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Heart Rate, Oxygen Uptake, and Anaerobic Thresholds During a Maximal Treadmill Test with World Class Mixed Martial Arts Fighters

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Measuring heart rate responses during a competitive mixed martial arts (MMA) fight is not feasible; therefore, a method is needed to assess physiological responses in MMA fighters outside of competition. Quantifying and evaluating heart rate, oxygen uptake, and anaerobic threshold during a maximal treadmill test can provide interpretation for in-competition physiological responses of MMA fighters. The retrospective analysis was conducted on 20 world-class MMA fighters predating the beginning of their fight camps (ages 29.0 ± 4.8 years old). A maximal treadmill test utilizing a ramp protocol was conducted eight weeks prior to a professional competition. Fighters' data were divided in two groups based on weight status: lighter, < 185 pounds ($n = 12$) and heavier, ≥ 185 pounds ($n = 8$) weight groups. Heart rate (HR), anaerobic thresholds from respiratory exchange rate (RER-AT), and oxygen uptake (VO_{2max}) were recorded and compared between weight groups. VO_{2max} was the only physiological variable measured that differed between lighter (53.4 ± 4.5 ml · kg^{-1} · min^{-1}) and heavier (48.1 ± 5.7 ml · kg^{-1} · min^{-1}) fighters ($p = 0.033$). Previous literature has commonly used 1.0 RER to determine the breaking point in anaerobic thresholds. All other variables were not different ($p \geq 0.204$) between groups. Differences in VO_{2max} between lighter and heavier fighters are likely due to differences in body mass. While there were no differences in heart rates at RER-AT or time to exhaustion between weight status groups, using RER-AT at 0.95 or 1.0 RER may be a valuable way to ensure an MMA athlete achieve anaerobic training in fight preparation. Performance coaches may utilize physiological variables such as RER-AT acquired from maximal treadmill testing to guide the training demands of MMA competition.

Keywords: performance, energy systems, high-intensity training, competition, mixed martial arts

Introduction

There are currently no studies to assess elite mixed martial arts (MMA) fighters' physiologic capacity and physiological limits prior to a competitive fight camp. Therefore, the purpose of the study was to assess peak physiological performance in elite MMA fighters assessed via a maximal treadmill exercise test and to determine if there is a difference in physiological performance, anaerobic thresholds from respiratory exchange rate (RER-AT), and minutes to exhaustion beyond the RER-AT between fighters that fight above and below the 185-pound (83.9 kilogram) weight class.

MMA is an aggregate of striking and grappling combat sports. Combat sport athletes might compete in MMA, boxing, kicking boxing, jiu-jitsu, wrestling, or even karate (Noh et al., 2015; Siqueido, 2010). MMA fighters must engage in a unique combination of physiological training to develop their aerobic and anaerobic energy systems (Alm & Yu, 2013; James et al., 2016; Kirk et al., 2020; Lachlan et al., 2018; Peacock et al., 2018). MMA bouts last 15 to 25 minutes with championship fights consisting of five 5-minute rounds and non-championship fights consisting of three 5-minute rounds. Although the anaerobic system is predominant in MMA, fighters must have great reliance on a well-trained oxidative (aerobic) energy system (Kirk et al., 2020). Training aerobic energy systems is beneficial for autonomic function and heart rate recovery in elite athletes (Daanen et al., 2012). Improved autonomic function can lead to benefits for MMA fighters that would improve heart rate recovery in between rounds as well as recovery between workouts. To this end, performance coaches must be able to ensure that athletes are training at specific physiologic levels to achieve optimal training (Daanen et al., 2012).

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Throughout competition, fighters will execute intense moves in close proximities and short durations, such as striking the opponent, thus utilizing their phosphocreatine-adenosine triphosphate (PCr-ATP; anaerobic) energy system (Alm & Yu, 2013; Lachlan et al., 2018). Combat athletes must train both energy systems to be able to compete throughout a full-length competition, as well as be highly impulsive or reactive to upper and lower body strikes, as well as grappling (Noh et al., 2015). Combat fighters are not able to wear heart rate monitors and other forms of wearable technology during competitive fights; therefore, competition-based heart rate and other physiological workloads are not known, which is a challenge for performance coaches. Understanding aerobic and anaerobic thresholds of fighters prior to prefight training can improve training considerations and strategies made by performance coaches. Conducting maximal performance tests to measure oxygen capacity and other physiological variables is a non-invasive method that can inform MMA skill coaches, physiotherapists, and performance coaches how to adequately stress an athlete's energy system.

The physiological demands of MMA athletes during competition are relatively unknown and may differ based on weight class. Internal monitoring via heart rate sensors are not worn during elite competition, and heart rate is a key performance indicator to help optimally prepare for competition (Kirk et al., 2020). A recent study examining the heart rate of combat athletes in training found that heart rate and maximum heart rate (HR_{max}) significantly increased in successive combat rounds, but this was not assessed in MMA athletes, only boxers, kickboxers and taekwondo competitors (Slimani et al., 2018). Further, HR_{max} during combat sports has been reported to range between 83% to 100% of an athlete's HR_{max}, but differences may occur depending on the specific combat sport, such as judo, taekwondo, and karate (Slimani et al., 2018). Another study recorded heart rates of amateur fighters between matches and found sustained high heart rates after each match; the average heart rate taken after each match was 176 beats per minute (Petersen & Lindsay, 2020). Combat sports place a high level of internal stress on the cardiovascular system; however, recording heart rate values alone does not translate to proper training thresholds for energy system development. Further, identifying if training thresholds are different based on weight status can allow practitioners to better approach training for heavy weight and non-heavy weight fighters.

Mixed martial arts fighters vary in size (Peacock et al., 2022) and must have the ability to sustain intense cardiorespiratory work. Maximal oxygen uptake (VO_{2max}) is a key determinant when assessing an individual's level of cardiorespiratory fitness (Kirk et al., 2020; Poole & Jones, 2017). A study on the physiological characteristics of competitive MMA fighters found the VO_{2max} of a few different combat sport athletes (Kirk et al., 2020; Schick et al., 2010; Siqueido, 2010). Black belt karate athletes were found to have a VO_{2max} of 575 ml · kg^{-1} · min^{-1}, white belt karate athletes were found to have a VO_{2max} of 572 ml · kg^{-1} · min^{-1}, and England International boxers were found to have a VO_{2max} of 638 ml · kg^{-1} · min^{-1} (Slimani et al., 2017; Slimani et al., 2018). Untrained males are considered to have a healthy VO_{2max} at 40 ml · kg^{-1} · min^{-1} and are considered excellent at 50 ml · kg^{-1} · min^{-1} (Slimani et al., 2017; Slimani et al., 2018). MMA fighters have been reported to have VO_{2max} greater than 55 ml · kg^{-1} · min^{-1} (Alm & Yu, 2013; Schick et al., 2010).

In addition to VO_{2max}, a treadmill test can be a simple, non-invasive way to assess RER-AT and has been found to be comparable to blood lactate concentrations (Solberg et al., 2005). Individually assessing RER-AT is a validated way for coaches to determine heart rate intensities for optimal training that develops or accurately stimulates training to achieve desired physiological adaptations to enhance aerobic capacity and improve anaerobic conditioning (Ghosh, 2004). Research has suggested an RER of .95 or 1.0 is indicative of estimating anaerobic threshold (Ghosh, 2004; Solberg et al., 2005).

Methods

Participants

A total of 20 professional MMA fighters participated in this retrospective study (ages 29.0 ± 4.8 years old). Fight camps are typically eight weeks in duration (Kirk et al., 2020). MMA fighters prepare physiologically through sparring rounds, prepare their MMA disciplines through drilling or skills training, and prepare their fight IQ using training partners who attempt to mimic their opponent's array of techniques. Lighter weight classes include Flyweight (125 pounds, 57 kg), Bantamweight (135 pounds, 61.2 kg), Featherweight (145 pounds, 65.8 kg), Lightweight (155 pounds, 70 kg), and Welterweight (170 pounds, 77.1 kg). Heavier weight classes include Middleweight (185 pounds, 83.9 kg), Light Heavyweight (205 pounds, 93 kg), and Heavyweight 265 pounds, 120.2 kg). All fighters in the study were physically cleared by a physician prior to the maximal treadmill test, which occurred directly before their fight camp in preparation for a professional fight. The fighters provided informed consent for researchers to use their de-identified data. After informed consent, fighters reported their age, while their height and weight were measured (Table 1). All athlete data were de-identified prior to the researchers' obtainment and the University Institutional Review Board approved the study and analysis.

Table 1. Age, Height, and Weight for All Athletes and by Non-Heavy Weight and Heavyweight Classification

	All Athletes $n = 20$	Lighter < 185 lbs. $n = 12$	Heavier ≥ 185 lbs. $n = 8$
Age, Years	29.0 ± 4.8	27.7 ± 3.3	31.0 ± 6.1
Weight (kg)	85.6 ± 13.9	76.3 ± 8.7	99.5 ± 6.0
Height (cm)	180.6 ± 10.1	175.2 ± 8.0	188.7 ± 7.1

Note: Data are mean ± *SD*; *Significant difference, $p \leq 0.001$ for all.

Protocol

The data were a retrospective analysis of tests results for fighters as they prepared for the pre-fight preparation camp. Prior to the beginning of the fighters' eight-week camp, athletes were maximally tested on a treadmill and physiological measurements were recorded throughout. Prior to the treadmill tests, athletes completed a 10-minute warm-up at a self-selected pace. Once the athlete indicated they were ready to perform, a VO_2 mask and head strap were appropriately secured and connected to a calibrated metabolic cart (Pravo Medics, Truemax 2400, UT, USA) with an integrated heart rate monitor (Polar Global, Kempele, Finland) synced to the cart. Athletes participated in a modified ramp protocol that began with a two-minute walk at 3.5 mph (5.6 km/h) and a 6% grade. Following the initial phase, the speed increased to 6.0 mph (9.7 km/h) and then increased 1.0 mph (1.6 km/h) every two minutes until the athlete reached volitional fatigue (completion of tests ranged from 7-12 minutes). While utilized in previous research, the 6% grade stayed constant throughout the test. The athletes' respiratory exchange ratios (RER) were 1.17 ± 0.05, which was acceptable for maximal oxygen uptake tests, and the protocol has previously been utilized with high-level athletes (Sanders et al., 2019, 2021, 2022). Oxygen consumption was measured using 15-second intervals and oxygen consumption was reported as the highest relative VO_2 in $ml \cdot kg^{-1} \cdot min^{-1}$. Heart rate was reported as beats min^{-1} (BPM) and HR_{peak} was reported as the highest heart rate achieved at any point throughout the test (Poole & Jones, 2017).

After the test was completed, the following physiological variables were assessed to better identify performance, potential anaerobic threshold, and to determine time to exhaustion once specific RER thresholds were achieved. Maximum values for VO_2 (VO_{2max}), RER (RER_{peak}), and HR_{peak} were recorded. Then RER-AT of 0.95 and 1.0 were reported and included the athlete's corresponding HR and percent HR_{peak} at each RER threshold. RER thresholds of .95 and 1.0 were used, as previous research suggest these are good indicators of anaerobic thresholds for athletes and can predict heart rate ranges to optimize performance (Ghosh, 2004; Solberg et al., 2005). Lastly, minutes running on the treadmill after each RER threshold (minutes above RER 0.95, 1.0, and total time to exhaustion) was included to indicate how long these athletes can push beyond an anaerobic threshold. It is likely MMA athletes must be able to push beyond anaerobic thresholds in competitive fight scenarios.

Statistical Analysis

Descriptive statistics (means and standard deviations) were calculated for physical characteristics and all physiological and performance variables throughout the test (see Table 2). Data was divided into two groups: one lighter weight group competing under the 185-pound weight class and one heavier group competing at or above the 185-pound weight class. The 185-pound weight class (Middleweight), and above (Light Heavyweight and Heavyweight) are distinguished as larger sized fighters in the field. Independent samples *t*-tests were utilized to determine if differences existed between groups. Cohen's *d* for estimates of effect size was provided for all testing variables compared between light and heavier fighters. All statistics were analyzed using IBM SPSS 28.0 (version 28.0, IBM Inc., Armonk, NY). The criterion for statistical significance was set a priori at $p \leq 0.05$.

Table 2. Physiological and Performance Variables by Group Based on the VO_{2peak} Treadmill Test

	All Fighter ($N = 20$)
VO_{2max} (ml · kg^{-1} · min^{-1})	51.3 ± 5.6
RER_{peak}	1.2 ± 0.1
HR_{peak} (BPM)	182.5 ± 8.1
HR at .95 RER (BPM)	160.8 ± 9.3
HR at 1.0 RER (BPM)	167.2 ± 9.5
$\%HR_{peak}$ at .95 RER	88.1 ± 4.0
$\%HR_{peak}$ at 1.0 RER	91.6 ± 4.2
Minutes running at .95 RER	3.1 ± 0.8
Minutes running at 1.0 RER	2.3 ± 0.8
Minutes to Exhaustion	8.1 ± 1.0

Note: Data are mean ± *SD*

Results

Results of the independent *t*-test revealed there was a significant difference in VO_{2max} between the lighter weight class and heavy weight class groups (see Table 3, $t = 2.303$, $p = 0.033$). There were no other differences in any physiological performance variable assessed via the treadmill test between groups (see Table 3, $p \geq 0.204$ for all).

Table 3. Physiological and Performance Variables by Group Based on the VO_{2peak} Treadmill Test

	Lighter < 185 lbs.	Heavier ≥ 185 lbs.	*p*-value	Effect Size (Cohen's d)
VO_{2max} (ml · kg^{-1} · min^{-1})	53.4 ± 4.5	48.1 ± 5.7	0.033	1.05
RERpeak	1.2 ± 0.0	1.2 ± 0.1	0.204	-0.60
HRpeak (BPM)	184 ± 9.5	180.4 ± 5.4	0.386	0.44
HR at .95 RER (BPM)	160.6 ± 10.1	161.1 ± 9.0	0.911	-0.06
HR at 1.0 RER (BPM)	167.2 ± 9.9	167.2 ± 9.7	0.998	-0.001
%HRpeak at .95 RER	87.3 ± 3.6	89.3 ± 4.7	0.321	-0.51
%HRpeak at 1.0 RER	90.9 ± 3.4	92.7 ± 5.2	0.395	-0.43
Minutes running at .95 RER	3.1 ± 1.0	3.0 ± 0.5	0.794	0.12
Minutes running at 1.0 RER	2.4 ± 0.9	2.2 ± 0.7	0.535	0.29
Minutes to Exhaustion	8.1 ± 0.8	8.2 ± 1.3	0.804	-0.12

Note: Data are mean ± *SD*; *p*-values and effect sizes provided for each comparison.

Discussion

The primary findings of the study identified a 10.4% difference in maximal oxygen uptake between fighters competing at weights < 185 pounds and heavier fighters competing at weights ≥ 185 pounds. Between the groups, there were no other differences in physiology and performance testing numbers. Regardless of weight, MMA fighters are presented with unique metabolic demands when training and competing inside the cage. The rigors of fighting may not be accurately indicated on a continuous treadmill test. Maximum oxygen uptake from the elite, professional fighters (e.g., some fighters measured were world champions) in the current study had a VO_{2max} of 48.1 - 53.4 ml·kg^{-1}·min^{-1}. These results slightly varied from previous research that reported that VO_{2peak} in elite fighters was 55.5 and 50.6 ml·kg^{-1}·min^{-1} in one study (Barbier, 2020; Schick et al.,

2010) and 62.75 ± 4.86 ml·kg^{-1}·min^{-1} in a separate study (Alm & Yu, 2013). While these studies assessed elite fighters, the exact level of fighter is not known (James et al., 2016). In the current study, the fighters competed in the UFC and Bellator, which is the highest level of MMA fighting in the world.

Previous studies did not identify the current training status of the fighters (e.g., stage of fight preparation; Kirk et al., 2020). Fighters in the current study were preparing for a fight eight weeks before their respective competition. Therefore, the other data might be different immediately before a fight compared to an offseason treadmill test. Nevertheless, establishing objective anaerobic thresholds for fight training, primarily as a fight nears, may help fighters optimally train and push anaerobic threshold (Kirk et al., 2020). In the current study, according to RER ranges at 0.95 and 1.0, which likely indicate AT, fighters became more anaerobic at 91-93% of the HR_{max}, which was an average heart rate near 167 BPM. While fighters' average RER and HR levels were reported, individualized thresholds can be easily obtained via a maximal metabolic test on a treadmill for a better use of HR training zones designed to enhance both aerobic and anaerobic conditioning (Ghosh, 2004).

The lack of differences between lighter and heavier groups for all variables except VO_{2max} can be explained, as the primary VO_{2max} limiting factor is cardiac output and body mass and, therefore, body mass can further limit VO_{2max} when other variables are similar (Bassett & Howley, 2000). The data may have implications for MMA fighters due to the higher number of total strikes thrown in the lighter weight classes compared to the heavier weight classes. All other variables such as RER, HR, and time to exhaustion are not as dependent on mass. Because MMA fighting is not an aerobic sport, it is recommended for athletes to optimally stress the anaerobic system to meet the demands of competition (Ghosh, 2004). Previous research suggests MMA consists of work-to-rest ratios of 1:2-1:4 and high intensity work lasting 6-14 seconds (del Vecchio et al., 2011; James et al., 2016). While researchers have a general indicator of work and ideal training zones, Kirk. et al. (2020) suggests more research is needed to identify the physical demands of actual combat training and competition. Until physical demands of competition are known, measuring VO_{2max} to obtain information about fighters' AT, using the RER-AT is a viable option to stress AT and improve cardiorespiratory conditioning.

Time to exhaustion is the amount of time a runner can maintain a certain pace before they are unable to continue. It is a measure of a runner's fitness and is often used to track progress over time. Both time to exhaustion and time running beyond an RER of 0.95 and 1.0 are provided in Table 3. This metric can be valuable for performance coaches to develop conditioning protocols that aim to train athletes at HR intensities designed to elicit a RER-AT response. Over time, stressing the RER-AT can produce a favorable training response, allowing the MMA athletes to compete beyond RER-AT for a longer period of time, thus potentially increasing the likelihood of a winning performance. Performance coaches can utilize physiological variables associated with maximal treadmill testing by correlating HR response at RER-AT to design optimal conditioning programs. HR response at RER-AT can better inform performance coaches to train above and below HR thresholds and ensure performance coaches are stressing the proper energy systems to achieve desired adaptations. Further, understanding HR response can help specify nutritional strategies to fuel MMA fighters for the demands of the training session.

While the study provides valuable information for practitioners and fighters to better understand the physiological makeup of elite MMA fighters, the data is not without limitations. First, there were only 20 subjects total, and there are a total of eight weight classes for males and four classes for females. Additionally, performance tests and data are required to better describe physiological performance across weight classes for males and females, as previously literature supports differences across weight classes for weight cuts (Peacock et al., 2022). Further, the data holds limitations on specific training regimens related to the fighters, as well as dietary considerations that can affect RER-AT during a maximal treadmill test. The current data and information may be valuable if compared to live sparring or fight scenario training, which would help identify if these thresholds are valuable indicators of intensity when fighters engage in training sessions aimed to mimic competition fighting.

Conclusion

The data presented in this study is the first to describe RER-AT parameters for elite, world-class fighters eight weeks prior to competition. For performance coaches, the study presents AT assessed via an objectively measured metabolic test that can create a guide for optimal high-intensity training to meet anaerobic demands of MMA training. This data may be valuable for MMA fighters, MMA skill coaches, and performance coaches to meet the demands of in-competition physiological demands. Additional research is needed to better understand the physiological demands of competition, which would vastly improve cardiovascular training for MMA athletes.

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Authors' Note

The authors declare no conflict of interest.

Although de-identified, the datasets analyzed during the current study are not publicly available due to the fighters' request not to disclose any results of their performance test for competitive reasons.