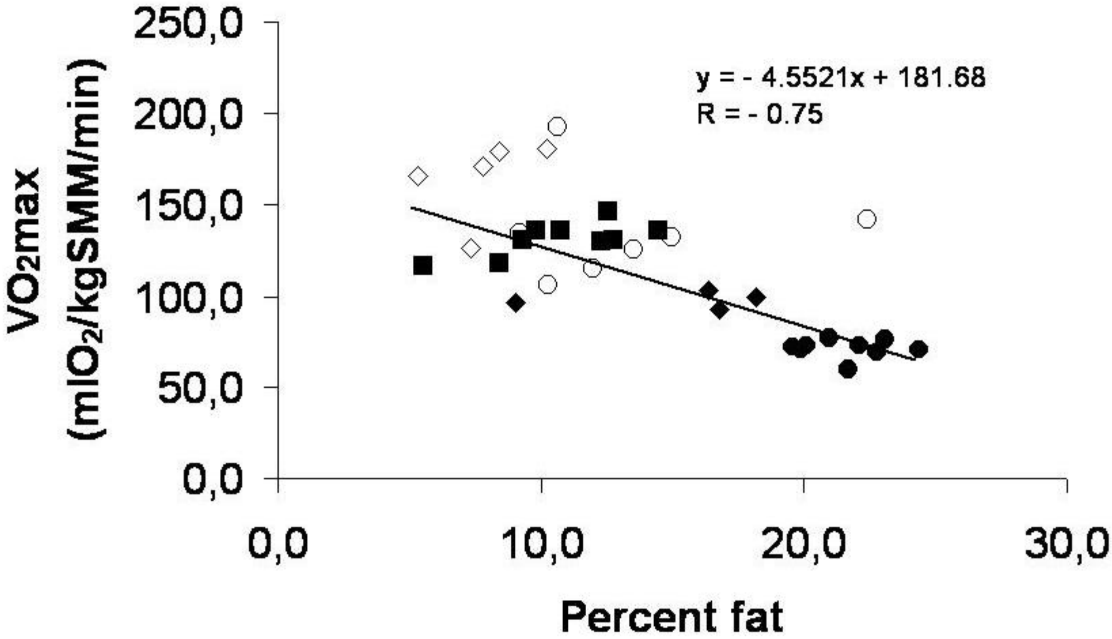

Figure 2. Relationship between percent body fat and VO_{2max} /SMM in sumo wrestlers (filled circles), untrained controls (unfilled circles), and combat (filled squares), aerobic (unfilled diamonds), and power sport athletes (filled diamonds).

predicted skeletal muscle mass (SMM) - SMM being the functional tissue for oxygen uptake during strenuous physical work. The calculation of VO_2max /SMM should provide an indication of the "aerobic muscle quality" of the athlete's skeletal muscle. We use the term "aerobic muscle quality" to refer to the amount of oxygen consumed per skeletal muscle mass. The higher this value, the higher the aerobic muscle quality. We found that sumo wrestlers have a low "aerobic muscle quality" (low VO_2max /SMM), compared to untrained controls and other combat sports, and aerobic and power sports (Table 1). Why might the aerobic muscle quality, i.e. VO_2max /SMM, be low in sumo wrestlers?

Maximum oxygen uptake is equal to the product of cardiac output (itself a function of heart rate and stroke volume) and the arterial-venous oxygen differences in the blood. Clearly one or more of these factors must be affected in sumo wrestlers to account for the low VO_2max /SMM. It is possible that the massive skeletal muscle hypertrophy in sumo wrestlers is not matched by increases in heart size and/or stroke volume; that is, cardiac output may be low per unit of SMM for sumo wrestlers, resulting in abnormally low VO_2max /SMM values. However, a recent study of professional Japanese sumo wrestlers suggests that left ventricular dilation is indeed very large in these athletes (median left ventricular [LV] end-diastolic volume ~ 60 mm), although it should be noted that LV function is normal, and LV dimensions were significantly correlated with body size, which would lead one to assume that sumo wrestlers have normal LV sizes and stroke volumes for their amount of skeletal muscle mass (Kinoshita, et al., 2003). Additionally, we noted normal (within ± 5 % of predicted) maximal heart rates (see Results) in sumo wrestlers at VO_2max. This suggests cardiac output of these athletes is not compromised.

The low VO_2max /SMM results for sumo wrestlers should therefore be the cause of alterations in arterial-venous oxygen content differences, indicating a "peripheral" limitation. It is possible that the massive skeletal muscle hypertrophy in sumo wrestlers could decrease the capillary density, or mitochondrial density, of skeletal muscle, resulting in less oxygen delivered or utilized per volume of myofibrillar tissue and thus a lower VO_2max /SMM. Another possibility could be that the high fat, high calorie diet and/or high fat storage mass in sumo wrestlers results in higher than normal intramuscular stores of lipid (obesity has been shown to increase intramuscular triglyceride stores; Gray et al., 2003; Goodpaster et al., 2000). This could result in a "diluting" of myofibrillar content and a decrease in VO_2max /SMM, although the amounts of triglycerides stored would have to be substantial.

Perhaps the low VO_2max /SMM in sumo wrestlers is related to the content of aerobic enzymes in their skeletal muscle. The training and competition style of sumo is very brief and anaerobic - most competitions are over in < 1 minute. Thus, the aerobic energetic system probably receives little stress during sumo training and competition. On the other hand, grappling style sports (i.e. wrestling, Judo) probably require a combination of aerobic and repeated anaerobic types of energy (Amtmann and Cotton, 2005). This is because they typically last for > 2 minutes, with times of very high intensity interspersed throughout the competition. Likewise, striking combat sports (i.e. karate, boxing, Kendo) also require a combination of aerobic and repeated anaerobic types of energy. Therefore increases in skeletal muscle aerobic enzymes (and thus increases in VO_2max /SMM) should occur in other combat sports and aerobic sports, but not in sumo wrestlers. Perplexing, however, is the fact that sumo wrestlers appear to have a lower VO_2max /SMM than other power athletes, and untrained controls (Table 1). More research examining the intracellular content and structure of sumo wrestler's skeletal muscle is needed.

Sumo wrestlers have a higher fat-free mass (FFM), fat mass, and predicted skeletal muscle mass (SMM) compared to other combative sports (Table 1). Indeed, sumo wrestlers have some of the largest absolute FFM (and thus, SMM) measured in humans (Hattori, et a., 1999, Kanehisa, et al., 1997, 1998, Kondo, et al., 1994, Yamauchi, et al., 2004). Why might these attributes be helpful in the sport of sumo wrestling? These attributes make the wrestler difficult to push off his feet or move. The large fat mass of sumo wrestlers plays a part in lowering the center of gravity of the body, providing stability to the wrestler. The large muscle mass allows the sumo wrestlers to create enormous absolute force and power to move their opponent, and also provides stability.

The large SMM and fat mass (FM) in sumo wrestlers may also play a role in the shape of results in Figure 1: the relationship between SMM and absolute VO_2max is generally linear until about 45 kg of SMM; then the relationship begins to disappear (right hand side of Figure 1) for the athletes with large SMM, i.e. power athletes and sumo wrestlers. This may indicate that athletes with a very large SMM incur a "penalty" in the form of an aerobic plateau. It is well known that energy cost per distance increases with increases in body mass in humans (McArdle et al., 2001). The results of Figure 2 support this concept: VO_2max /SMM is negatively related to percent body fat, indicating that excess fat is detrimental to work because it increases the carried load, which increases oxygen costs. Although the data analyzed are limited in scope, the ceiling of increasing SMM in human athletes without incurring a "penalty" in the guise of plateaued or decreasing aerobic performance seems to be ~ 45 kg of SMM based on the data analyzed (Figure 1).

CONCLUSION

In conclusion, sumo wrestlers have a low VO_2max /skeletal muscle mass compared to untrained controls and combat, aerobic, and power sport athletes, which is currently unexplainable, but may be related to the lack of aerobic training particular to sumo wrestling practice/competition, and/or the large fat mass in these athletes. The enormous fat and skeletal muscle mass in sumo wrestlers is unique in the combat sports, and in all of sport. Further investigation into sumo wrestler aerobic skeletal muscle function is warranted.

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KEY POINTS

- Sumo wrestlers have a high absolute VO_{2max} compared to untrained controls.
- However, sumo wrestlers have a low VO_{2max} /kg of skeletal muscle mass compared to other combat sports, other strength/power sports, and untrained controls.
- The reason for this is unknown, but is probably related to alterations in sumo skeletal muscle compared to other sports.
- Based on the present and previous data, there appears to be a “ceiling” at which increases in skeletal muscle mass do not result in additional increases in absolute VO_{2max}.

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