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Original Research

Developing a Comprehensive Testing Battery for Mixed Martial Arts

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ABSTRACT

International Journal of Exercise Science 14(4): 941-961, 2021. Mixed martial arts (MMA) is a combat sport that employs techniques from different combat disciplines. There are a multitude of technical and physiological characteristics that contribute to competitive success. Developing a single scientific assessment that can predict competitive outcomes poses great difficulty due to the complexity of MMA. While previous research has investigated some important physiological characteristics, there is no accepted best-practice for a comprehensive testing battery. As such, this study aimed to design and utilize a battery of physiological assessments to cover aerobic and anaerobic function, strength measures including explosive and maximal strength, body composition and repeat effort ability in Australian MMA athletes. Six participants with competitive experience were recruited. Testing involved a familiarization, three experimental sessions and including assessments such as the isometric midthigh pull, Wingate test, graded exercise test, countermovement jump and body composition scan. Results showed the testing battery in this study was realistic and able to be completed by the participants without issue and that regional Australian MMA athletes were similar physiologically to elite standard compared with previous research taken from a range of sources. However, future research with the testing battery is required with larger and more diverse samples to better understand the full profiles of MMA athletes. The results of the study can help inform athletes, researchers and support staff alike when deciding upon which testing protocols to use for MMA athletes. Future research should aim to develop normative data using the battery proposed in the current study.

KEY WORDS: Combat sports, performance assessment, athletic development.

INTRODUCTION

Mixed Martial Arts (MMA) is a combat sport permitting both grappling and striking techniques under a unified ruleset and is comprised of many complicated facets, including technical skill, conditioning and strategic planning (5). Due to the multifactorial nature of MMA, it is difficult to develop a comprehensive assessment of combat sports performance. However, it is possible to assess select physiological and physical characteristics which contribute to competitive success. Strength-based characteristics have been relatively well explored within MMA with previous research finding strength to be a predictor of success and greater competitive level in MMA (30, 32, 34, 35). However, there is a paucity of research investigating repeat effort performance and the underlying physiology in MMA, with much of the relevant research not being in MMA athletes specifically or using field-based tests to estimate relevant physiological function (14, 34, 36). The optimal body composition for MMA is also unclear which is especially important given that it is a weight-restricted sport (1, 16, 43). The lack of clear wholistic data in MMA may stem from the lack of best-practice guidelines for a comprehensive testing battery or the relative novelty of MMA as a global sport.

When deciding which factors to assess, it is important to consider what specifically is entailed in MMA performance. MMA competitions are repeat effort in nature as they involve up to 15 or 25 minutes of activity alternating from high to low intensities with limited recovery times (17). Previous research has reported between a 1:4 to 1:3 and even 1:1 work rest ratio in MMA competition, dependent on whether the one-minute recovery between rounds was included (17, 40). A comprehensive review of the literature by Girard et al. (23) identified the high intensity component of repeat-effort exercise is primarily determined by anaerobic function, even after multiple high-intensity efforts. As such, assessments of anaerobic function such as a Wingate test (WAnT) would likely provide results relevant to MMA performance and while it has been suggested in the past, we are not aware of research that has investigated this test in MMA athletes specifically (56). Performance and recovery during the low-intensity components is driven aerobically (23). As a result, the assessment of maximal oxygen uptake (VO_2max) could plausibly provide important information regarding performance in MMA (1, 33, 34). It is also important to note that aerobic function is not as simple as maximal oxygen uptake. Factors such as anaerobic thresholds including ventilation thresholds have been proposed to be potentially more relevant to MMA performance than VO_2 max, though the veracity of such a statement has not been systematically tested (5). Ventilation thresholds tend to encompass the shift from aerobic to anaerobic and thus will be relevant for performance in the repeat-efforts of MMA (49). Greater aerobic and anaerobic capacities in higher-level athletes competing in other combat sports including judo and wrestling have been observed (3, 21). It is worth noting while some research has investigated VO_2max and metabolic thresholds, this area has not been thoroughly researched (1).

While there is value in understanding the underlying physiology of repeat-effort performance, it is also important to evaluate performance itself. This is because repeat-effort is complicated and has been found by previous research to poorly correlate to many markers of physiology such as VO_2max (5, 10, 22). However, developing an ecologically valid assessment of repeat-effort ability for MMA is difficult because the testing protocol will need to consider many factors such as duration, intensity, recovery, type of resistance and loading. The repeated sled push test (RSPT) was designed with these considerations in mind, as the work to rest ratio noted in MMA of 1:4 in previous research (17). The RSPT includes upper and lower body activation at a given resistance, with phases of activity and recovery. Given these points, the RSPT would plausibly be a suitable candidate to fill the gap in the current literature that exists. However, there is a paucity of research implementing physiologically specific performance tests in MMA, including studies using the RSPT.

Due to MMA allowing athletes from various competitive combat backgrounds to compete under one unified ruleset with multiple paths to victory, there are a wide range of competitive styles within the same sport focusing on different aspects of grappling and striking. As a result, it would not be realistic to expect a sport with such diverse range of skill sets to have a unified profile of preferable physiology or physical characteristics. Comparing separate energy system requirements of different styles of combat sports (e.g. striking-based or grappling-based) may show a vast difference in physiological requirements from the practitioners. For example, Brazilian Jiu Jitsu requires a great amount of isometric strength and muscular endurance while boxing requires high aerobic ability (24). Despite the differences between different combat disciplines, two athletes with vastly different styles could compete within MMA with similar success but divergent physiological profiles. Research attempting to find factors important for MMA is typically conducted by comparing the physiological traits of higher- and lower-level athletes (30, 34). However, such research has focused on markers of strength and power but utilized less robust markers of aerobic function and endurance performance without much consideration for competitive style (6, 34). Understanding such differences will allow for the identification of the characteristics that underpin competitive success. Therefore, the purpose of this study was to design and implement a wholistic performance and physiological testing battery for MMA that could be utilized by future research. Furthermore, it was important to determine that the testing was feasible for athletes to complete within a timely fashion, so it can be incorporated in research and practical settings. The results will provide guidelines for the use of a testing battery for MMA performance that can be implemented by researchers and coaches in the future. Additionally, this study aimed to present a potential method of assessing competitive style.

METHODS

Participants

A total of 6 MMA athletes (two professional and four amateur) over the age of 18 and active in MMA competition within the last two years volunteered to participate in the study. As the primary purpose of this study was to demonstrate a comprehensive testing battery which could be used by future research, sample size was not a priority and thus a power analysis has not been performed. Therefore, those who were within the criteria were recruited as a sample of convenience. Participants provided details regarding their competitive level, win-loss record, experience in other combat sports, total training age and current weight class. Furthermore, their competitive style was placed on a spectrum of 0 – 100 with 0 being entirely striking-based while 100 was grappling-based. A second spectrum of 0 – 100 was used with 0 representing aggressiveness while 100 represented defensiveness. These were plotted onto a visual analogue scale (VAS). The factors encompassing MMA competitive styles are difficult to quantify and as such, a scale was devised to provide some measure which could give an approximate indication of competitive style based on selections in prior research (35). The authors designed this scale to give an approximate indicator of competitive style, as we are not aware of previous research that had attempted to do this. Participants were asked to complete a medical history questionnaire and were accepted in the study if they had no contraindications (i.e. orthopedic injuries or diseases). Participants were provided written informed consent forms and were made aware they could withdraw from the study at any time with no penalty. This research study was approved by the Human Research Ethics Committee (Project Number 2019-00445) and the Radiation and Biohazard Safety Council at Edith Cowan University. Additionally, this research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (48).

Protocol
Participants attended the laboratory on four occasions separated by a minimum of 48 hours and no more than 10 days. These sessions included a familiarization and three experimental sessions, each lasting between one to one and a half hours. During the familiarization session, select anthropometric data (body mass, height) was collected. Body mass was measured to the nearest 0.1 kilogram using a calibrated scale (A&D UD-321, Australia) and height measured to the nearest 1 centimetre using a stadiometer (SECA mod 220, SECA, Germany). Additionally, participants were instructed on the correct technique for the physical testing battery including the countermovement jump (CMJ), Isometric Midthigh Pull (IMTP), Wingate Anaerobic Test (WAnT) and be required to complete the Repeat Sled Push Test (RSPT). Experimental session 1 consisted of the CMJ, grip strength and the Wingate Anerobic tests, as well as familiarization of the IMTP test. Experimental session 2 entailed the IMTP collection as well as the collection of the RSPT. Experimental session 3 included the Dual X-Ray Absorptiometry (DEXA) body composition scan and concluded with a Graded Exercise Test (GXT).

Grip Strength: Grip strength was assessed using a hand dynamometer (Hand dynamometer, Lafayette Instrument Company, United States). Grip strength assessment has been used in previous research in combat sports and thus was selected (2, 16). For each assessment three maximal efforts of 5 seconds were performed with the dominant hand with 1 min rest between efforts. The trial with the highest force was taken for analysis.

Countermovement jumps: CMJ trials were performed on a calibrated force plate (9290AD, Kistler Instruments, Switzerland) to assess force generating capacity and are considered a reliable and valid measure of such (47). In addition, the CMJ has also been used in previous MMA research (6). To remove the effect of arm swing on CMJ performance, the participant held a wooden dowel across their shoulders, were instructed to step onto the force plate in their own time. A total of three attempts were performed by the subjects and the best trial was determined by jump height and used for data analysis. Vertical ground reaction force was collected at 1000 Hz using BioWare software (version 5.3.0.7: Kistler Group, Winterthur, Switzerland) and exported as text files for analysis in a custom Excel spreadsheet (Microsoft, WA, USA). Bodyweight (BW) was calculated as the average force during a one second 'quiet standing' period prior to countdown (51, 55). The initiation of the trial was identified as the point 100 ms prior to BW ± 5 SDs (50). Phases of the jump were identified according to the recommendations of Harry et al. (27), while take-off and landing were identified according to the procedures outlined by Lake et al. (42). Centre of mass velocity was determined by first dividing the net force at each sample by body mass and then integrating the product with respect to time using the trapezoid rule (44). Power was calculated as the product of force and velocity, with peak power defined as the highest instantaneous value and mean power as the average power over the propulsive phase respectively. Jump height was calculated from take-off velocity (44). Reactive strength index modified (RSImod) was calculated as jump height divided by time-to-take off (20, 31).

Wingate anaerobic test (WAnT): The WAnT was selected to assess anaerobic capacity as it has been considered a gold standard of anaerobic function in laboratory setting (46). The WAnT trials began with a standardized warm up of 3 minutes of cycling on a cycle ergometer (Velotron Ergometer, Racemate, USA) at 0.8W/kg of body mass (4). After the warm-up, the participant was instructed to pedal at a comfortable pace for 20 seconds. All resistance then dropped off and the participant was instructed to pedal as fast as possible. A resistance that was equivalent to 7.5% of body mass was applied after 10 seconds. Participants were encouraged to maintain a maximal pedaling rate for the 30 second test duration. From this test, peak power was calculated as the highest power output recorded, mean power as the average power maintained throughout the test and fatigue index as the amount of decline in power output expressed as a percentage (8).

Maximal oxygen uptake (VO_2max) and ventilation thresholds: Expired gas analysis during incremental exercise is considered the gold standard in measuring VO_2max and thus a GXT was selected (46). The participants began with a general warm up with a dynamic stretching routine before being attached to the treadmill via a harness (150/50 Mercury, H/P/Cosmos, Germany). Following a modified Astrand protocol, the speed for the participants was 9.5 km/h with 0% incline to start (37). The participants began running, with speeds remaining constant while gradient increased every 2 minutes by 2.5 % until the participant reached volitional exhaustion. The participants wore nose clips and had a one-way mouthpiece connected to computerized metabolic cart (Parvomedic, Sandy, UT, USA) to assess expired gases in a mixing chamber for analysis. (54). Oxygen values were calculated every 5 seconds, with the greatest consecutive values were averaged to find absolute maximal oxygen consumption in litres. Relative oxygen consumption was calculated by dividing body mass into absolute oxygen consumption and recorded in millilitres of O2 per kilogram of body mass per minute (54). Cessation of testing happened when participants self-reported exhaustion and was confirmed by either a plateau in oxygen consumption despite workload increase, a respiratory exchange ratio of > 1.1, an RPE of 18-20 and heart rate being within 10 beats per minute of predicted maximum heart rate (54). The data collected during the GXT was used to determine ventilation threshold 1 (VT1) and 2 (VT2) using the methodology outlined by Neder and Stein (49) and plotted using an Excel spreadsheet (Microsoft, WA, USA).

Isometric Midthigh Pull (IMTP): The IMTP is a test that can be used to assess measures including maximal strength. The IMTP was selected for use in this battery as it is considered the gold standard in strength testing, has been used in MMA research previously and is utilized in the field of elite MMA athlete assessment (25, 29, 30). Prior to IMTP testing, participants were asked to do a generalized warm up involving dynamic stretching, bodyweight squats and lunges (9). Once the general warm-up procedures were completed, the participants were positioned in the

IMTP rack, with a barbell position corresponding to the second pull of the clean, with hip- and knee-angles of 140-145º respectively (7). Hip- and knee-angles were confirmed using hand-held goniometry and then maintained for each participant across all subsequent testing sessions. This testing position was chosen as it has previously been reported within the literature as optimizing the generation of force-time characteristics during the performance of the IMTP (7). Self-selected grip and foot position were recorded and maintained across each trial. The IMTP was performed according to current standardized methodological practices (13). Once positioned correctly, the participants performed pulls as a specific warm up at 50, 75 and 90% of max intensity, with one-minute recovery between pulls. Following this, the participants performed five maximal IMTP trials. Each trial was terminated after 5 seconds or when the force-trace visually declined, whichever occurred first. One minute of recovery was allotted between each trial. Prior to the first trial, participants were instructed to "pull as hard and as fast as possible while pushing your feet into the ground" (26). To ensure the removal of 'slack' in the participant's body immediately prior to the commencement of a trial, they were instructed to apply the minimum amount of pre-tension needed upon the immovable barbell (< BW + 50N). Upon attaining a stable start position for a minimum of one second, the participants received a countdown of "3, 2, 1, Pull!" and received strong verbal encouragement throughout to ensure maximal effort. If there was a difference in peak force greater than 250N between trials (41), or a countermovement upon force application was visually obvious during real-time observation of the force-trace, that trial was excluded, and an additional trial performed. All IMTP trials were performed in a custom-designed power rack (Fitness Technology, Adelaide, Australia) which allows for the barbell to be positioned at any height through a combination of pins and hydraulic jacks, while standing on dual portable force plates (PS-2141, PASCO Scientific, CA, USA). Vertical ground reaction force was collected at 1000Hz using PASCO Capstone software (version 2.0.0, PASCO Scientific, CA, USA) and exported for analysis in a custom Excel spreadsheet (Microsoft, WA, USA) (12). Force onset was identified as the point where vertical ground reaction force exceeded BW ± 5 SDs (18). No filtering was applied to the raw force-time curve data (19). After analysis, the average value of each force-time characteristic was calculated from the three trials with the highest PF outputs as this has been suggested to improve the reliability of the calculated characteristics (45).

Repeat sled push test (RSPT): The RSPT was chosen for testing as it was designed with MMA work to rest ratios and total duration in mind (6). The RSPT required the participants to push a sled (Predator Sled, Aussie Strength Equipment, Australia) with a total of 75% of their body mass over a ten-metre distance for 30 repeats on short strand, sports-grade artificial turf (Figure 1). Participants were instructed to perform each sled push with maximal effort and strong verbal encouragement was provided throughout to ensure this occurred (6). Following the completion of each 10 m effort the participant will be given 20 seconds to complete a 10 m active recovery walk before the next effort. The duration of each sprint effort was recorded with timing gates and that information was sent wirelessly to the corresponding application on the computer (Speedlight TT wireless timing system, Swift, Queensland). Heart rate (HR) was measured with a heart rate monitor (A30, Polar, Finland) after each run. Rate of perceived exertion (RPE) was recorded after each run verbally (6) using the BORG scale. Termination of the test occurred when the subject completed 30 sled pushes successfully, reached exhaustion of their own volition or the sled stopped moving mid push for two consecutive efforts. Sled push effort times, HR and RPE were averaged into six blocks (1-5, 6-10, 11-15, 16-20, 21-25 and 26-30) for data analysis. When this test was developed, it was found to be within acceptable reliability limits (ICC > 0.95; CV% < 4,0; TE < 0.45 s) for peak sprint, average sprint and fatigue index (6).

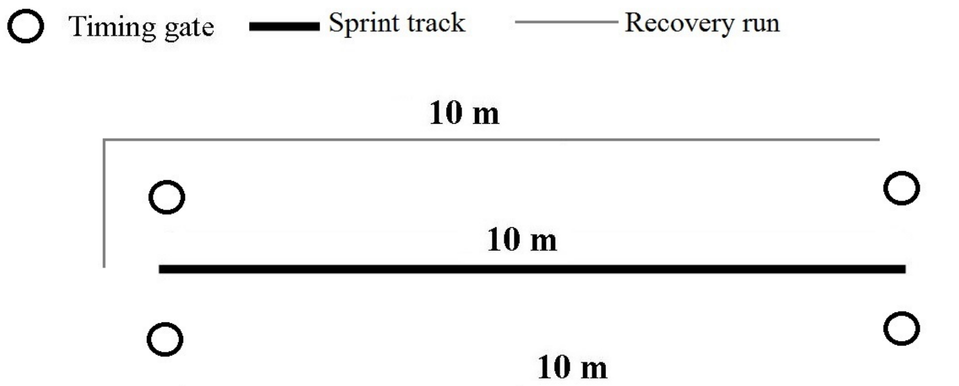

Figure 1. Visual representation of the layout of the RSPT.

Dual x-ray absorptiometry (DEXA): A full body composition scan was undertaken using the DEXA equipment (Discovery DXA System, Hologic Inc., MA, USA) to record a full body composition, including total fat and regional body fat distribution, lean mass and body fat percentage. The DEXA was chosen as it considered to be the current gold standard in body composition measurement due to its high precision in differentiating different types of tissue (53). Participants were encouraged to follow their natural dietary intake and be fully hydrated for prior to DEXA testing. Participants were positioned on the bed during the scanning process, which takes approximately 10 minutes in total including preparation. The scanning process went for a duration of roughly three minutes and results were printed off for the participant as well as saved to a secure hard drive for integration into data analysis.

Statistical Analysis

Descriptive statistics were calculated as mean ± SD. Where applicable, results were compared to the Ultimate Fighting Championship Performance Institute's (UFC PI) normative data (29) and other cases compared to previous research (16, 38). Spearman's rank-order correlation coefficients were performed using the R programming language (version 4.0.2) (52) to establish the association of competitive style to each of the assessments. Bias corrected and accelerated 95% confidence intervals for each estimate were calculated via bootstrap resampling (11, 15). Correlation coefficients were interpreted as small (0.1-0.3), moderate (> 0.3-0.5), large (> 0.5-0.7), and very large (> 0.7-0.9) (28).

RESULTS

The average peak force (PF) in the IMTP was 2684.63 ± 597.04 N, while the average relative PF was 3.32 ± 0.61 N/kg (Figure 2A). Grip strength was also performed, showing mean max force of 498.67 ± 50.97 N (Figure 2B). A total of two participants were above the UFC average in the IMTP and all but one participant achieved greater grip strength than the average presented by de Oliveira (16). The mean jump height of the participants was 26.02 ± 6.49 cm (Figure 2C). Mean net peak force and mean relative net peak force were observed at 930.61 ± 246.71 N and 1.10 ± 0.20 N/kg while the individual participant findings reported in Table 1. No participants in this study achieved a higher jump height than the UFC average in their weight division.

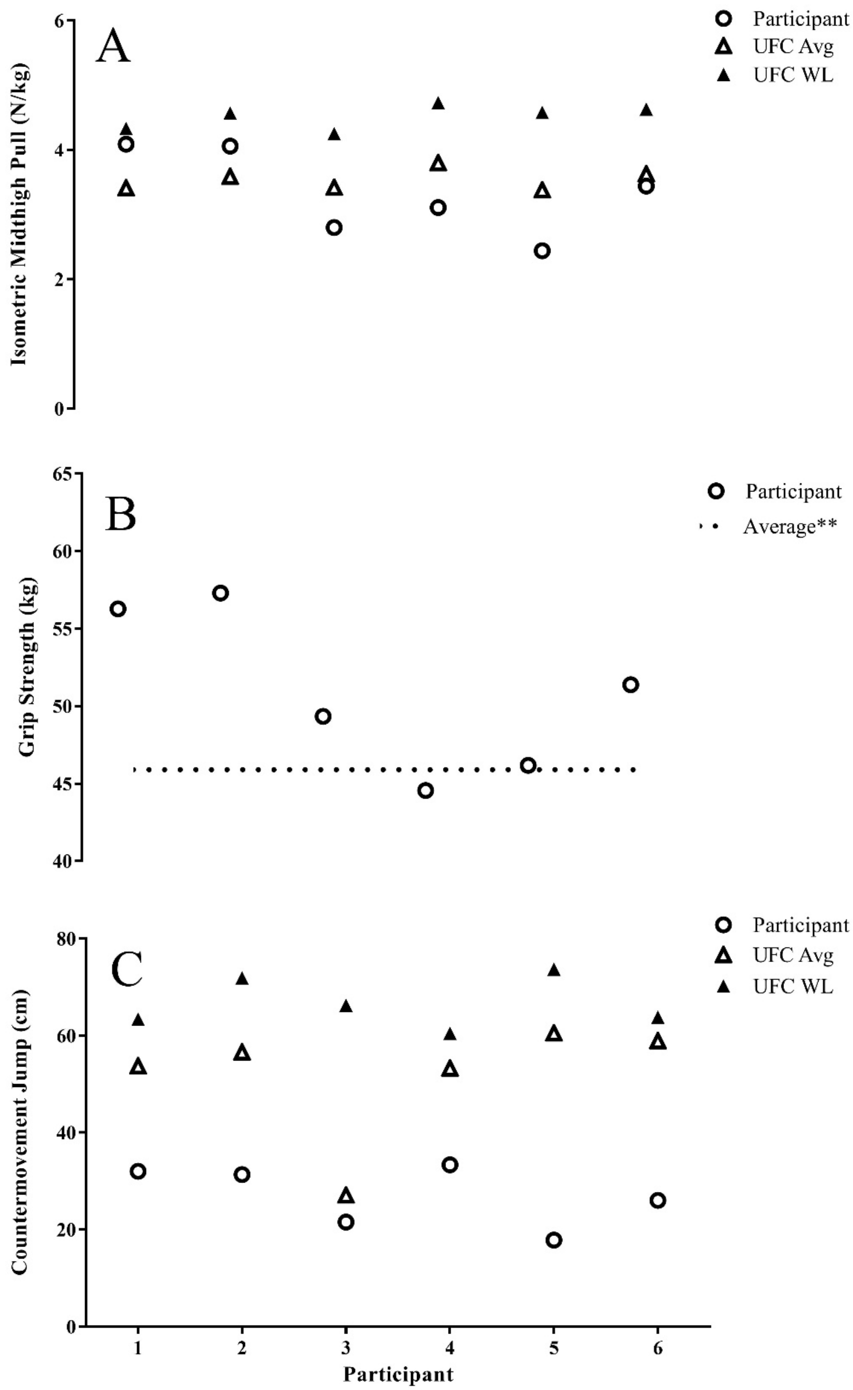

Figure 2. (A) Isometric Midthigh Pull relative net peak force (N/kg) compared to Ultimate Fighting Championship (UFC) average and UFC world leading (WL) athletes in weight classes corresponding to the participant. **(B)** Grip strength (GS) (kg) compared to de Oliveira, et al. (16)**. **(C)** Countermovement jump height compared to Ultimate Fighting Championship (UFC) average and UFC world leading (WL) athletes in weight classes corresponding to the participant.

Table 1. Countermovement jump net peak force (N) and net relative peak force (N/kg) with mean ± SD

	Net Peak Force (N)	Relative Net Peak Force (N/kg)
Participant One	1050.69	1.37
Participant Two	1149.38	1.30
Participant Three	763.50	0.93
Participant Four	854.74	1.13
Participant Five	1201.89	0.94
Participant Six	563.48	0.94

Mean peak power was observed in the Wingate anerobic test as 1023.67 ± 332.17 W (Figure 3A) whilst mean average power was noted as 614.17 ± 89.15 W (Figure 3B). Fatigue index was taken as the difference between the peak power and minimum power, converted into a decline of wattage per second average and was observed as 20.9 ± 12.76W/s (Figure 3C). The mean peak power of 4 of the participants in this study was greater than the mean peak power observed in Karimi (38). All participants presented a greater average power than observed in Karimi (38) and three participants displayed a lower fatigue index.

The mean relative VO_2max measured using a graded exercise test was 54.06 ± 13.83 ml/kg/min (Figure 4A) while ventilation thresholds 1 and 2 were 37.90 ± 11.08 ml/kg/min and 48.78 ±12.46 ml/kg/min, respectively (Figures 4B, 4C). Two participants were observed above UFC averages in relative VO_2max and ventilation threshold 1, while five participants' second ventilation threshold was observed as above the UFC average.

Mean peak speed durin
g the repeat sled push test was 3.63 ± 0.45 s while mean average speed was 4.17 ± 0.75 s (Figure 5). Fatigue index was taken as average of the final 5 runs taken from the average of the first 5 runs. The mean fatigue index was 0.94 s ± 0.95 s (Figure 5). Fatigue index could not be recorded for the fifth participant due to inability to complete the full test.

Body fat percentage average was observed at 17.02 ± 10.96 % and bone mineral density observed at 1.27 ± 0.02 g/cm^2. Individual descriptive statistics are found in Table 2.

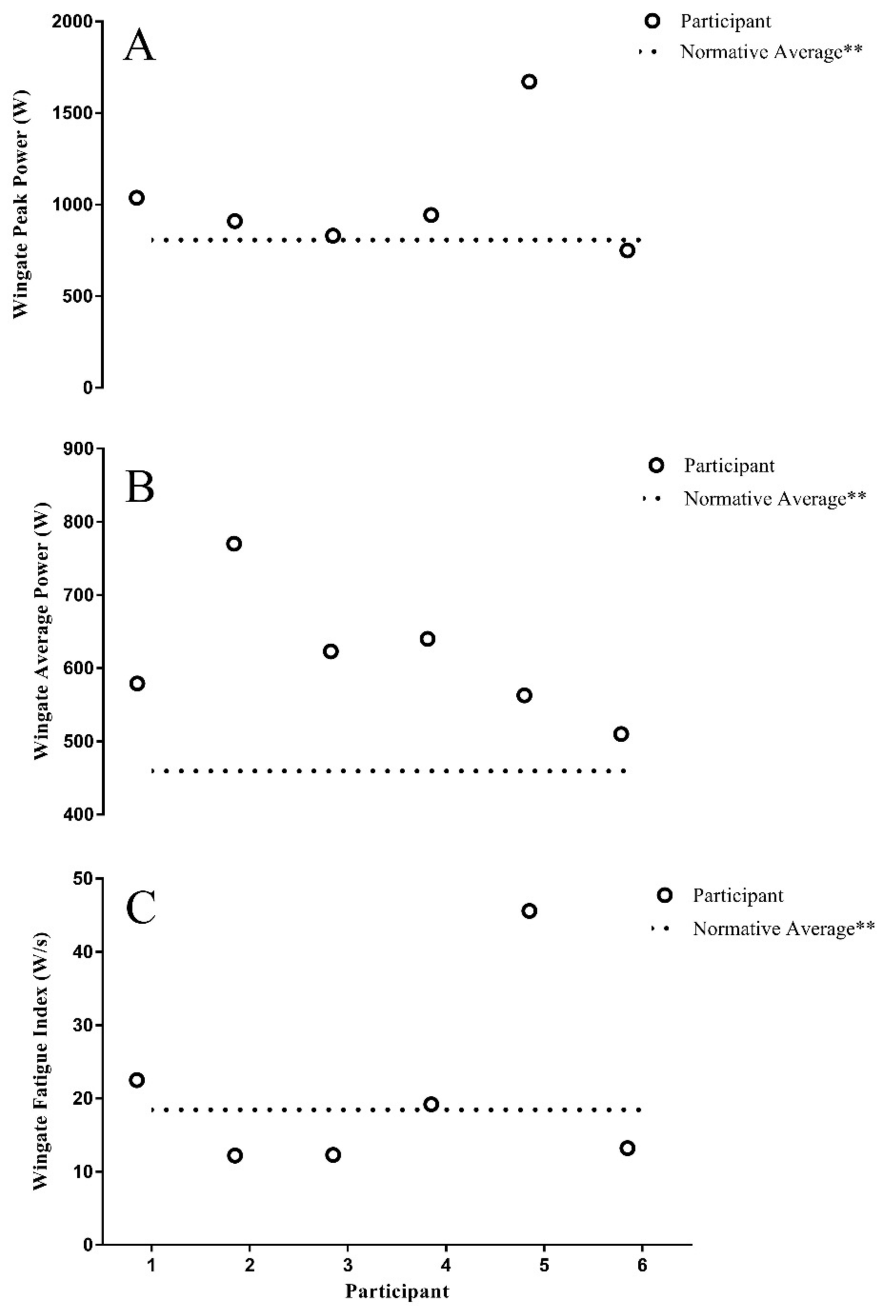

Figure 3. Wingate test **(A)** peak power (W), **(B)** average power (W) and **(C)** fatigue index (W/s) compared to average of elite wrestlers, Karimi (38)**

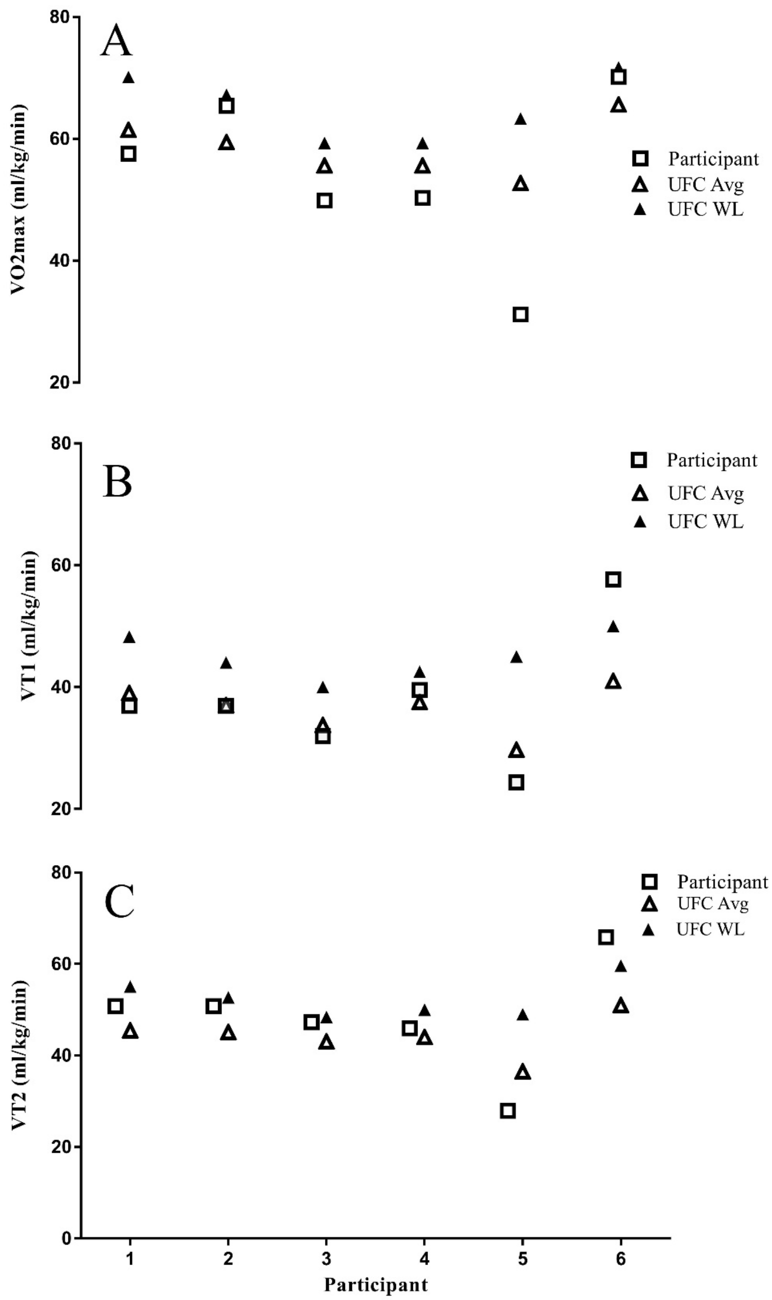

Figure 4. (A) Relative VO_2max (ml/kg/min), **(B)** ventilation threshold 1 (ml/kg/min) and **(C)** ventilation threshold 2 comparable to UFC average (UFC Avg) and UFC world leading (UFC WL) athletes in weight classes corresponding to the participant.

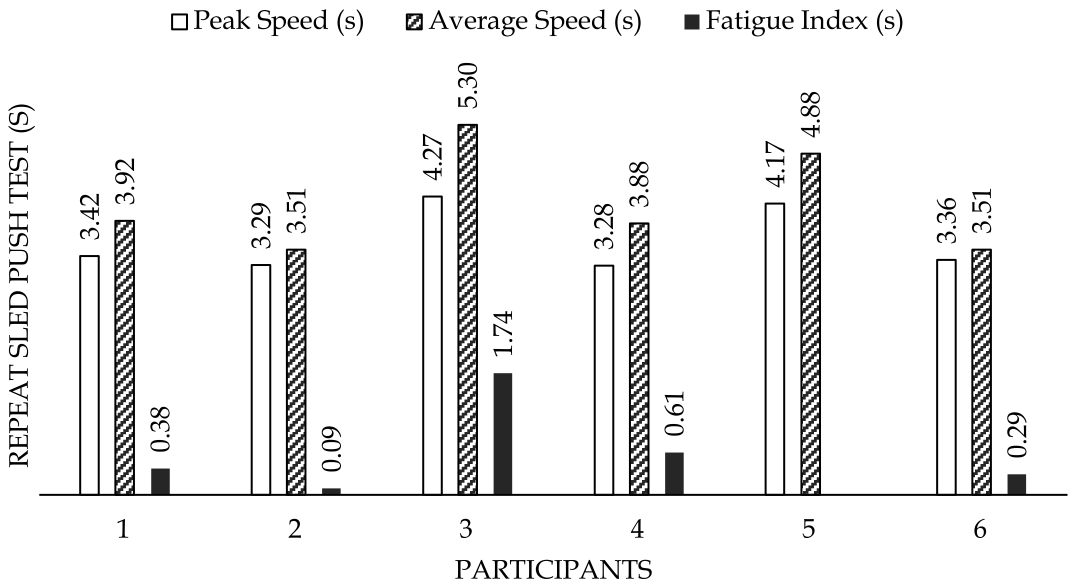

Figure 5. Repeat sled push test peak speed (s), average speed (s) and fatigue index (s)

Table 2. Descriptive statistics of participants in this study including body composition and whole-body bone mineral density measures.

	Age (y)	Height (cm)	Mass (kg)	Competitive Weight Class (kg)	Body Fat (%)	Bone Density (g/cm^2)
Participant One	24	181	78	70	10.60	1.31
Participant Two	32	180	86	77	10.50	1.23
Participant Three	24	170	82	84	19.50	1.31
Participant Four	31	172	75	65	14.50	1.33
Participant Five	22	177	128	120	38.00	1.20
Participant Six	21	167	58	57	9.01	1.22

Figure 6 displays how the athletes scored their competitive styles, with three participants identifying as more defensive while the other three participants identified as more aggressive in their competitive style.

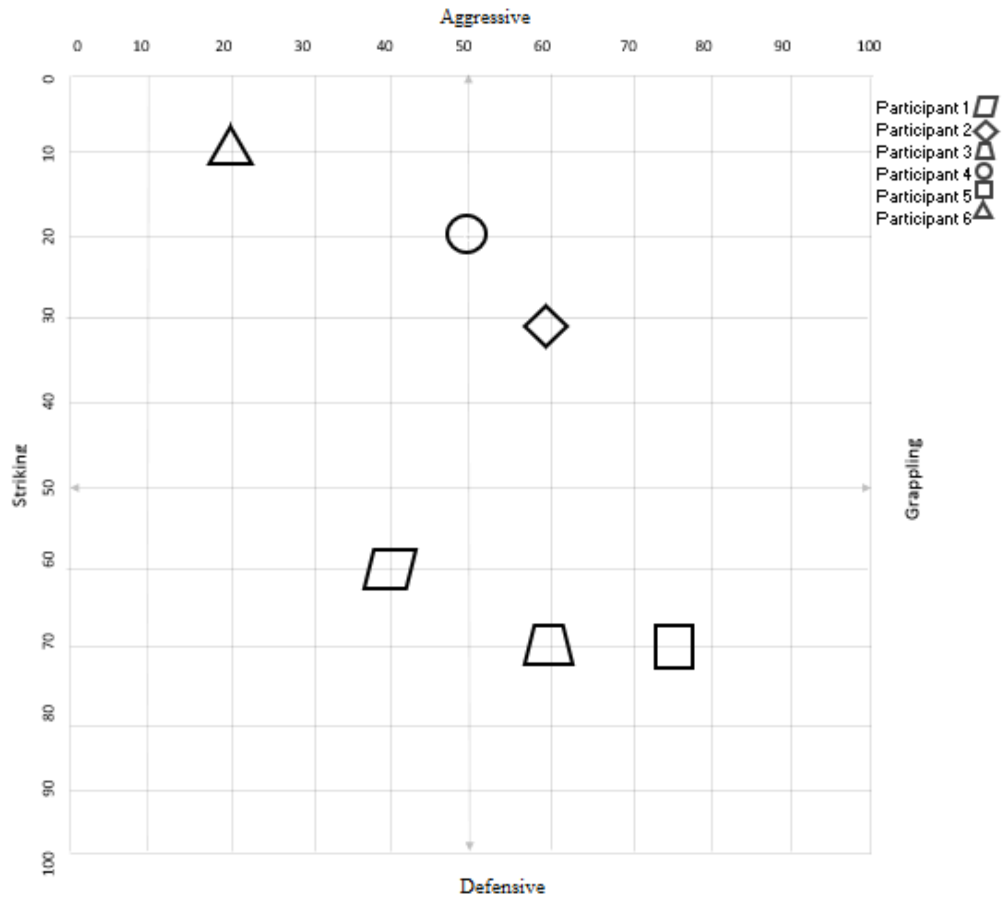

Figure 6. Visual Analogue scale illustrating competitive style based on perceived aggressiveness (0) to defensiveness (100) and striking-based (0) to grappling based (100)

Table 3: Confidence Intervals of select tests to Aggressive/Defensive Competitive Style

Test	Estimate	95% Lower	95% Upper
IMTP Relative Force	-0.46	-0.99	1.00
RSImod	-0.58	-0.99	1.00
WAnT Anaerobic Power	-0.03	-1.00	0.80
WAnT Anaerobic Capacity	-0.73	-1.00	0.00
WAnT Fatigue Index	0.26	-0.80	1.00
Grip Max Force	-0.12	-1.00	0.80
Relative VO_2max	-0.81	-1.00	0.80
VT1	-0.99	-1.00	-0.71
VT2	-0.61	-1.00	0.80
RSPT Peak	0.81	-0.80	1.00
RSPT Average	0.88	-0.45	1.00
RSPT Fatigue Index	0.70	-0.80	1.00

Table 4: Confidence Intervals of select tests to Striker/Grappler Competitive Style

Test	Estimate	95% Lower	95% Higher
IMTP Relative Force	-0.64	-1.00	0.50
RSImod	-0.32	-1.00	1.00
WAnT Anaerobic Power	-0.29	-1.00	0.95
WAnT Anaerobic Capacity	-0.35	-1.00	1.00
WAnT Fatigue Index	0.06	-0.98	1.00
Grip Max Force	-0.23	-1.00	0.95
Relative VO_2max	-0.75	-1.00	0.60
VT1	-0.78	-1.00	0.80
VT2	-0.67	-1.00	0.58
RSPT Peak	0.38	-0.80	1.00
RSPT Average	0.52	-0.47	1.00
RSPT Fatigue Index	0.46	-0.80	1.00

Large relationships were observed from the aggressive/defensive scale to RSImod (r = -0.56), VT2 (r = -0.61) and RSPT fatigue index (r = 0.70) while very large relationships were observed in anaerobic capacity (r = -0.73), relative VO_2max (r = -0.81), VT1 (r = -0.99), RSPT peak (r = 0.81) and RSPT average (r = 0.88). Similarly, large relationships were observed from the striker/grappler scale to IMTP relative (r = -0.64), VT2 (r = -0.67) and RSPT average (r = 0.52) while very large relationships were noted with relative VO_2max (r = -0.75) and VT1 (r = -0.78).

DISCUSSION

The primary aim of this study was to develop and utilise a comprehensive testing battery for MMA as well as improving the understanding of the physical characteristics present in Australian MMA athletes. A secondary aim of this study was to present a novel tool to potentially assess competitive styles in MMA. One of the main observations from this study was that the testing battery was viable and able to be completed by the subjects recruited in a timely fashion, as an athlete could get through all testing within 7 days when accounting for familiarization to testing protocols. Additionally, the VAS scale used appeared to show differences in competitive styles between the participants of the study.

While the purposes of this study were to develop a comprehensive testing battery and introduce a method by which competitive styles can be determined, the data needs to be easily digestible and understood by those undertaking future research as well as coaches and support staff in the field. As such, the following discussion will act as a method to analyse the data and how to apply it practically in the field comparable to normative and non-normative data available in the literature.

The participants in this study were all either amateur or semi-professional MMA athletes of varying competitive backgrounds within Australia. Most athletes had some experience with striking- and grappling-based sports such as boxing, kickboxing and BJJ. In addition to this, the athletes all experienced widely different success in the sport within their competitive level. Their competitive records range from a mixed record in professional bouts, undefeated in over 10 amateur bouts to 0 – 1 record in amateur competition. Even with the lack of top-level MMA experience by the participants in this study, there are some notable similarities in given physical characteristics between them and the elite MMA athletes (29). This could potentially indicate that skill level is far more important than physical conditioning when trying to reach the higher levels of competition, but this finding must be interpreted with caution due to the small sample size.

Results for assessments including VO_2max, IMTP and countermovement jumps were compared to data acquired by the UFC PI. It is worth noting that the UFC PI data is both not peer-reviewed but also possibly the best quality normative data regarding the elite level of MMA athletes. While the data might not be the most realistic to compare amateur and regional level athletes to, it informs athletes of what the upper echelon of the sport sees as a baseline. Maximal strength was assessed with the IMTP and two of the participants in this study performed above the average elite MMA athlete in their weight division. Additionally, all the participants had greater grip strength than the Brazilian MMA athletes who participated in De Oliveria's study (16) (Figure 2). Force generation during dynamic tasks were assessed using the countermovement jump and the participants of this study performed worse than the average elite MMA athlete (Figure 2). It is worth considering that due to the exact testing methodology being unclear within the UFC Performance Institute (29), direct comparisons between their results and this study are difficult to make. Anaerobic function was assessed utilizing a Wingate test. The peak power of the participants was observed above the mean for five of the six participants compared to the wrestlers assessed by Karimi (38) (Figure 3). Additionally, average power rated above the mean for all six participants and the fatigue index below the mean for three of the six participants (Figure 3). There are potential limitations with comparing the participants of this study to elite wrestlers in assessed by Karimi (38), as the physiological profiles of MMA athletes and freestyle wrestlers may greatly vary due to differences between the sports. Regardless, Australian MMA athletes appear to be at the elite level for markers of maximal relative strength and anaerobic function but not dynamic force generation, though small sample size necessitates caution to be exercised when making interpretations. The measures of strength and anaerobic function within this study can be applied in different ways and have diverse effects within MMA performance. For example, an athlete with greater than average force-generating capacity may be more likely to finish a contest by knockout than a contemporary with lesser ability to generate force. However, it is unclear exactly how different characteristics translate to the successful execution of techniques within real MMA competitions. It is also important to consider that different athletes within MMA may have vastly different strength and conditioning programming due to the individual nature of the sport, which could hinder any expectation of unity among physical characteristics such as force-generating capacity.

Multiple facets of aerobic function were assessed including relative VO_2max and ventilation thresholds. The athletes in this study had an average relative VO^2max of 54.06 ± 13.83 ml/kg/min. When comparing individual participants to elite MMA athletes relative to weight division, two participants had greater VO_2max than the average while the remaining four had lower VO_2max (29) (Figure 4). Previous research has assessed VO_2max and found an average of

44.22 ± 6.7 ml/kg/min in north Brazilian MMA athletes as well as other combat athletes such as wrestlers where the average relative VO_2max was 60.24 ± 5.13 ml/kg/min (16, 59). Relative VO2max is an important factor in MMA performance as the aerobic system is a primary driver of recovery within the lower intensity stages of competition (23). Aerobic function is more difficult than purely VO_2max as ventilation thresholds have been posited as a potential key point within MMA performance (5). Indeed, the second ventilation threshold being where the increase in CO2 can no longer be buffered metabolically and is understood to be the upper limit of intensity an athlete can participate in before succumbing to fatigue. Therefore, it stands to reason that this measure would be useful for MMA athletes and should be included in a testing battery in the future. The mean VT2 of the participants in this study was 48.78 ± 12.46 ml/kg/min, which is slightly lower than the average elite MMA athlete in all weight divisions excluding middleweight (29). Furthermore, the athletes who identified themselves as more aggressive appeared to have greater VO_2max than their defensive counterparts. While it would be difficult to attribute this to any one factor, a potential explanation for this would be the athletes who have the more aggressive styles would need a greater VO_2max to allow more opportunities to dictate the pace of the contest. In a similar vein to the points made above in the section regarding strength measures, no unequivocal answer can be gleaned from this. It does, however, open an intriguing avenue for future research.

Repeat effort ability was assessed using the RSPT where the participants mean peak speed, average speed and fatigue index was recorded. Other studies in MMA athletes have implemented assessments for repeat efforts using repeated sprint ability (RSA) tests and Yo-Yo Intermittent Recovery Level 2 Test (YYIR2) (34). As the methods that were being utilized to measure repeat effort ability were vastly different, it is difficult to make comparisons between the two. James et al., (34) utilized an unloaded 10 and 20m run on a field while the RPST utilized in this study involved pushing a sled weighted to 75% of the participant's body mass on a 10m turf track as fast as possible for 30 repetitions. Furthermore, the UFC Performance Institute (PI) does not include any repeat effort ability testing. As the sport itself is quite heavily reliant on repeat efforts, it would be more ecologically valid for a testing battery in the future to include a measure of repeat effort ability. However, there is no current consensus on the best repeat effort protocol for MMA athletes with many protocols being utilized. For example, the RSPT was designed specifically with similar physical loads and competitive time of MMA in mind, as the full test approximates the duration of a three round professional MMA bout. However, at present, while the RSPT has sound theoretical basis, it is unclear how similar the physiological response is to real world competition which should be investigated by future research for validation. Regardless, it is still essential to include a measure of repeat effort ability in any testing battery of MMA performance that is at least well justified theoretically until future research can investigate further.

The mean body fat percentage of the participants was 17.02 ± 10.96%. While this finding is higher than other studies of body composition in MMA athletes (12.25 ± 0.54% (1); 14.9 ± 7.2%, (16)), it should also be noted that one participant skewed the data upwards, as the mean body fat percentage with this participant's data removed was 12.82 ± 4.25%. However, it is important to consider that there has not been established norms for MMA athletes regarding body composition. There is some evidence that subcutaneous body fat can have a protective effect from blunt force trauma, although this research has not extended to MMA (57). Conversely, body fat has been referred to in previous research as anatomical dead mass, as it does not contribute metabolically and can limit mobility. Due to these factors, it can be reasonably assumed that having a lower body fat percentage would be preferential for MMA competition (39). Additionally, as MMA is a sport divided by weight categories, the potential for optimizing an athlete's lean mass can be reasonably concluded to be favored. However, while weight categories are rigid, adherence to an "ideal" body composition does not necessarily lend itself to competitive success, as seen in other combat sports like wrestling where heavyweights tend to have higher body fat percentages than their lower weight category contemporaries (58).

In the case of this study, the participants performed near the level of the average elite MMA athlete on several athletic assessments. This could be a demonstration that physical characteristics are not the paramount differentiator between higher- and lower-level MMA athletes, although more research would need to be undertaken in this area to develop a firmer understanding of the physical and physiological diversity of the differing competitive levels. It would also be highly beneficial to develop a peer reviewed set of normative data for the elite level MMA athletes using the comprehensive testing battery proposed in the current study.

Conclusion: It is worth considering that the primary purpose of this study was to propose a comprehensive testing battery for MMA and to be descriptive in nature to outline avenues for future research to explore in greater detail. Future research should be conducted using similar parameters as this study with a larger sample of higher-level athletes to provide athletes, support staff, organizers, and researchers with a better understanding of the physiology of MMA competitors. Moreover, with access to more participants, the likelihood of variation between competitive styles would plausibly increase. This in turn, may offer even more useful information regarding what physical characteristics would stand out for specific competitive styles in MMA athletes. Any relationships observed between tests or competitive styles must be interpreted with caution as the findings are not as sensitive due to the small sample size, solidified by widely separated confidence intervals. As such, the analyses in the current study were intended as demonstratively for further studies with greater number of participants. This can potentially be rectified in future research with more subjects, to allow more sensitive analysis to take place.

Directions for Future Research: There are many directions for future research based on the findings of this paper. Validation of the VAS scale for self-assessment of competitive styles as well as the RSPT for repeat effort ability in MMA athletes are areas that could be explored further in future studies. Stratification of athletes by competitive level and success has been investigated previously (30, 32, 35) but gaps exist including assessing the diverse competitive styles present in MMA athletes that should be addressed with future studies (e.g. are certain competitive styles associated with different success and if so, does competition level have an effect on this?). Participant readiness is also a potentially confounding factor for future research as participants of this study were accepted for assessment regardless of their current training cycle. Athletes in MMA tend to train year-round but undergo a specialized training plan at specific time-points as well as a nutritional overhaul known colloquially as a "training camp" while preparing for competitive bouts. The phase of training camp the athlete is in can influence how sensitive and practical the data collected would be as someone towards the end of a long training camp might experience symptoms of general fatigue compared to athletes in the midpoint of camp. Future research may attempt to account for this by stratifying athletes based on their current training cycle as physiologically similar athletes in different stages of their training cycle may respond to testing in different ways.

Practical Applications: The physical characteristics that were assessed in this study have been indicated as important for athletic performance in MMA by previous research (1, 16, 30, 34) and as such a testing battery should be adhered to for the sport of MMA. The present study developed a suggested battery that evaluates the physical and physiological characteristics important to MMA performance in a more comprehensive manner than previous research. However, more research should be undertaken with a greater sample size to allow validity measures to be taken as well as develop normative data about MMA athletes. The need for competitive styles to be considered within analyses is necessary for future research. Coaches moving forward should implement appropriately comprehensive physical assessment methods to gain a better understanding about the athlete they are training as this will increase the likelihood of maximizing their performance at specific time-points. Moreover, the testing battery adopted may need to be specific to the competitive style of the athlete that the strength and conditioning practitioner is working with.

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