

Anthropometric and Physiological Characteristics of Brazilian Jiu-Jitsu Athletes

Characteristics of BJJ athletes

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This work was supported by the Norwegian University of Science and Technology.

Abstract

The aim of this study was to describe anthropometric and physiological characteristics of Brazilian jiu-jitsu (BJJ) athletes. For this purpose, 42 male athletes were recruited from one of the largest BJJ academies in central Norway. The subjects were 32 ± 6 (SD) years old, 181.9 ± 7.2 cm tall, had a body mass (m_b) of 85.7 ± 10.6 kg, and 5.5 ± 3.7 years of BJJ training experience. The subjects underwent segmental multifrequency bioelectrical impedance analysis (BIA) of body composition, direct measurements of pulmonary function and maximal oxygen uptake ($\dot{V}O_{2max}$), assessments of one-repetition maximum (1RM) in the parallel squat and paused bench press, and one set of pronated-grip pull-ups to muscular failure. The average body fat (BF) percentage was 12.9 ± 5.3 %. The subjects achieved a $\dot{V}O_{2max}$ of 50.6 ± 4.6 ml·kg⁻¹·min⁻¹. Absolute squat 1RM (113.2 ± 20.4 kg) was significantly higher than bench press 1RM (87.6 ± 16.5 kg) ($p < 0.001$). The mean number of pull-ups achieved were 9 ± 4 . These characteristics were generally independent of rank, training experience, weekly training volume, competition volume, and style preference. Additional strength training appeared to improve bench press performance ($p < 0.05$). Beyond that, additional strength and/or conditioning training had no apparent effect on any variable ($p > 0.05$). This study provides novel insight into the fitness levels of BJJ athletes. These findings indicate the degree of exercise response to BJJ training and are applicable in athlete assessment and exercise prescription in this population.

Keywords: maximal oxygen uptake; maximal strength; allometric scaling; BJJ; combat sports; martial arts

INTRODUCTION

Brazilian jiu-jitsu (BJJ) is a modern martial art that stems from the traditional art of jujutsu, commonly translated as “the gentle art”, which originated in feudal Japan (32). Jujutsu reached Brazil in the early 20th century via Japanese practitioners such as Sada Miyako, Takeo Yano, Kazuo Yoshida, and Mitsuyo Maeda. Maeda, a judoka and prizefighter, arrived in Brazil in 1914, and eventually started teaching a blend of judo and wrestling under the label “jiu-jitsu” (9). Among his students was teenager Carlos Gracie, who, along with his brother Hélio and subsequently numerous other Gracie family members, is credited with developing BJJ into its own art (20).

From the challenge matches of the early days to the international tournaments of today, competition has always been an integral part of BJJ. As BJJ evolved throughout the 20th century and into the 21st, a distinction between art and sport emerged, where the evolution of the latter is considerably influenced by competition ruleset. Many rulesets award points for achieving and maintaining a dominant position, whereas securing a submission due to a competition legal chokehold or joint lock universally leads to victory. Official matches can last anywhere from a few seconds, in the case of early submission, to hours, in the case of no time limit. The International Brazilian Jiu-Jitsu Federation (IBJJF) operates with regulation match durations of 5-10 minutes for adults, depending on age and rank (28). Analyses of BJJ combat characteristics reveal an effort/pause ratio of 6:1 to 13:1 and a low/high intensity ratio of approximately 9:1 (1).

Based on match duration and intensity characteristics, BJJ can be described as predominantly an aerobic sport. Maximal oxygen uptake ($\dot{V}O_{2max}$) reflects the maximal rate of adenosine triphosphate (ATP) resynthesis via aerobic metabolism, and is generally recognized as the most important determinant of aerobic endurance (37). Direct pulmonary gas exchange analysis during large muscle mass exercise is widely considered to be the gold standard

measurement of $\dot{V}O_{2\max}$. The current literature on $\dot{V}O_{2\max}$ in BJJ athletes is scarce and there is an explicit lack of direct measurements. Based on the available data, athletes appear to have an average $\dot{V}O_{2\max}$ of $\sim 50 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, independent of rank (5). This reflects a moderate ability to utilize oxygen during exercise compared to other athlete populations (43), and could indicate a limited cardiovascular exercise response to BJJ training. However, more research using gold standard measurements is required to establish normative $\dot{V}O_{2\max}$ values in this population.

The need for different forms of strength in BJJ, such as maximal strength and muscular endurance, has previously been identified (29, 30, 42). Past investigations have shown that advanced athletes tend to score better on various strength measurements than their non-advanced counterparts, indicating an important utility of strength in BJJ (11, 13, 15). As both offensive and defensive techniques often involve large muscle groups in the upper and lower body, the ability to produce force in multi-joint exercises such as the squat and bench press is relevant for the BJJ athlete. Further, these exercises are widely used in general athlete assessments, including in combat sports (10, 17, 21). To date, few studies have included measurements of both these exercises in BJJ athletes, with limited data on squat performance in particular (5).

While Olympic grappling sports such as judo and wrestling have been investigated extensively, there is a paucity of research on BJJ (3, 5). As the sportive aspect of BJJ continues to develop, investigations into the physiological demands of the sport and the characteristics of the athletes are sought after. At present, the physiological characteristics of BJJ athletes remain to be fully elucidated. Thus, the aim of this study was to determine anthropometry, pulmonary function, $\dot{V}O_{2\max}$, maximal strength, and muscular endurance in active BJJ athletes with varied training and competition backgrounds.

Additionally, the relationship between these characteristics and rank, training experience and volume, competition status and volume, style preference, and training habits were assessed.

METHODS

Experimental Approach to the Problem

Eligible athletes from all ranks were recruited from one of the largest BJJ academies in central Norway to represent a randomly selected academy sample. As the athletes maintained a similar training and competition schedule year-round, recruitment and testing was carried out over the span of several months without specific considerations for upcoming competitions. All tests were performed in the same consecutive order by the same exercise physiologist for all subjects. Anthropometric data were collected first, with the subjects instructed to be in a euhydrated state. This was followed by pulmonary function testing and a cardiopulmonary exercise test (CPET). As uphill running generally elicits a higher $\dot{V}O_{2\max}$ than cycling, all subjects were tested on an incline treadmill (6). A protocol consisting of a warm-up at a set workload, followed by incremental one-minute intervals, was applied. To avoid any impact of excess post-exercise oxygen consumption on oxygen uptake ($\dot{V}O_2$), pulmonary ventilation (\dot{V}_E), and heart rate (HR), assessments of strength were performed last (31). The temperature in the exercise laboratory was kept constant at 21° Celsius.

Subjects

42 active, male BJJ athletes (10 white, 16 blue, 9 purple, 2 brown, 1 black belt, 4 non-ranked; see table 1 for subject characteristics) from eight different countries were recruited to participate in this study. The subjects were required to keep a consistent training schedule with BJJ as their main sport, as well as have ≥ 2 years of experience, or be regular competitors with ≥ 2 training terms (~1 year) of experience to be eligible for participation.

A questionnaire was used to collect information on rank, training experience, competition status, and training habits. The sample included accomplished competitors at all ranks with multiple gold medals in international IBJJF tournaments, former amateur and professional mixed martial arts fighters, as well as recreational practitioners. The study was approved by the local ethics committee. All subjects were required to review and sign a consent form prior to participation.

Anthropometry

Stature was measured to the nearest 0.5 cm with a wall-mounted stadiometer (Seca Corp., Hanover, MD). Body mass (m_b) and composition were assessed with segmental multifrequency bioelectrical impedance analysis (BIA) (MC-980-MA, Tanita Corp., Tokyo, Japan). The subjects were instructed to avoid same-day exercise prior to testing and be in a euhydrated state with empty bladder and bowel at the time of the test.

Pulmonary function

Forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), maximal voluntary ventilation (MVV), and diffusing capacity of the lungs for carbon monoxide (D_{LCO}) were obtained with a calibrated clinical respiratory analyzer (SensorMedics Vmax Spectra 229d, Yorba Linda, CA, USA). The subjects were required to perform at least three successful attempts for the measurements of FVC, FEV_1 , and MVV, and two for the measurement of D_{LCO} . The highest values were recorded for analyses.

Maximal oxygen uptake

$\dot{V}O_{2\max}$ was determined during an incremental CPET on a motorized treadmill (PPS 55 Med, Woodway GmbH, Weil am Rhein, Germany) at a 3° inclination. All subjects had previous experience with treadmill running. The warm-up included 10 minutes of running at 7 km·h⁻¹, where the average $\dot{V}O_2$ during the last minute was used to calculate running economy (C_R) as the oxygen cost of running per meter (ml·kg^{-0.75}·m⁻¹) at this workload (23). Following the warm-up, treadmill speed was increased by 1 km·h⁻¹ every minute until exhaustion, which generally occurred within 5 to 10 minutes. $\dot{V}O_2$, respiratory exchange ratio (RER), and \dot{V}_E were obtained with the Vmax Spectra 229d. Breathing reserve was calculated as the relative difference between MVV and \dot{V}_E ((MVV - \dot{V}_E / MVV) x 100). HR was continuously monitored (M400, Polar Electro, Kempele, Finland) and the maximal HR achieved during the CPET was defined as HR_{max}. Immediately following the CPET, the subjects gave their rating of perceived exertion (RPE) on the 15-point Borg scale (8). Blood was sampled from the tip of the finger and blood lactate concentration ($[La^-]_b$) was analyzed with the Biosen C-Line (EKF Diagnostics GmbH, Barleben, Germany). $\dot{V}O_{2\max}$ was calculated as the highest 30-second interval and accepted if at least two of the following criteria were met: $\dot{V}O_2$ leveling off despite increasing workload; a proximity of ≤ 5 beats·min⁻¹ to HR_{max} if this was known; RER ≥ 1.1 ; and/or $[La^-]_b \geq 8$ mmol·L⁻¹.

Strength measurements

One-repetition maximum (1RM) in the squat and bench press was assessed with a competition standard Olympic bar and weights (Eleiko Sport, Halmstad, Sweden). Required squat depth was determined as the point where the femur was parallel to the floor. The bench press was performed with a marked stop of ~1 second at the chest before initiating the

concentric phase. The subjects were required to keep the gluteal and scapula regions in contact with the bench, as well as the heel of the foot in contact with the floor, throughout the lift. Warm-up and relative progression towards 1RM was the same for both exercises. Subjects warmed up with the bar followed by 50 % of their estimated 1RM. The load was increased progressively until muscular failure was reached or form was severely compromised. Increments were adjusted per the subject's RPE. For both lifts, the aim was to reach 1RM within five attempts. Pull-ups were performed with a shoulder-wide pronated grip. Each repetition started with the elbows fully extended. The subjects were required to elevate their chin over the bar with no kip in the concentric phase. One set of as many repetitions as possible was performed.

Allometric scaling

As neither $\dot{V}O_2$ nor force increases proportionally to m_b , allometric scaling should be applied when comparing individuals of different sizes (6, 26). Because BJJ has weight classes, normalizing these variables to size is important (18). Thus, allometric equations where $\dot{V}O_2$ is proportional to $(\propto) m_b^b$ and $1RM \propto m_b^b$, in which b represents the exponent, were applied (26). $\dot{V}O_2$ was calculated with the exponent 0.75 (7, 22); 0.67 was used for 1RM values (26); and pull-up performance was calculated as being inversely proportional to $m_b^{0.33} (m_b^{0.67} \cdot m_b^{-1})$ (6).

Statistical analyses

Statistical analyses were performed using IBM SPSS version 24 (Chicago, IL, USA). The data were assessed for normality with the Shapiro-Wilks test and quantile-quantile plots. Pearson product-moment correlation coefficients were calculated to determine the direction and strength of significant relationships between characteristics.

Differences in characteristics based on competition status, additional strength training, and additional conditioning training were assessed with independent samples *t*-tests. The effects of rank and style preference were determined with one-way analysis of variance (ANOVA) with Fisher's Least Significant Difference post-hoc test. Data are presented as mean \pm standard deviation (SD). The alpha level was set at $p \leq 0.05$.

RESULTS

All subjects except one, due to injuries not related to this study, successfully completed the CPET. No adverse events occurred during any measurement procedure. Anthropometry, pulmonary function, and training habits are presented in table 1. Table 2 show the results from the $\dot{V}O_{2\max}$ and strength measurements expressed in absolute, relative to m_b , and scaled values.

Insert table 1 here

Insert table 2 here

The relationship between anthropometric and physiological characteristics and rank, training experience and volume, competition status and volume, style preference, and training habits were assessed.

The average BF percentage was 12.9 ± 5.3 %. Competitors (12.0 ± 5.2 %) had significantly lower BF than non-competitors (16.3 ± 4.6) ($p < 0.05$). Inverse correlations between BF and relative ($r = -0.693$, $p < 0.001$) and scaled ($r = -0.530$, $p < 0.001$) $\dot{V}O_{2max}$ were observed. Further, m_b correlated inversely with relative ($r = -0.562$, $p < 0.001$) and absolute ($r = -0.657$, $p < 0.001$) $\dot{V}O_{2max}$. Additionally, m_b correlated with absolute load lifted in the squat ($r = 0.367$, $p < 0.05$) and bench press ($r = 0.367$, $p < 0.05$), and inversely with absolute ($r = -0.556$, $p < 0.001$), relative ($r = -0.682$, $p < 0.001$), and scaled ($r = -0.501$, $p < 0.001$) pull-up performance.

D_{LCO} correlated with absolute ($r = 0.446$, $p < 0.01$), relative ($r = 0.329$, $p < 0.05$), and scaled ($r = 0.427$, $p < 0.01$) $\dot{V}O_{2max}$. Age was inversely correlated with relative $\dot{V}O_{2max}$ ($r = -0.360$, $p < 0.05$), as well as with relative ($r = -0.474$, $p < 0.01$) and scaled ($r = -0.404$, $p < 0.05$) squat performance, and relative ($r = -0.324$, $p < 0.05$) pull-up performance.

Overall, absolute 1RM in the squat (113.2 ± 20.4 kg) was significantly higher than absolute bench press 1RM (87.6 ± 16.5 kg) ($p < 0.001$). Blue belts had a significantly higher absolute squat 1RM than purple belts (121.1 ± 24.4 kg vs. 102.1 ± 14.7 kg, $p < 0.05$). These groups also tended ($p = 0.07$) to differ in scaled squat performance. No other relationships between rank and any anthropometric or physiological measurement were detected ($p > 0.05$). Subjects who reported to do regular strength training in addition to BJJ had a 93.1 ± 15.8 kg bench press 1RM, which was significantly higher than the 82.6 ± 15.9 kg 1RM among those who reported no additional strength training ($p < 0.05$). The discrepancy in bench press strength was the same when applying allometric principles ($p < 0.05$). No other differences between the groups were detected. Further, no differences in any anthropometric or physiological measurement were observed among those who reported additional conditioning training compared to those who did not ($p > 0.05$).

Purple belts reported a BJJ training volume of 10.5 ± 5.0 hours/week, which was significantly higher than both white belts (7.3 ± 2.5 hours/week) and blue belts (7.0 ± 2.8 hours/week) ($p < 0.05$). In general, athletes who preferred to train in the gi had the highest BJJ training volume with 9.0 ± 3.7 hours/week, which was significantly higher than the 6.0 ± 1.4 hours/week among those who preferred no gi ($p < 0.01$), and tended ($p = 0.08$) to be higher than the 6.0 ± 1.6 hours/week among those with no style preference. Total BJJ training experience correlated with rank ($r = 0.569$, $p < 0.001$), and both rank ($r = 0.578$, $p < 0.001$) and BJJ training experience ($r = 0.637$, $p < 0.001$) correlated with competition volume.

DISCUSSION

The aim of this study was to describe anthropometric and physiological characteristics of BJJ athletes. This is the first study using gold standard measurements of $\dot{V}O_{2\max}$ and maximal strength expressed as absolute, relative, and mass-independent values in BJJ athletes, providing novel normative data for this population. The main findings were that BJJ athletes had an average of 12.9 % BF; a $\dot{V}O_{2\max}$ of $50.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; a squat 1RM of 113.2 kg, $\sim 1.3x m_b$; a bench press 1RM of 87.6 kg, $\sim 1x m_b$; and the ability to do 9 pull-ups. Unsurprisingly, aging was associated with a reduction in $\dot{V}O_{2\max}$ and several expressions of strength, while rank had no apparent effect on any anthropometric or physiological measurement, with the exception of squat performance in favor of the lower rank (blue vs. purple), despite differences in weekly BJJ training volume.

Body composition can have considerable implications for performance in weight class sports such as BJJ, affecting both weight class allocation and physiological responses to BJJ combat. Thus, maintaining a lean physique is important for the competitive grappler (30). According to BIA, the athletes in the present study had a mean BF of ~ 13 %, which can be considered lean (21). Other studies using BIA in BJJ athletes have reported BF percentages from 9.1 % (13) to 15.7 % (38).

When merging different measurement procedures, BJJ athletes appear to have an average BF of ~12 % (5). As such, the present study exhibits consistency with previous findings.

The athletes demonstrated normal pulmonary function and breathing reserve. In healthy subjects, pulmonary limitations of $\dot{V}O_{2\max}$ in the normal range during exercise at sea level are rare (47). As D_{LCO} correlated with all expressions of $\dot{V}O_{2\max}$, some subjects might have had a degree of pulmonary diffusion limitation at maximal work rate, which could have impacted arterial oxygen saturation and consequently oxygen delivery to the working muscles. However, because hemoglobin concentration was not controlled for, the potential causes of the low-normal D_{LCO} measurements remain unknown.

Despite engaging in an aerobic sport, improvements in oxygen transport and utilization following BJJ training appears limited, as indicated by the athletes' $\dot{V}O_{2\max}$. With an approximate $\dot{V}O_{2\max}$ of $50 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, about 8 % higher than the general population (14), the athletes can be described as recreationally trained (12). This, however, should not be confounded with a lack of importance of this attribute in BJJ. Previously, researches have suggested emphasizing the development of anaerobic endurance in BJJ athletes (30). However, capacity and power of the energy systems are inversely related, where the capacity of the anaerobic systems are limited by rapid reductions in stored PCr and the onset of metabolic acidosis, and the power of the aerobic system is limited by oxygen supply and/or demand (19). Anaerobic capacity, while trainable, represents a distinctly finite source of energy (19, 44). Conversely, aerobic ATP resynthesis is more limited in rate than capacity, with considerable potential for rate improvement via efficient aerobic exercise (23, 24).

Although high levels of $[\text{La}^-]_b$ following simulated and official BJJ competition indicate a considerable reliance on anaerobic metabolism (1), $[\text{La}^-]_b$ appears to decrease with consecutive BJJ matches (4). This could be caused by reduced work rate due to PCr depletion

and inhibition of the glycolytic pathway, indicating the limitations of anaerobic energy contribution during BJJ. An increased ability to utilize oxygen at high intensities lowers the metabolite response and improves recovery during intermittent exercise such as BJJ (42). However, despite the potential implications of $\dot{V}O_{2\max}$ for BJJ performance, practicing the sport alone does not appear to produce improvements significantly beyond the population average. The apparent absent effect of rank and BJJ training volume on this variable further contributes to the notion of a ceiling effect in BJJ in terms of developing $\dot{V}O_{2\max}$. The cause of a such a limitation could be multifactorial.

Ground fighting, where the athlete is in a supine or semi-supine position, is a major part of BJJ combat. Body position affects the kinetics and magnitude of the ventilatory and circulatory responses to exercise, which in turn can impact adaptations. At submaximal intensities, stroke volume (SV) and cardiac output (\dot{Q}) are augmented in the supine position due to reduced hydrostatic pressure, which appears to compensate for the gravitational factors impacting muscle blood flow and thus resulting in similar submaximal $\dot{V}O_2$ compared to upright exercise (33). However, at maximal work rate, $\dot{V}O_{2\max}$, HR_{\max} , and $\dot{V}O_2$ kinetics are reduced in the supine position, accompanied by an earlier onset of lactate accumulation (33, 41). The latter could reflect an increased anaerobic energy yield as a consequence of attenuated $\dot{V}O_2$ kinetics, as rapid $\dot{V}O_2$ kinetics is important to reduce the initial oxygen deficit and thus the impact on muscle pH (39). As such, positions inherent to ground fighting can reduce both maximal work rate as well as aerobic energy yield. Because $\dot{V}O_{2\max}$ affects the speed of $\dot{V}O_2$ kinetics (40), BJJ athletes with a high $\dot{V}O_{2\max}$ could have a major advantage in matches with multiple variations in intensity due to more rapid adjustments to changes in metabolic demand.

In addition to the potential physiological impact of body position, the degree of intermittency and high volume of low intensity efforts, as well as the reliance on energy-conserving strategies and techniques involving skeletal structures, timing, and leverage, can further impact the exercise response in BJJ. Maintaining a high exercise intensity for sufficient periods, i.e. > 3 minutes, has been shown to be essential for effective cardiovascular adaptations (23, 36). Thus, the effort characteristics of BJJ combat might negate adaptations above a certain level of $\dot{V}O_{2max}$, as high-intensity efforts typically only last ~3 seconds (1). Interestingly, despite a lower effort/pause ratio of 2-3:1 (16, 35), grappling-based combat sports such as judo and wrestling tends to produce athletes with slightly higher $\dot{V}O_{2max}$ (10, 17). Possible explanations for these differences could be the ratio of upright to supinated positions, a higher volume of high-intensity efforts, and/or increased \dot{Q} due to greater muscle mass involvement.

In addition to $\dot{V}O_{2max}$ and lactate threshold, the oxygen cost of exercise is considered to be one of the most important determinants of aerobic endurance performance (37). Due to the nature of BJJ, directly assessing the cost of exercise is challenging (4). However, as improvements in motor skill can lead to reduced metabolic cost of movement (27), technical proficiency has implications for sport-specific endurance. As such, discrepancies in the oxygen cost of common techniques might explain differences in grappling endurance between higher and lower belts, despite a similar $\dot{V}O_{2max}$. The oxygen cost of submaximal running was assessed as part of the CPET in the present study. A similar assessment has previously been used in university students of comparable size and baseline fitness levels (23). Compared to these students, the BJJ athletes had ~11 % poorer C_R . However, there is no inherent need for non-competitive runners to improve C_R .

In fact, it could even be counterproductive as it would reduce the energy cost at a given running speed and consequently impact training intensity (45). Thus, a poor C_R is not detrimental to BJJ athletes wanting to expend energy to reduce m_b and/or improve $\dot{V}O_{2max}$ via running.

Maximal strength can benefit the athlete in several aspects of BJJ, such as in improving position or preventing submission (11). Additionally, increased maximal strength reduces the fraction of maximal force required to perform a given movement, which can reduce the oxygen cost of exercise and thus improve aerobic endurance performance (25). It has been suggested that 1RM in the bench press can be used to distinguish between advanced and non-advanced BJJ athletes (11). Further, some research indicate that BJJ emphasizes upper-body strength, with athletes appearing to perform better in the bench press than the squat (15). This was not the case in the present study, as the athletes were significantly stronger in the squat. Compared to the available data on maximal strength in BJJ, the athletes generally performed better in the squat and slightly worse in the bench press (5). However, as the bench press was performed with a marked stop between the eccentric and concentric phase, the actual strength discrepancy might be smaller than the data suggest. The relationship between maximal strength and performance, e.g. match outcome, has yet to be thoroughly investigated in BJJ (5, 15). In grappling sports such as wrestling (10) and judo (17), however, there appears to be a relationship between maximal strength and competition success. This suggests that, at least in stand-up grappling, maximal strength in multi-joint exercises can affect match outcome.

Muscular endurance as determined by pull-up performance has previously been associated with competition success in wrestlers (10). The average number of repetitions achieved by the athletes in the present study were considerably lower than those often observed in wrestlers, with studies reporting over 30 repetitions in successful senior wrestlers

(34). However, due the considerable influence of variations in m_b , caution should be taken when comparing pull-up performance (46). Despite using allometric equations to reduce the impact of m_b , m_b correlated inversely with all expressions of pull-up performance in the present study. As maximal strength appears to be more closely related to muscle cross-sectional area than dynamic muscular endurance, the application of allometric scaling differs for measurements of mass-relative repetitions to failure and 1RM (46). Thus, comparisons of mass-relative muscular endurance in grapplers are likely more appropriate between athletes in the same weight class.

The fact that nearly half of the subjects did additional strength training, and ~25 % did additional conditioning training, suggests a willingness to improve their level of fitness. However, these athletes produced similar results as those who did BJJ exclusively. As such, they might not have had an optimal approach to strength and conditioning, which highlights the importance, and perhaps lack, of proper training strategies in this population. Interestingly, although purple belts reported the highest weekly BJJ training volume, they did not perform better in any anthropometric or physiological measurement, and even did worse than blue belts in the squat. Thus, despite a 40 to 50 % higher BJJ training volume compared to white and blue belts, purple belts appeared no more fit. Interestingly, only 20 % of the white belts did additional strength and/or conditioning training, the least of all, but were seemingly just as fit as the other ranks. This could be partly due to the comparably low technical proficiency of a white belt, causing them to rely more on physical effort and less on technique, which could lead to a greater exercise response.

BJJ is a sport that has been developed with an emphasis on technique and strategy (20). This might cause some athletes to neglect the importance of improving their physical abilities. As athletes are typically matched up against opponents of similar size and skill level in competition, physical ability can be what separates winners from losers.

Interestingly, Andreato et al. (3) observed an increased number of effective attacks in the last match of a simulated BJJ tournament, and suggested that cumulative fatigue could be the cause, as it likely compromised defensive techniques. As such, it is reasonable to assume that the more well-trained athlete would be better able to sustain performance in the later stages of individual matches and in tournaments. Attributes such as $\dot{V}O_{2max}$, maximal strength and muscular endurance can all impact fatigue, and they can all be improved with efficient training (23-25). As the present study did not differentiate athletes based on their level of performance, such as competition success, the degree of impact these attributes have on BJJ performance has yet to be thoroughly explored.

The distribution of rank in the study sample was skewed towards the lower belts. However, belts are a subjective estimation of skill and not necessarily indicative of proficiency. Several participants had opted to not undergo the belt tests required to advance in rank. Four participants, due to not training in the gi, had never even received a belt despite several of them having more than a decade of training and competitive experience at both national and professional levels. On average, the athletes had trained BJJ for ~5.5 years, with a volume of ~8 hours/week at the time of this study. To achieve a representative sample, only athletes with a certain level of training experience were included, with competitive experience being used as an additional qualifier for athletes with the least training experience. The general lack of differences in physiological measurements between ranks observed in this and other studies (5), indicates that the present findings are applicable to the general BJJ population.

In summary, this study provides novel insight into the fitness levels of BJJ athletes. Although the degree of impact these characteristics might have on performance remain to be fully elucidated, these data provide normative values that can be applied in athlete assessment and exercise prescription in this population.

PRACTICAL APPLICATIONS

This study describes key anthropometric and physiological characteristics of a typical BJJ athlete. The level of $\dot{V}O_{2\max}$ indicates a limited efficacy of BJJ for developing aerobic endurance. This observation highlights an area of considerable potential for improvement in these athletes. Previous investigations have suggested emphasizing anaerobic endurance (30), and simulating sport-specific intensity as a conditioning approach for BJJ athletes (2, 4, 29). However, it is important to distinguish between the principle of specificity and training that is designed to elicit improvements in single performance components, such as $\dot{V}O_{2\max}$. Thus, strength and conditioning programs that targets specific components, rather than mimic the characteristics of the sport, is often preferable. For instance, high-intensity, upright exercise using large muscle groups could be implemented as a low-volume adjunct to BJJ training to effectively increase $\dot{V}O_{2\max}$ (23). Further, multi-joint exercises using heavy loads and few repetitions could be used to achieve rapid improvements in maximal strength, power, and work economy (25). The specific intensity, volume, frequency, and type of strength and conditioning training should be tailored to the baseline fitness level and goals of each individual athlete.

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ACKNOWLEDGEMENTS

The author would like to thank the athletes that participated in this study.

Tables

Table 1 Anthropometry, pulmonary function, and training habits

Table 2 Maximal oxygen uptake, running economy, maximal strength, and muscular endurance

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Table 1 Anthropometry, pulmonary function, and training habits

	Mean \pm SD	Range
Age (years)	32 \pm 6	23 - 46
Height (cm)	181.9 \pm 7.2	161.5 - 202.5
Body mass (kg)	85.7 \pm 10.6	67.6 - 114.1
Fat-free mass (%)	87.1 \pm 5.3	74.6 - 95.7
Body fat (%)	12.9 \pm 5.3	4.3 - 25.4
FVC (L)	5.7 \pm 0.7	4.4 - 7.5
FEV ₁ (L)	4.6 \pm 0.5	3.5 - 5.9
FEV ₁ /FVC (%)	81 \pm 6	63 - 91
MVV (L·min ⁻¹)	196.3 \pm 26.1	134.0 - 266.0
D _{LCO} (mmol·min ⁻¹ ·kPa ⁻¹)	13.9 \pm 1.8	10.8 - 19.0
BJJ experience (years)	5.5 \pm 3.7	0.8 - 18.0
BJJ training weekly (hours)	7.8 \pm 3.4	4.0 - 22.0
BJJ tournaments competed in (n)	7 \pm 10	0 - 40
Competitors (%)	79	
Non-competitors (%)	21	
BJJ style preference		
Gi (%)	62	
No gi (%)	29	
No preference (%)	9	
Strength and conditioning training		
Strength (%)	48	
Conditioning (%)	24	

Continuous data are presented as mean \pm SD. Categorical data are presented as frequencies (%). FVC, forced vital capacity; FEV₁, volume exhaled during the first second of forced expiration; MVV, maximal voluntary ventilation; D_{LCO}, diffusing capacity of the lung for carbon monoxide; BJJ, Brazilian jiu-jitsu.

Table 2 Maximal oxygen uptake, running economy, maximal strength, and muscular endurance

	Mean \pm SD	Range
$\dot{V}O_{2max}$		
L \cdot min ⁻¹	4.30 \pm 0.46	3.60 - 5.69
ml \cdot kg ⁻¹ \cdot min ⁻¹	50.6 \pm 4.6	39.5 - 60.5
ml \cdot kg ^{-0.75} \cdot min ⁻¹	153.3 \pm 12.3	128.9 - 185.9
% of age-expected	108 \pm 10	81 - 131
HR _{max} (beats \cdot min ⁻¹)	191 \pm 10	166 - 211
\dot{V}_E (L \cdot min ⁻¹)	152.1 \pm 18.6	118.5 - 196.5
Breathing reserve (%)	24 \pm 9	7 - 42
[La ⁻] _b (mmol \cdot L ⁻¹)	13.30 \pm 2.68	7.64 - 18.99
RER	1.22 \pm 0.07	1.09 - 1.36
Borg rating	18 \pm 1	16 - 20
Running economy		
$\dot{V}O_2$ (ml \cdot kg ^{-0.75} \cdot m ⁻¹)	0.90 \pm 0.08	0.75 - 1.06
HR (beats \cdot min ⁻¹)	157 \pm 14	123 - 184
RER	0.96 \pm 0.04	0.86 - 1.06
Squat		
1RM (kg)	113.2 \pm 20.4	70.0 - 150.0
1RM (kg \cdot m _b ⁻¹)	1.3 \pm 0.2	0.8 - 1.9
1RM (kg \cdot m _b ^{-0.67})	5.8 \pm 1.0	3.5 - 8.0
Bench press		
1RM (kg)	87.6 \pm 16.5	60.0 - 140.0
1RM (kg \cdot m _b ⁻¹)	1.0 \pm 0.2	0.7 - 1.7
1RM (kg \cdot m _b ^{-0.67})	4.5 \pm 0.8	3.0 - 7.4
Pull-ups		
RM	9 \pm 4	2 - 19
RM (kg \cdot m _b ⁻¹)	0.1 \pm 0.1	0.02 - 0.2
RM (kg \cdot m _b ^{0.33})	40.0 \pm 16.6	8.8 - 80.0

Data are presented as mean \pm SD. $\dot{V}O_{2max}$, maximal oxygen uptake (reference values from Edvardsen et al. (16)); HR_{max}, maximal heart rate; \dot{V}_E , pulmonary ventilation; [La⁻]_b, blood lactate concentration; RER, respiratory exchange ratio; 1RM, one-repetition maximum; RM, repetition maximum.