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The physical demands of mixed martial arts: a narrative review using the ARMSS model to provide a hierarchy of evidence.

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The physical demands of mixed martial arts: A narrative review using the ARMSS model to provide a hierarchy of evidence

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Abstract

The physical and physiological demands of mixed martial arts (MMA) training and competition is not yet well quantified. The Applied Research Model for the Sport Sciences (ARMSS) provides a framework through which to conduct sport science, determining pertinent questions to apply and test research findings in real world settings. The aim of this review was to evaluate MMA research within the context of ARMSS to critically analyse our understanding of the physical and physiological requirements of MMA training and competition. Research databases were searched, with 70 peer-reviewed articles being discussed in relation to the specific stage of the ARMSS in which their results best fit. MMA research was found to be mostly foundational and descriptive in nature and has generally not developed along systematic lines. The internal and external physiological loads and responses to training and competition have not been adequately identified. Therefore, it is not currently possible to state which variables are key predictors of success, or how coaches can optimally manipulate these variables. We propose that MMA research could be refocused to be conducted within ARMSS. Specifically, stage 2 studies describing the physical, physiological and technical demands of MMA training and competition, and stage 3 studies determining the physiological predictors of competition performance should be initially prioritised.

Key Words

Combat sports; ARMSS; performance

Word Count = 5,663

1 – Introduction

The aim of scientific research is to provide a structured understanding of a particular field to develop solutions to encountered problems (Niiniluoto 1993). Though many disciplines have histories of achieving this within a formal framework, sports science has not generally proceeded in this manner. This has been suggested to inhibit the translation of science to practice (Bishop 2008). Research lacking robustness and/or applicability tends to be most evident, though not exclusively, in young sports where the knowledge base is under-developed. One such sport where this is the case is mixed martial arts (MMA). MMA is a body-mass regulated combat sport in which competitors engage each other using kicks, punches, elbows and knees along with grappling manoeuvres to overcome their opponent. Bouts are 3 x 5 minute rounds (5 x 5 minute rounds for championship bouts or bouts deemed to be of significance) for professionals and 3 x 3 minute rounds for amateurs (NJSAC 2002, James et al. 2016, Kirk 2018a). A contest is won or lost when: i) the referee is given reason to believe either opponent is no longer intelligently defending themselves against strikes (deemed a technical knockout (TKO)), or is no longer physically able to intelligently defend themselves against strikes (deemed a knockout (KO)); ii) either opponent 'submits' by indicating they are no longer willing to continue the contest due to joint manipulation, choking or injury, or if a submission hold has rendered them unconscious or physically debilitated; iii) either opponent or their coaches indicates they are unable or unwilling to continue the contest, iv) if an appointed medical doctor determines that either participant is no longer fit to continue safely, or, v) all scheduled rounds of the bout are completed and judges decide the winner based on pre-set criteria (ABC 2018).

Though MMA has been compared to the ancient Greek sport of pankration (Buse 2006, Seidenberg 2011) it developed from Brazilian vale tudo (no holds barred) contests of the early to mid-20th Century(Gracie and Danaher 2003). This format was imported to the USA in the 1990s by several organisations, most notably the Ultimate Fighting Championship (UFC) (Gracie and Danaher 2003, Souza-Junior et al. 2015). MMA became a codified sport with the 2002 adoption of the 'unified rules' (NJSAC 2002). Due to its recent establishment, research into this population of athletes is nascent, as discussed previously (Lenetsky and Harris 2012, Del Vecchio and Franchini 2013, Andreato and Branco 2016, Kirk 2018a). Presently, there are 4,000+ male and female professional competitors worldwide(Fightmatrix 2020), with the International MMA Federation (IMMAF) consisting of 85+ national governing bodies across five continents (IMMAF 2019). MMA has rapidly increased in popularity and participation, as highlighted by the 2016 sale of UFC for $4 billion, just 16 years after being bought for $2 million(Rovell and Okamoto 2016). As an indication of the use of sports science in MMA, UFC established performance institutes designed to provide training and support for its contracted athletes(UFC 2019). However, there is evidence that MMA coaches do not view scientific research as important to their role (Bujak et al. 2013). If this perspective is to be altered the work produced by researchers must be demonstrated to be of real-world value to the end user, allowing a symbiotic relationship to occur.

To improve the quality of data produced by sport science, Bishop (2008) proposed the Applied Research Model for the Sport Sciences (ARMSS). Consisting of eight interacting stages (Table 1) that guide the logical progression of research by building on the findings of each stage, ARMSS aims to ensure results are based firmly on cumulative knowledge. Hence, research is continuously tested and verified before being applied to improve performance or health. This approach may ensure sport science is more focused and integrative, which should result in applicable findings avoiding stand-alone studies with little or no practitioner or researcher impact. Whilst other suggested models focus on improving research to practice transfer (Drust and Green 2013, Verhagen et al. 2014, Eisenmann 2017), ARMSS provides a more detailed structure of the cumulative steps of the evidence gathering process. This structure allows a nuanced assessment of the current research base. Therefore, the aim of the present paper is to review our current understanding of the physiological and physical demands of MMA training and competition, as presented within a hierarchy of evidence provided by the ARMSS framework. This work is important is it provides coaches, applied practitioners and researchers an important and valuable summation of the performance related research completed during developmental stages of the sport. The findings provided here lay the foundations of future work to be performed to better understand the requirements and effects of MMA.

2 – Categorising MMA research within the ARMSS model

Studies included in this review were acquired between the months of March 2017 and November 2019 inclusively by searching peer-reviewed articles written in English (or providing an abstract in English) in the following databases and repositories: PubMed, OVID, Google Scholar, Researchgate.net, LibraryPlus and Academia.edu. Keywords used in searches included: MMA, mixed martial arts, training load, time motion analysis, S&C, strength and conditioning, performance, performance analysis, anthropometry, age, physiology. Finally, reference lists and bibliographies were searched for additional sources. The only inclusion criteria was that articles had to discuss performance and/or preparation related aspects of MMA from a physical or physiological standpoint. Studies discussing psychological, sociological or other non-physiological aspects were excluded.

The discussion that forms the body of this review is split into sections corresponding with each stage of ARMSS. Articles were assigned to ARMSS stages based on how closely their key findings fit the stage explanations provided by Bishop (2008**).** Articles which could fit into more than one stage have been placed according to the main conclusion provided by the article author(s). Review and placement of each article was initially undertaken by the lead author, then reviewed and agreed by the remaining authors. To ensure a coherent narrative, articles within each ARMSS stage were grouped into the following themes and discussed in turn:

- Characteristics of the MMA athlete (any article that describes the physical and/or physiological capabilities and/or capacities of MMA participants);
- Characteristics and/or physical/physiological effects of MMA training (any article that describes training methods used and/or the effects of training methods used by/suggested for MMA participants, inclusive of intervention and non-intervention based research);
- Characteristics of MMA performance (any article that describes the internal/external load or the technical/tactical aspects of official competition or simulated bouts, and the technical, physical or physiological predictors/characteristics of successful MMA performance);

These themes were chosen from common areas of sports science research and areas of concern around combat sport athlete preparation (Ruiz 2017). In total, 70 unique articles were found and included. Table 1 details the distribution of these articles in each ARMSS stage. 8 were retrieved that are related to MMA performance but do not fit in any ARMSS stage. Each article included in the review is summarised in Table 2. Whilst injuries, concussions and body-mass regulation are recognised as key facets of MMA, they are outside the scope of this review. The incidences, rates and severity of each of these areas are, however, in need of more focussed research in order to support and protect the participants involved (Seidenberg 2011, Lockwood et al. 2018, Barley et al. 2019).

Table 1 – Descriptors of each ARMSS(Bishop 2008) **stage and the number of MMA related articles that have been reviewed and placed within each stage.**

Purpose	Stage		n = MMA related studies included in each stage
Description	**1**	**Defining the problem** Identification of types of real-world problems and issues that coaches and athletes face. Discussions with practitioners, reviews and meta-analyses.	**11**
	2	**Descriptive research (hypothesis development)** Studies that describe what is currently occurring in the field, cross-sectional studies and methodological studies.	**25**
	3	**Predictors of performance** Studies to identify which factors are most likely to affect performance. Should include replication studies.	**21**
Experimentation	**4**	**Experimental testing of predictors** Studies that determine which of the previously identified predictors are likely causal (controlled, randomised, double blind studies).	**5**
	5	**Determinants of key performance predictors** Studies to determine which intervention(s) most effect the previously identified causal predictors.	**0**
	6	**Efficacy studies** Studies to determine whether the previously highlighted interventions cause substantial positive or negative effects on performance in controlled conditions.	**0**
Implementation	**7**	**Barriers to uptake** Which real world factors may hinder the application of the research findings from the previous stages?	**0**
	8	**Implementation studies** Studies to determine how effective at improving performance the previously identified interventions are when used in a real-world, uncontrolled setting.	**0**

Nb. 8 additional performance related publications do not fit into any stage of the ARMSS model.

3 – ARMSS Stage 1: Defining the Problem

Stage 1 research is currently lacking in MMA, despite calls for work of this kind to be conducted (Lenetsky and Harris 2012, Andreato and Branco 2016). Due to this lack of information, several authors have used data from related combat sports to provide suggestions about the requirements of MMA competition and preparation strategies (James et al. 2016). A lack of understanding about the potential positive and negative effects of training methods amongst practitioners has been highlighted (Amtmann 2004, 2010). Whilst the details of each of these studies are discussed in other sections of this review, this lack of foundational research presents an immediate deviation from the ARMSS. As the aim of stage 1 is to define the nature of the event being studied and the problems requiring attention(Bishop 2008), the absence of this understanding in MMA may have negative implications for the applicability of much of the data discussed in this review.

4 – ARMSS Stage 2: Descriptive Research

4.1 – Characteristics of the MMA Athlete

It has been suggested via needs analyses of other combat sports that MMA participants would likely require a range of physiological capabilities, including high lower body power and anaerobic capacity (James et al. 2016, Lonergan et al. 2018), but these conclusions are based on limited evidence. Though most studies report stature and mass of participants, lean tissue and fat distribution data is limited to the studies reported in Table 3. Each of these used a cross-divisional cohort without delineating between mass divisions, which may mask important distinctions in performance and requirements. A greater but still limited number of papers outlined physical capabilities of MMA participants (example data can be viewed in Table 4). These data tend to suggest that MMA competitors have relatively low $\dot{V}O_2max$, hand grip strength and muscular endurance, alongside moderate relative strength, vertical jump and linear sprint speed, especially when compared to other combat and non-combat sports (Guidetti et al. 2002, Bosquet et al. 2007, Argus et al. 2012, Lockie et al. 2018). A review of anthropometry and physical capabilities demonstrated that MMA competitors tend to have low body fat, high hip and lower torso flexibility and muscular endurance, but moderate cardiovascular capacity(Spanias et al. 2019). The key finding, however, was that most studies use different testing protocols and methods, making conclusions about the population as a whole difficult.

Regarding laboratory measurements, electromyography (EMG) found evidence of a double activation peak of the latissimus dorsi, erector spinae, gluteals and rectus femoris muscles during punches and kicks onto a heavy bag (McGill et al. 2010). Though providing an interesting discussion of relative muscle activation during MMA related techniques, the importance or otherwise of these measurements to performance is not alluded to. Finally, the UFC Performance Institute published suggested normative data (not peer reviewed) for assessing an MMA athlete’s performance in several physiological components, including reactive strength index (RSI), peak power output, $\dot{V}O_2max$ and rate of force development (RFD)(Institute 2018). This provides a useful resource for practitioners to understand the physical abilities of high-level competitors. A limitation of this document from a research viewpoint is that it does not provide specific means or methods for each of these indices, reducing the opportunity for comparison, benchmarking or replication.

Table 3 – Example anthropometrical and body tissue distribution data of MMA competitors

Study	n	Stature (cm)	Body mass (kg)	Body fat (kg)	Body fat (%)	BMI (kg·m^{-2})	Muscle mass (%)	Fat free mass (kg)
(Marinho et al. 2016)	8	177 ± 5	82.1 ± 9.6	11.8 ± 6.2	13.4 ± 5.6*	26 ± 3.3	69.6 ± 4.6	
(Schick et al. 2010)	11	175 ± 5	77.4 ± 11.4		11.7 ± 4*			
(Marinho et al. 2011)	13	176 ± 5	82.1 ± 10.9		11.9 ± 5.1*			
(de Oliveira et al. 2015)	18	172 ± 5	78.3 ± 6.9		15 ± 7.3**			
(LaRocca et al. 2019)	40					24.6 ± 3.3		
(Kasper et al. 2018)	1		80.2	11.7	15***			63.5
(Alm and Yu 2013)	5	180.4 ± 9	80.8 ± 11.1	9.9 ± 2	12.25 ± .5***		83.2 ± 0.8	

*Nb. BMI = body mass index; * = estimated using skinfolds; ** = estimated using air displacement plethysmography; ***estimated using dual energy x-ray absorptiometry*

Table 4 – Example physiological and physical assessment data for MMA competitors

Study	n	$\dot{V}O_2$max (ml·kg·min^{-1})	Hand grip strength (kg)	1RM squat (kg)	1RM relative bench press (kg·kg^{-1})	CMJ (cm)	Relative CMJ (cm·kg^{-1})	SJ peak power (W·kg^{-1})	SJ (cm)	Standing broad jump (cm)	10m sprint (s)	Upper body peak power (W·kg^{-1})
(Schick et al. 2010)	11	55.5 ± 7.3	45.8 ± 6.2		1.2 ± 0.1							
(Marinho et al. 2011)	13			73 ± 15						219 ± 0.25		
(Lovell et al. 2013)	1	Pre = 55, Post = 56.8 training program										Pre = 8.9, Post = 9.7
(Alm and Yu 2013)	5	Pre = 50 ± 6.5, Post = 48.5 ± 5.7 training program					Pre = 0.63 ± 0.4, Post = 0.59 ± 0.1 training program		Pre = 40.3 ± 3.8, Post = 36.2 ± 3.6			
(de Oliveira et al. 2015)	18	44.2 ± 6.7	R = 46 ± 9, L = 45 ± 8.5									
(Marinho et al. 2016)	8			69 ± 6	1 ± 0.2					219 ± 0.31		
(Kostikiadis et al. 2018)	10	Pre = 41.5 ± 11.1*, Post = 46.2 ± 10.3* training program		Pre = 140.7 ± 22.5, Post = 167.1 ± 25.6		Pre = 33.1 ± 5.2, Post = 35.1 ± 3.8			Pre = 31 ± 4.6, Post = 31.6 ± 3.9		Pre = 1.95 ± 0.06, Post = 1.88 ± .05	
(James, Beckman, et al. 2017)	29				HL = 1.21 ± 0.18, LL = 1.07 ± 0.2			HL = 44.45 ± 7.54, LL = 38.47 ± 6.74				

*Nb.1RM = one repetition maximum; CMJ = countermovement jump; SJ = squat jump; * = estimated; R = right hand; L = left hand; HL = pro/semi pro competitors with ≥50% wins; LL = pro/amateur competitors with ≤50% wins*

4.2 – Assessment of MMA Training Loads

In terms of training load assessment, there are large gaps in our knowledge. Two attempts have used participant questionnaires to understand how competitors prepare for bouts (Amtmann 2004, 2010). Both instances found that training in MMA has wide variations in frequency and type (1 – 7 strength and conditioning sessions, 3 -12 MMA sessions per week). Additionally, 83% of participants used resistance training, only 26% incorporated Olympic lifting derivatives and 53% used neck strengthening movements. It was concluded that most participants had poor strength and conditioning knowledge or a lack of support in this area. The only study reporting actual training load data is a case study of an elite participant (n=1) preparing for a professional world championship tournament (Jukic et al. 2017). This competitor experienced mean weekly sessional rating of perceived exertion (sRPE) of 3,653 AU during a 9-week training camp (range = 1,345 - 6,035 AU). Unfortunately, these data are from preparations for a 2006 defunct competition format (one-night, multi-bout tournament), so its utility for current performers is limited. A second more recent training case study does provide details as to the distances, times and prescribed intensities of training for a male professional competitor and the measurable effects of this program(Tota et al. 2014). However, this article does not describe the specific content or training modes of the sessions themselves, nor how they were incorporated alongside the participant's technical training. Torso-mounted accelerometry has been used to measure the external load of standing and grounded MMA strikes and takedowns. Punches, right sided kicks and double leg takedowns elicited greater external loads in training compared to the same techniques in simulated competition (Kirk et al. 2015a). How these loads affect the athlete's overall readiness to perform or how this can be manipulated by the coaches is, however, unknown. The paucity of data regarding the current training practices and loads of MMA participants makes it extremely difficult to form conclusions regarding the efficacy of the methods used. This gap in our understanding of the sport's preparatory practices is a key limitation of MMA research.

4.3 – Physiological adaptations to MMA Training

Alm and Yu (2013) observed a reduction in squat jump (SJ) and countermovement jump (CMJ) relative to body mass after 12 months of MMA training(Alm and Yu 2013). These results are limited, however, as it was conducted with 5 participants being tested in the first instance and only 4 being tested in the second instance due to injury and as such does not provide robust data for practitioners to work from. Furthermore, individual training content and volume were not reported. A case study (n = 1) reporting responses to an 8-week training period demonstrated increased $\dot{V}O_2$max on a cycling ergometer and increased relative upper body peak power(Lovell et al. 2013). This study did report training content, allowing more nuanced considerations to be made by researchers and trainers. This facet of detail was further developed by Kostikiadis et al. (2018) demonstrating significant improvements in physiological variables in this population through employment of a specific 4-week strength and conditioning program. Further details of this study are discussed in section 6.1.

4.4 – Physical and physiological demands of MMA competition

4.4.1 – External Load of MMA competition

External load of MMA competition has been measured directly and by proxy in official competitions and simulated bouts. Torso mounted accelerometry measured accumulated player load (PL_{ACC} = 224.32 ± 26.59 AU) and accumulated player load per minute ($PL_{ACC}{\cdot}min^{-1}$ = 14.91 ± 1.78 AU) in simulated bouts of 3 x 5 minute rounds (Kirk et al. 2015b). This demonstrates that MMA external loads may be comparable to those of an Australian rules football match (Mooney et al. 2013), but greater than those experienced by elite netball players(Cormack et al. 2014) and defenders in association football (Domene 2013). Given accelerometry displays high reliability in the measurement of external load of MMA (Hurst et al. 2014), this method shows promise for use within training and competition and should be explored further by researchers and practitioners alike.

The physical demands of MMA competition has also been measured by proxy through time motion analyses (TMA). Del Vecchio et al. (2011) determined that within a 5 minute round, there was 2-3 minutes of activity, which generally reduced as the round and the bout commenced. Work-to-rest ratio (W:R) was 9:1 – 6:1, when taking the 1 minute break between rounds into account. When excluding the 1 minute break, W:R was 1:2 – 1:4, with the briefest category being high intensity standing (9 ± 8 s) and the longest being low intensity groundwork (21 ± 19 s). 'Rest' periods included low intensity combat phases (stable positions requiring little effort or movement) and pauses (Del Vecchio et al. 2011). The same research group used their TMA method to show female competitors spend longer engaged in low intensity standing movements, less time in high intensity standing movements and less groundwork time in total than males. The same study also reported the ratio of high to low intensity (H:L) to be 2:1, indicating that MMA participants utilise higher intensity movements more often than low intensity movements (Del Vecchio et al. 2015).

Further analyses demonstrated W:R differences between divisions, with the greatest differences in H:L being observed in the standing phases of each bout. For example, flyweight (FlW) reported values of 1:15 whereas heavyweights (HW) reported values of 1:7(Miarka et al. 2015). In terms of total effort time, HW displayed shorter time than all other divisions in the first (212.4 ± 101.5 s) and third (246.3 ± 89.1 s) rounds, whilst bantamweight (BW) was shortest in the second round (132.8 ± 90.9 s). MMA competitors also increase their time spent in standing preparatory actions (non-striking or grappling) as the bout progresses, a potential effect of fatigue (Antoniettô et al. 2019). In simulated competition, MMA participants had a W:R = 1:1.01, with most active time being spent in the clinch (aggressor = 100.33 ± 65.87 s; defensive = 95.5 ± 58.48 s) and striking low activity (95.5 ± 12.63 s). Conversely, participants in this study only spent 15.33 ± 11.22 s in striking high activity(Kirk et al. 2015b). When comparing results of each of these papers, it becomes clear that actions in MMA are intermittent, with differing requirements for participants of different divisions and sex (Del Vecchio et al. 2015, Antoniettô et al. 2019). Equally, relative intensities of competition and simulated competition can be very different, an observation that has also been made in other combat sports (Andreato et al. 2016, Slimani et al. 2017).

Importantly, there are no studies analysing the physical demands of amateur bouts, with each of the discussed studies using professional or semi-professional participants and most using data from high level international bouts. Because of this, it is unknown whether there are any differences in bout characteristics between this level and the developmental levels of the sport. Such knowledge would likely be important to the successful development of training frameworks. One key issue with much of the external load data is the subjective manner in which 'rest' and 'work' have been identified. For example, the load of isometric movements associated with grappling has not been quantified, so determining whether these are genuinely rest or work is largely a judgement-based decision. This needs to be considered when reviewing TMA data in MMA.

4.4.2– Internal Load of MMA competition

Data regarding internal load is presented in Table 5. Such data demonstrate that MMA seems to induce physiological responses within the same ranges as other contact and non-contact sports (Klapcinska et al. 2001, Lippi et al. 2004, Paccotti et al. 2005, Nunes et al. 2012). These responses appear to be similar regardless of whether it is official or simulated competition, with the exception of cortisol. The specific movements, techniques and tactical approaches that bring about these responses have not yet been identified, whilst the medium term (24 – 48h post) metabolic and muscle damage responses have also not been fully determined. This would be a key area for identifying the true internal load of MMA. Also highlighted is the need for researchers to use a consistent protocol of sampling and measurement in terms of biomarkers and sampling points.

Table 5 – Summary of internal load measures of MMA technical training, official competition and simulated competition

Study	Mode	Variable measured	Pre	Post	24 hours post	48 hours post
(Amtmann et al. 2008)	Official competition	Lactate (mmol·L^{-1})		10.2 – 20.7		
		RPE (AU)		13 – 19		
	Simulated competition	Lactate (mmol·L^{-1})		13.3 – 18		
		RPE (AU)		15-18		
	Training	Lactate (mmol·L^{-1})		13 – 19.7		
		RPE (au)		17 – 19		
(Kirk et al. 2015b)	Simulated competition	Lactate (mmol·L^{-1})	2.7 ± 1.46	9.25 ± 2.96 ↑		
(Coswig, Ramos, et al. 2016)	Official competition	Urea (mg·ml^{-1})	44.15 ± 8.93			36.31 ± 7.85 ↓
		Uric acid (mg·ml^{-1})	5.17 ± 0.91			4.62 ± 0.78 ↓
(Coswig, Fukuda, et al. 2016)	Official competition	Creatine kinase (U·L)	221 (median)	237 (median) ↑		
		Lactate (mmol·L^{-1})	4 (median)	16.9 (median) ↑		
	Simulated competition	Creatine kinase (U·L)	225 (median)	297 (median) ↑		
		Lactate (mmol·L^{-1})	3.8 (median)	16.8 (median) ↑		
(Souza et al. 2017)	Official competition	Cortisol (nmol·L^{-1})	594 ± 144.9	876 ± 107.84 ↑	436 ± 126.26 ↓↓	
		Glucose (mg·dl^{-1})	4.81 ± 0.92	10 ± 2.55 ↑	3.82 ± 0.28 ↓↓	
		Testosterone (nmol·L^{-1})	13.03 ± 3.9	11.92 ± 1.79 ↓	17.75 ± 2 ↑↑	
		Creatine kinase (U·L)	433.89 ± 215.95	491.81 ± 219.17 ↑	1,412.69 ± 758.63 ↑↑	
(Ghoul et al. 2017)	Simulated competition	Cortisol (ng·dl^{-1})	88.3 ± 19.6	131.2 ± 56.4 ↑	79.3 ± 23.2 ↓↓	
		Testosterone (ng·dl^{-1})	3.5 ± 0.3	4.6 ± 0.3 ↑	3.4 ± 0.3 =↓	
		Uric acid (µmol·L^{-1})	308 ± 53	342 ± 54 ↑	344 ± 48 ↑=	
		Lactate dehydrogenase (U·L)	169 ± 70	230 ± 116 ↑	226 ± 75 ↑=	

Nb. ↑/↓/= on Post and 48 hours post measurements indicate either increase/decrease/no practical change from Pre measurements; first ↑/↓/= on 24 hours post measurements indicate either increase/decrease/no practical change from Pre measurements; second ↑/↓/= on 24 hours post measurements indicate either increase/decrease/no practical change from Post measurements; RPE = rating of perceived exertion.

5 – ARMSS Stage 3: Predictors of Performance

5.1 – Physical and Physiological Characteristics

5.1.1 - Physiology

Analysis of muscular force production in relation to success in MMA was found in one study (James, Beckman, et al. 2017). High level semi-professional competitors (HL) were capable of superior lower body neuromuscular force production than low level semi-professional and amateur competitors (LL). This was based on significant differences in relative back squat one repetition maximum (1RM) (HL = 1.84 ± 0.23; LL = 1.56 ± 0.24 kg·kg^{-1}), squat jump (SJ) peak power (HL = 44.45 ± 7.54; LL = 38.47 ± 6.74 W·kg^{-1}) and SJ peak velocity (HL = 3.06 ± 0.33; LL = 2.81 ± 0.33 m·s^{-1}) between both groups (for other results see Tables 1 and 3). Professional and amateur competitors may also be distinguished with at least a small or better effect size in 10 and 20 m sprint times, repeat sprint ability and Yo-Yo Intermittent Recovery results (James et al. 2018). The authors of each of these studies suggest that training for this population should maximise lower body force capacity and impulse, as well as sprint and repeat sprint capability. Given the limited number of studies completed and the largely subjective distinction between high and low-level competitors, more work is required to unequivocally link these variables to success in MMA.

5.1.2 – Anthropometry

Anthropometry has an anecdotal relationship to success in combat sports, with a competitor's 'height and reach' being reported as a matter of course. This assumption has been tested in MMA, mostly by the lead author of this review. Stature and/or arm span differences have small to moderate correlations with technique use differences between winners and losers of professional bouts. These relationships were found in heavyweight (HW), welterweight (WW) and featherweight (FW) with less than half of the variance in technique use being explained by anthropometrical differences between opponents (Kirk 2018a). Anthropometry has also been studied in relation to divisional rank and attainment of world title bouts, with only a negligible effect being found in two divisions. These were in flyweight (FlW), where shorter competitors were ranked highest and in women's strawweight (WSW) where shorter competitors were ranked in the middle of the division. Arm span was found to have no influence at all(Kirk 2016a). Though taller participants were more likely to win individual bouts via strikes than submission or decision, this was found to be anecdotal using Bayesian inference (BF_{10} – see note marked * in Table 6). In comparison, if the bout loser was taller than their opponent, the evidence for them losing due to strikes was classed as very strong. Equally, competitors with longer arm spans were more likely to lose due to strikes rather than decision, and at WW they were moderately more likely to lose due to submission(Kirk 2016b).

Each of these papers also discussed the so called 'ape ratio', a measurement representing the scale of a person's arm span in comparison to their stature (S:W), showing that despite this variable influencing success in other sports, it has none in MMA(Kirk 2016a, 2016b, 2018a). This conclusion has been questioned as it was found that S:W can predict MMA participant's winning percentage. This result, however, showed that less than 1% of variance in winning percentage can be explained by this anthropometric measurement(Monson et al. 2018). The anecdotal link between success and anthropometry appears to be vastly over-estimated in MMA, potentially due to the use of grappling to negate any potential dis/advantages stature or arm span provides in the striking phases of competition.

5.1.3 – Aging

Competitive bout winners (30 ± 4 years) were likely to be younger than bouts losers (31 ± 4 years) when examined at as cross divisional cohort (Kirk 2016b). This age gap was different for each division with the greatest found at lightweight (LW) and bantamweight (BW) (~ 3 years difference in each). A potentially more important effect of age was found in the methods of winning or losing. If the winning participant was older they most likely won due to a decision and in cases where older participants lost, it was most likely due to strikes. This could provide evidence that participants become more susceptible to strikes as they age, possibly due to a reduction in speed and reaction times (Korhonen et al. 2009, Hunter et al. 2016). This is supported by the odds ratios of suffering a KO or a TKO increasing with age(Hutchison et al. 2014). This could result in a cyclical pattern of performance and health deterioration, as physiological decrements have also been related to the effects of repeated concussive strikes in training and competition (De Beaumont et al. 2013, Richmond and Rogol 2014).

The effects of age related adaptations have been revealed over a 10 year period as reduced strike accuracy and rate, fewer successful takedowns and lower markers of intensity (Santos et al. 2018). Another potential consideration could be that as participants age they become more attuned to tactical requirements of the sport and are better able to achieve decision wins instead of taking increased risks to attain a stoppage victory. An analysis of the top 100 male competitors in each division indicated that a combination of these two factors could result in 'peak performance windows'. Older participants were generally ranked higher, with the highest 20% of a cross-divisional cohort being older than the other 80%. Equally, this study also found that as divisional mass limit increases, so too does the average age of the top 100 competitors. This pattern starts at BW (29 ± 4 years) and progressively increases up to HW (33 ± 5 years) (Kirk 2018b). We conclude here that performances in lighter divisions could be more affected by physiological decrements of aging on speed, force production and reaction time than in heavier divisions, leading to lighter competitors dropping out of the top 100 earlier. However, without currently knowing the respective contributions of these variables to performance in MMA, this conclusion remains an early supposition.

5.2 – Technical Actions of Competition

Table 6 provides a brief summary of distinguishing technical factors of successful MMA performance. These results suggest that being competent in all phases of combat is a prerequisite of success, and that skills needed are highly dependent on situation and opponent. Though the studies listed elucidate technical requirements of MMA, they do not distinguish between divisions, which have understandably large differences in anthropometrical measurements (Kirk 2016a). It would be natural to assume that these differences would lead to distinguishable movement and skill characteristics. Such technical differences have been reported (Miarka, Brito, Dal Bello, et al. 2017), showing that each division displays differences in the time spent engaged in striking, clinch work, keeping distance and attacking the body, as well as diverse frequencies of technique use in each area.

In a similar vein, there is evidence of differences between each division in terms of which techniques contribute most to a winning performance (Kirk 2018a). The summary in Table 7 shows wide variations in technical characteristics separating winners and losers. WW and LW participants arguably require a more complete skill set than HW and light heavyweight (LHW), who appear to display little influence of grappling. These results strongly indicate that future studies should be conducted on a division-by-division basis, not treating MMA participants as a homogenous group. There could also be a need to perform replications of some of the studies named in this section for the same purpose, thus allowing a clearer picture with more applicable results to emerge. Equally, there may need to be more research of bouts that end due to stoppage(Miarka et al. 2018) and bouts that go beyond the standard three rounds(Miarka et al. 2019). Though a reasonable amount of work has been done to better understand technical and tactical performance in MMA, these criteria seem to be evolving as the sport matures (Santos et al. 2018), often in response to adaptations to rule changes in the sport (Fernandes et al. 2018). With this in mind, it is important that this work continues to monitor these changes to better inform coaching decisions.

Table 6 – Summary of key determining factors of successful MMA performance

Study	Mode	Sample	Key determining factor	Other info
(Kirk et al. 2015b)	Simulated competition	6 male participants	Successful takedowns achieved	
(Miarka, Brito, and Amtmann 2017)	Official competition	584 professional bouts	Head strikes landed at distance, guard passes, successful takedowns	
(Miarka, Del Vecchio, Camey, et al. 2016)	Official competition	215 professional bouts	Total strikes, submission attempts, ground positional changes	
(Miarka et al. 2018)	Official competition	678 professional bouts	Less time engaged in low intensity standing actions at any point in the bout, and more time in high intensity groundwork in the first 2 rounds	Bouts ending in judge's decision excluded
(dal Bello et al. 2019)	Official competition	304 professional rounds	Type and frequency of grappling techniques used (takedowns, sweeps and submission attempts) appear to have a direct influence on whether the bout ends in a unanimous/split decision, submission, KO or TKO	
(Miarka, Coswig, et al. 2016)	Official competition	174 professional rounds	Bouts that ended via stoppage (TKO, KO or submission) consist of more time spent striking and grappling; bouts that ended in a decision characterised by more time spent performing standing strikes only	Female bouts only
(Miarka et al. 2019)	Official competition	779 professional rounds from bouts ended in rounds 3 – 5	Activity profiles are different dependent on whether the bout ended in the 3rd, 4th or 5th rounds	
(James, Robertson, et al. 2017)	Official competition	234 professional bouts	Strike and takedown accuracy concomitant with ground strikes landed	

Nb. KO = knockout; TKO = technical knockout

Table 7 – Summary of variables found to distinguish between winners and losers of professional MMA bouts according to Bayes Factor (BF_{10})* hypothesis test thresholds greater than moderate (Kirk 2018a)

	Distinguishing Performance Variables by BF_{10} Likelihood Threshold					
Division	**Decisive**	**Decisive to Very Strong**	**Very Strong**	**Very Strong to Strong**	**Strong**	**Strong to Moderate**
Heavyweight	Significant strikes landed; significant strikes attempted					Significant ground strikes landed; knockdowns
Light Heavyweight	Strikes landed					Significant ground strikes landed
Middleweight	Significant strikes landed; strikes landed; strikes attempted; significant strikes attempted; significant ground strikes landed.		Significant distance strikes landed		Guard passes	
Welterweight	Significant ground strikes landed; strikes landed; significant strikes landed; guard passes; strikes attempted; knockdowns; successful takedowns; distance knockdowns	Takedowns attempted			Significant strikes attempted; significant distance strikes landed.	
Lightweight	Significant strikes landed; significant ground strikes landed; strikes landed; strikes attempted; significant strikes attempted; submissions attempted; knockdowns; distance knockdowns; guard passes.		Significant distance strikes landed	Successful takedowns; significant clinch strikes landed		Significant distance strikes attempted.
Featherweight	Knockdowns; Distance knockdowns		Submissions attempted			Significant strikes landed; significant ground strikes landed.
Bantamweight	Significant strikes landed; significant ground strikes landed; Significant strikes attempted.		Significant clinch strikes attempted.	Strikes attempted	Knockdowns	Strikes landed; significant distance strikes landed; submissions attempted
Flyweight	Significant strikes attempted	Successful takedowns	Submissions attempted	Strikes attempted	Passes	Significant ground strikes landed
Women's Bantamweight			No variables greater than moderate			
Women's Strawweight	Strikes landed	Strikes attempted	Significant strikes landed		Guard passes; significant strikes attempted	Significant distance strikes landed

*Nb. Variables for each division shown in order of BF_{10} likelihood magnitude. *For an explanation of the use and application of Bayesian inference and BF_{10}, please see Wagenmakers et al. (2018)*

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6 – ARMSS Stage 4 Experimental Testing of Key Performance Predictors

6.1 – Physiological adaptations associated with MMA Training

A small number of studies provide experimental data assessing effectiveness of training methods applied in MMA. A recent study suggested a 6-week strength and power training program likely caused increases in cross punch, roundhouse kick and lower limb force production amongst MMA and kickboxing participants(Vecchio et al. 2019). However, the authors do not clarify how the MMA and kickboxing participants are distributed between the intervention and control groups. More importantly, there is no evidence that strike force in itself is a key determinant of success. The content of the 6-week training program, however, is provided in sufficient detail to allow replications. The physiological effects of a 4-week MMA specific strength and conditioning programme on a group of MMA competitors (specific training group (STG)) were compared to a control group of MMA competitors (regular training group (RTG)) completing their normal technical and non-MMA specific strength and conditioning sessions (Kostikiadis et al. 2018). Use of the specific strength and conditioning programme alongside technical training elicited greater increases in comparison to technical training alone: estimated $\dot{V}O_2max$ (STG = 13.3 ± 14.5%, RTG = -0.1 ± 6.9%); back squat 1RM (STG = 19.5 ± 10.4%, RTG = 2.05 ± 8.45%); CMJ (STG = 7.4 ± 4.4%, RTG = 1.2 ± 1%); 10m sprint (STG = -3.7 ± 1.4%, RTG = -0.4 ± 1.1%).

Further evidence of the acute effect of strength and conditioning was observed between two groups of participants split by their preferred combat style (group A = striking based; group B = grappling based) (Chernozub et al. 2018). Each group was prescribed a 3-month power training programme based on their combat style to be completed alongside their technical training. Upon completion of the programme both groups then completed the opposite style's training programme for the next 3 months. Bench press 1RM data was collected at months 0, 3 and 6. Both groups significantly increased strength at each sampling point regardless of the style of training completed. Though between group analysis was absent, it does appear that both groups responded better to training designed for striking style than grappling style. Due to the programmes being completed in series, this cannot be confirmed. Equally, there is no comparison to a control group, and the measurement chosen does not necessarily reflect MMA performance.

Though each of these studies provide experimental data of training interventions, there is little indication that the variables being improved directly influence competitive performance, showing a clear deviation from ARMSS. These data do, however, provide a starting point for understanding which types of training may bring about positive adaptations.

7 – ARMSS Stages 5-8

As can be seen in Tables 1 and 2, there are currently no studies that can be placed in any of the four later stages of ARMSS. This is likely due to the conclusions of sections 5 and 6, that a causal link between predictors of performance and success has not yet been established. This is likely to be important if successful stage 5 (and beyond) research is to be completed. Conversely, while this may initially appear to be a failing of MMA research, it may also demonstrate that researchers are working to build the foundation of our collective understanding sufficiently before attempting to undertake potentially flawed latter stage research. From this viewpoint, MMA research could be said to be following the process of ARMSS, in that it appears to have been recognised that stage

5-8 work cannot currently be performed. It does also mean, however, that we are currently not in a position to confidently state what the determinants of successful performance are, or how we can optimally prepare an athlete to achieve them. Most of the topics discussed throughout this review have been categorised to sit within the foundational, descriptive stages of the ARMSS.

8 – Performance studies that are not applicable to the ARMSS model

A number of retrieved articles do not fit into any stage of ARMSS. In response to the pressing needs of practitioners, several authors have presented suggestions for strength and conditioning models based on data from other combat sports and assumptions of the requirements of MMA (La Bounty et al. 2011, Tack 2013, Earnshaw 2015). Other protocols are specific towards injury prevention (James 2014), female competitors (Schick et al. 2012) or metabolic conditioning (Mikeska 2014, Harvey 2018). In summary, the recommendations are a combination of some or all of the following: strength and power training to improve torso stability and lower body force production; mobility and aerobic conditioning via the use of high intensity interval training (HIIT). Though each presents recommendations based on established strength and conditioning theory, none provide any data assessing the effectiveness of these models. Only one (Harvey 2018) provides details as to how their recommendations could be utilised alongside technical training to optimise preparation. The author in question presents an MMA specific HIIT protocol to integrate into technical training sessions, though admits that effectiveness of this protocol requires testing to demonstrate validity. This recommendation can be applied to each of the articles in this section: future research needs to address the absence of scientific evidence to support the suggested protocols for MMA.

9 – Conclusions and Future Research Directions

When considering the body of research as presented in the current review, it is clear that most is descriptive in nature and does not strictly follow ARMSS. Not all factors studied in stage 3 (predictors) are linked to stage 2 (descriptive) findings. Equally, none of the variables experimentally tested in stage 4 have been found to predict performance in stage 3. There has been little attempt at understanding the sport's current training practices. Research describing the movements and techniques used in professional competition is fairly well developed, but this does not seem to have transferred into experimental testing or training interventions. Training studies focus on physiological variables that have not been adequately linked to success. There is also a lack of distinction between sexes, with only two papers discussing females exclusively (Schick et al. 2012, Miarka, Coswig, et al. 2016). Given the inherently different responses to training and performance between sexes (Pitchers and Elliot-Sale 2019), this would be an important area for research focus. These conclusions place the current review in stage 1 of ARMSS, defining as it does the current gaps in MMA research.

Based on these findings, the authors have developed a series of questions within ARMSS to reflect the areas we feel are most in need of immediate attention (Table 8). These questions may begin the process of our collective foundational knowledge of MMA becoming better developed. This in turn would allow researchers and practitioners to access later stages of ARMSS. This would require active collaboration between researchers and practitioners with a coherent approach to issues raised, in turn reducing negative effects of disparate results caused by isolated questions. It should be noted that ARMSS is designed to improve the quality of information being delivered to practitioners only. Other models have been developed to improve the vital process of knowledge management and transfer (Drust and Green 2013, Verhagen et al. 2014, Eisenmann 2017). Given the aims of the current review, however, exploration of these models within MMA are beyond the scope of this article. Discussion of this kind may also be premature, given the lack of foundational knowledge within MMA science demonstrated here. Using ARMSS in MMA research at this point will allow researchers to fully develop early stage understanding of the sport in a consistent and effective manner. Once this has been achieved then impactful knowledge transfer can occur.

The current review provides an important resource for applied practitioners, coaches and researchers in outlining our current understanding of the demands of MMA. We have collated all extant data (Table 2) for a clearer appreciation of the differing requirements of success between divisions, the short term internal responses to competition, the potential physiological responses to MMA training, and to highlight our lack of data regarding the training practices used in the sport. This knowledge should be used by coaches as part of an ongoing evaluation of training methods in relation to their athlete's needs. Specifically, this could be avoiding reliance on unsupported predictive variables such as anthropometry; incorporation of targeted strength and conditioning programs alongside technical training; and devising tactical approaches to competition based on division specific performance characteristics. Researchers should use this article as a reference text to guide future research plans and questions to address the highlighted gaps in our knowledge. The application of ARMSS presented here also demonstrates how MMA research can be structured to ensure knowledge generation is efficient and purposeful, enabling future work to be conducted on a strong foundation. With MMA becoming more organised globally at both professional and amateur levels, now is the time to influence real change and progress within the scientific basis of the sport for everyone involved.

Table 8 – Suggested questions in the first three stages of the ARMSS model to inform future MMA research

Stage	
2	**Descriptive research** • What are the physical, physiological and technical demands of professional and amateur MMA competition? Such research studies should use a range of methods to quantify external and internal loads in both male and female participants as well as be specific to each weight division. • What are the habitual training practices undertaken by professional and amateur MMA athletes preparing for competition? Such research should describe the range of training modalities, activities and specific combat techniques across a time-scale that athletes typically complete when preparing for competition. Similar to the above, such studies should use a range of methods to quantify external and internal loads in both male and female participants as well as be specific to each weight division. • What are the physical and physiological effects of MMA training? Using a testing battery of reliable and valid performance tests, such research should examine the physiological adaptations associated with participating in an MMA training programme that is intended to prepare male and female professional and amateur athletes for competition.
3	**Predictors of performance** • Which physical, physiological and technical characteristics provide the strongest predictor of successful performance in MMA? On the basis of understanding the physical and physiological demands of training and competition, such studies should subsequently a range of factors that are associated with successful performance so as to provide a platform to then experimentally test each predictor.

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Table 2 – MMA performance related research placed within the ARMSS model

Stage of ARMSS Model, followed by Research Category	Study	Cohort n and type	Key Data	Conclusions
1: Defining the problem				
Athlete	(Lenetsky and Harris 2012)	N/A#	6 peer reviewed studies related to MMA performance.	Call for more MMA specific research to be conducted due to the paucity of extant research at the time. MMA training prescription based on physiological measurements of other combat sports.
	(Andreato and Branco 2016)	N/A#	Author communication.	Discussion of applicability of other combat sports physiologies to MMA research, and recommendation to base physiological profiling of MMA on work-to-rest (W:R) ratios and bout length.
	(James et al. 2016)	Systematic review of n = 23 combat sports related physiological studies	n of studies included and discussed: Brazilian jiu jitsu = 1 Boxing = 2 Judo = 8 Karate = 4 Wrestling = 8	The lack of robust physiological studies existing in MMA led authors to determine training requirements of MMA competitors based on findings from other related combat sports. Grappling based sports require a greater maximal strength in comparison to striking based sports, with greater movement velocity being characteristic of striking based sports.
	(Lonergan et al. 2018)	N/A#	Strength and conditioning (S&C) based needs analysis of MMA performance	S&C for MMA should be multifaceted and aimed towards the development of aerobic capacity and 'explosive' movements. *Nb. S&C = strength and conditioning*
	(Spanias et al. 2019)	Systematic review of n = 19 MMA related physiological studies	Review of existing studies into anthropometry and physical performance on MMA competitors.	MMA competitors tend to have low body fat, high flexibility, muscle strength, muscular endurance and anaerobic power, with moderate cardiovascular capacity. Lack of consistent testing protocols between studies make comparisons difficult, but there does not appear to be differences between performance levels.
Training	(Amtmann 2004)	n = 28 regional MMA competitors, age range = 19 - 37	Freq of S&C sessions per week range = 1 - 7; freq of MMA sessions per week range = 3 – 12; 12 participants stated using neck strengthening exercises; 8 participants stated using Olympic lift variations; 5 participants admitted to anabolic steroid use.	Questionnaire conducted immediately prior to competition. Large variations in frequency and types of S&C training, poor education regarding training methods
	(Amtmann 2010)	n = 32 regional MMA competitors, age range = 19 – 41	Freq of S&C sessions per week range = 1 - 6; freq of MMA sessions per week range = 2 – 10; 16 participants stated using neck strengthening exercises; 8 participants stated using Olympic lift variations; 2 participants admitted to anabolic steroid use.	Questionnaire conducted immediately prior to competition. Large variations in frequency and types of S&C training, poor education regarding training methods. *Nb. S&C = strength and conditioning*
	(Amtmann 2011)	N/A#	Author communication.	Discussion of MMA training based on other combat sports in lieu of detailed MMA research. Suggests basing training on work-to-rest ratio (W:R) found in MMA studies until more research is conducted.
	(Jay 2013)	N/A#	Narrative review of MMA research at time of publication in relation to strength and conditioning research	S&C recommendations based on general S&C research. Highlights the lack of MMA specific research as a barrier. *Nb. S&C = strength and conditioning*
	(Souza-Junior et al. 2015)	N/A#	Non-systematic review of MMA literature and other related combat sports literature.	Too little MMA specific research has been conducted to form specific physiological profile or training framework. Research from other combat sports and sports physiology in general should be used in the interim
	(Del Vecchio and Franchini 2013)	N/A#	Author communication.	Correspondence discussing the need for more W:R research to investigate the intermittent nature of MMA. Suggests basing training on W:R and individual athlete's responses until more research is conducted. *Nb. W:R = work-to-rest ratio*
2: Descriptive research				

Training	(Hurst et al. 2014)	n = 8 male MMA competitors, age = 25.5 ± 4.5	Player load (PLd) intraclass correlation coefficient (ICC) = 0.700 – 0.970 and accumulated player load (PLd_{ACC}) ICC = 0.794 – 0.984. Coefficient of variation (CV) = 2.4 – 7.8%.	Demonstration of reliability of body worn accelerometry to measure external load of MMA participation. Measured across 8 Catapult Minimax units, with 5 repetitions of 10 standing striking techniques, 6 ground striking techniques and 2 takedown techniques.
	(Tota et al. 2014)	n = 1 male, professional MMA competitor preparing for one bout over an 11-week period	Mean power: Pre = 6.9, Post = 7.1 $W{\cdot}kg^{-1}$; Peak power: Pre = 7.79, Post = 8.1 $W{\cdot}kg^{-1}$; $\dot{V}O^2max$: Pre = 57.1, Post = 58.4 $ml{\cdot}kg{\cdot}min^{-1}$; Lean body mass increase = 1.5 kg; Fat mass decrease = 1.4 kg.	11 weeks of a specific training program brought about positive, measurable changes in body composition and physiological capabilities. Though times, distance and prescribed intensities of the training program are reported, there is no detail about training methods or modes provided.
	(Kirk et al. 2015a)	n = 8 male MMA competitors, age = 25.5 ± 4.5	Significant differences in PLd (au) between sparring and isolation: jab = 2.04 ± .29 (sparring), 2.88 ± .37 (isolation); cross = 2.25 ± .26 (sparring), 3.37 ± .37 (isolation); left hook = 2.48 ± .31 (sparring), 3.18 ± .4 (isolation).	Accelerometry used to show that jabs, crosses and left hooks cause greater PLd in isolated training than in sparring, single leg takedowns cause greater PLd than double leg takedowns and takedowns cause greater PLd than strikes, with no differences in PLd between a successful and an unsuccessful takedown. Despite no significant differences found, right hook, left leg kick, right body kick, right high kick, successful double leg takedown (attacking and defending) all had either a moderate or large effect size (Cohen's d) between isolated training and sparring. *Nb.Pld = Playerload*
	(Jukic et al. 2017)	n = 1 male, professional MMA competitor preparing for a one night international tournament	Weekly sRPE (au): Week 1 = 2,210; Week2 = 5,132; Week 3 = 6,035; Week 4 = 3,240; Week 5 = 5,443; Week 6 = 2,925; Week 7 = 3,442; Week 8 = 3,105; Week 9 = 1,345; Mean = 3,653; Max HR = 182 $beats{\cdot}min^{-1}$; $\dot{V}O^2max$ = 55.2 $ml{\cdot}kg{\cdot}min^{-1}$	Case study detailing the S&C training practices and weekly loads over a 9-week training period of an elite participant preparing for competition in 2006. Training included strength, power, strength endurance, aerobic conditioning and injury prevention strategies in keeping with accepted S&C and periodisation theory *Nb. sRPE = sessional rating of perceived exertion*
	(Chernozub et al. 2019)	n = 40 MMA participants (age 21 ± 0.8), split into two groups: group A: resistance training low intensity/high volume; group B resistance training high intensity/low volume	Fat free BM: A pre = 69.1 ± 3.3 kg, post 70.8 ± 3.4 kg; B pre = 68.7 ± 3.4, 71.5 ± 3.3 kg. Cortisol: A pre = 283.5 $nmol{\cdot}L^{-1}$, post 483.9 $nmol{\cdot}L^{-1}$; B pre = 458.8 $nmol{\cdot}L^{-1}$, post = 641.3 $nmol{\cdot}L^{-1}$. LDH: A pre = 492 cu, post = 440 cu; B pre = 465 cu, post 366.5 cu.	MMA competitors respond as expected to high intensity/low volume and low intensity/high volume resistance training over 3 months. No indication of whether body composition or biomarker changes are related to MMA performance. *Nb. LDH = lactate dehydrogenase. cu = article authors do not define this unit*
Performance	(Amtmann et al. 2008)	n = 6 competitive males, age range = 21 - 41	Post MMA training (n = 4): Lac ($mmol{\cdot}L^{-1}$)= 13 – 19.7; RPE (au) = 17 – 19; Post MMA sparring (n = 4) : Lac = 13.3 – 18; RPE = 15 – 18; Post competitive MMA bout (n = 6): Lac = 10.2 – 20.7, RPE = 13 -19	Suggests that full competitive bouts (3 x 5 mins) require equal exertion to sparring bouts. 4 of the 6 bouts ended in the first round producing lower values for lactate and/or RPE for these participants. *Nb. RPE = rating of perceived exertion*
	(Del Vecchio et al. 2011)	n = 52 male professional competitors, age = 24 ± 5, n of bouts = 26	W:R = 9:1 – 6:1 when including the break between rounds; 1:2 – 1:4 when excluding the break between rounds.	Only significant difference between rounds found in low intensity groundwork between round 2 (36 ± 26 s) and round 3 (21 ± 6 s). Over half of bouts end in high intensity ground positions, meaning training should be aimed at simulating these positions and intensities.
	(Miarka et al. 2015)	n = 2,097 male professional bouts	Effort time (s): 1st round: Longest = 269.8 ± 64.1 (LW); Shortest = 212.4 ± 101.5 (HW); 2nd round: Longest = 277.8 ± 61.6 (FW); Shortest = 132.8 ± 90.9 (BW);	W:R profile of MMA bouts is significantly different between weight divisions and between rounds, demonstrating intermittent nature of event and potential differences in pacing strategies between divisions. *Nb. W:R = work-to-rest ratio*

			3^{rd} round: Longest = 289.6 ± 42.3 (WW) Shortest = 246.3 ± 89.1 (HW)	
	(Del Vecchio et al. 2015)	n = 64 professional MMA buts, 32 male bouts and 32 female bouts	High intensity to low intensity ratio = 2:1; Low intensity standing (min:s): Males = 04:19.7 ± 03:19.5; Females = 06:55.6 ± 04:47.7; High intensity ground (min:s): Males = 01:14.6 ± 01:16.4; Females = 0:40.8 ± 01:9.1; Freq of attacks: Males = 47 ± 22.83; Females = 21 ± 15.11; Attacks to head: Males = 31 ± 18.51; Females = 15 ± 6.28.	Female participants spend longer in competition engaged in low intensity standing movements than male participants, less time in low intensity standing and grounded movements than males.
	(Adam et al. 2015)	n = 1 professional, regional bout between two male MMA competitors (Comp A and Comp B)	Attack activity by round: Round 1 = 4.6 in favour of Comp A; Round 2 = 1.6 in favour of Comp B; Round 3 = 13.3 in favour of Comp A. Attack versatility index by round: Round 1: Comp A = 0.05, Comp B = 0.11; Round 2: Comp A = 0.12, Comp B = 0.1; Round 3: Comp A = 0.03, Comp B = 0.13	Single bout description of techniques used, showing one participant using stand up striking only, the other participant using a combination of stand up striking and ground grappling. *Nb. Attack activity = sum of attacks per minute minus sum of opponent's attacks per minute. Attack versatility = metric representing the range of different attacks from different technique groups*
	(Kirk et al. 2015b)	n = 6 male MMA competitors, age = 26.17 ± 5.04, one 3 x 5 minute sparring bout each	PLd_{ACC} per minute ($PLd_{ACC}{\cdot}min^{-1}$) (au) = 224 ± 26.59; Lactate ($mmol{\cdot}L^{-1}$)= 9.25 ± 2.96; W:R = 1:1.01; bout winners takedowns = 3 ± 1 (attempted 4 ± 2), bout losers takedowns = 0 (attempted 2 ± 2)	Lactate measurements significantly different across each sampling point (rest, post warm up, end of each round and 5 minutes post bout). PLd_{ACC} and $PLd_{ACC}{\cdot}min^{-1}$ displayed a linear reduction in each round. Successful takedowns only significant differences between winners and losers of bouts. *Nb.* PLd_{ACC} *= accumulated Playerload;* $PLd_{ACC}{\cdot}min^{-1}$ *= accumulated Playerload per minute*
	(Coswig, Fukuda, et al. 2016)	n = 25 male MMA competitors, age = 26.5 ± 5	Sparring bouts (13): Lac ($mmol{\cdot}L^{-1}$) Pre = 3.8 [2.8 – 5.5], Post = 16.8 [12.3 – 19.2]; Creatine Kinase (CK) (U.L) Pre = 225 [136.5 – 330], Post = 297 [208.5 – 403.5] *Results reported as Median [interquartile range]*	No significant differences in pre or post lactate, blood glucose (Glu), alanine aminotransferase (ALT) or creatine kinase (CK) between competition and sparring bouts. Glu significantly increased pre to post in both competition and sparring bouts. Pre and post measurements of ALT significantly lower in sparring bouts than in competition bouts, possibly suggesting onset of overtraining during period between bouts.
	(Coswig, Ramos, et al. 2016)	n = 13 male MMA competitors, age = 25 ± 5	Sparring bouts: Urea ($mg{\cdot}ml^{-1}$) Pre = 42.08 ± 8.77, Post = 44.15 ± 8.93, 48H post = 36.31 ± 7.85; Glu ($mg{\cdot}ml^{-1}$) Pre = 80.38 ± 12.7, Post = 156.54 ± 19.09, 48H post = 87.69 ± 15.5	Urea significantly decreased from resting 48H post bout with a large ES; Glu significantly increased with a large ES immediately post sparring bout, and a significant reduction with a small ES 48H post bout. No significant changes in alanine aminotransferase (ALT), magnesium (Mg) or uric acid (UA) over same time periods. MMA sparring bouts present low muscle damage and require relatively short physiological recovery times during training periods.
	(Souza et al. 2017)	n = 20 male professional MMA competitors paired in sparring bouts, bout winners age = 26.2 ± 2.39; bout losers age = 24.3 ± 1.83	Testosterone ($nmol{\cdot}L^{-1}$): Pre = 13.03 ± 3.9; Post = 9.53 ± 3.33; 24H post = 14.68 ± 4.02 (sig differences between bout winners and losers at all sample points). Cortisol ($nmol{\cdot}L^{-1}$):	Significant increase in testosterone (T) and cortisol (C) immediately post bout with return to resting levels 24H post. Creatine kinase (CK) displayed a significant increase immediately post bout, with an almost three-fold increase over the next 24H. Suggests MMA involves significant physiological, metabolic and muscular strain including acute muscle damage. More sampling points required over a longer time frame to assess the extent of these affects.

			Pre = 549.02 ± 144.99; Post = 876.09 ± 107.84; 24H post = 436.96 ± 126.26 Creatine kinase (CK) (U·L): Pre = 433.89 ± 215.95, Post = 491.81 ± 219.17, 24H post = 1412.69 ± 758.63	
	(Ghoul et al. 2017)	n = 12 male MMA competitors paired in sparring bouts, age = 26 ± 5	C (ng·dL^{-1}): Pre = 88.3 ± 19.6, Post = 131.2 ± 56.4, 30min post = 117.1 ± 46.3, 24H post = 79.3 ± 23.2; T (ng·dL^{-1}): Pre = 3.5 ± 0.3, Post = 4.6 ± 0.3, 30min post = 3.7 ± 0.3, 24H post = 3.4 ± 0.3; Uric acid (UA)(µmol·L^{-1}): Pre = 308 ± 53, Post = 342 ± 54, 30min post = 414 ± 58, 24H post = 344 ± 48; Lactate dehydrogenase (LDH) (U·L): Pre = 169 ± 70, Post = 230 ± 116, 30min post = 228 ± 94, 24H post = 226 ± 75.	Cortisol (C) and testosterone (T) significantly raised at end of 3 round sparring bout, with uric acid and lactate remaining significantly elevated 24H after bout. MMA is a physiologically demanding event with fatigue indices remaining high 24 hours after a bout. Results could inform training and recovery protocols.
	(Fernandes et al. 2018)	n = 1,496 professional MMA bouts, analysed as pre 2012 rule changes versus post 2012 rule changes	Total strike attempts: Pre = 41.5 ± 25.9, Post = 43.6 ± 26.4; Participant exposure time (mins): Pre = 383.3, Post = 480.2; Bouts ending in final round: Pre: 90, Post = 150; Rounds with injuries: Pre = 68.2%, Post = 44.8%	The frequency of some striking techniques and bout exposure time increased after a 2012 change to the MMA bout scoring criteria, with a lower injury incidence and a greater number of bouts ending in the final round
	(Antoniettô et al. 2019)	n = 678 professional MMA bouts	Standing preparatory time in bouts ending in: 1st round = 95.6 ± 62.9 s; 2nd round = 93.6 ± 67.9 s; 3rd round = 144 ± 88.5 s.	MMA competitors become less active as the bout progresses, demonstrating pacing strategies potentially being employed in bouts, or the onset of fatigue as the bout progresses.
Athlete	(McGill et al. 2010)	n = 5 international/elite standard males, age = 29 ± 1.8	EMG study demonstrating double peak of muscle activation (rectus abdominus, latissimus dorsi, erector spinae, gluteus medius, gluteus maximus and rectus femoris) during strikes on heavy bag.	Double peak of muscle activation possible due to contraction-relaxation-contraction pulses of observed muscles to achieve strike speed and force. May be affected by different specific training methods.
	(Schick et al. 2010)	n = 11 male regional MMA competitors, age = 25.5 ± 5.7	Body fat = 11.7 ± 4%; $\dot{V}O_2$max = 55.5 ± 7.3 ml·kg·min^{-1}; vertical jump = 57.6 ± 7.3 cm; relative bench press strength = 1.2 ± 0.1 kg·kg; relative squat strength = 1.4 ± 0.1 kg·kg^{-1}; absolute grip strength = 45.8 ± 6.2 kg.	MMA participants displayed lower maximal oxygen consumption than kickboxers, lower power than wrestlers, similar bench press and squat strength to judokas, and lower grip strength than boxers.
	(Marinho et al. 2011)	n = 13 male MMA competitors, age = 30 ± 4	Body fat = 11.87 ± 5.11%; squat strength = 73 ± 15 kg; broad jump = 219 ± 0.25 cm	MMA participants have relatively low levels of strength and moderate levels of power.
	(Alm and Yu 2013)	n = 5 male MMA competitors, age = 29.6 ± 5.5	$\dot{V}O_2$max (ml·kg·min^{-1}) Pre = 50 ± 6.5 , Post = 48.5 ± 5.7; Counter movement jump (CMJ) (cm) Pre = 43.1 ± 5.07, Post = 41.25 ± 2.13; Relative CMJ with arm swing Pre = 0.63 ± 0.4, Post = 0.59 ± 0.09;	Low strength and aerobic capacity before and after 12 months of MMA training, with some variables reducing (non significant). Only CMJ with arm swing displayed a statistically significant increase over the 12 month period. Suggests MMA training alone is not sufficient to bring about significant physiological performance adaptations.

			Relative hang clean (kg·kg^{-1}) Pre = 1.09 ± 0.07, Post = 1.06 ± 0.11;	
	(Lovell et al. 2013)	n = 1 case study, national standard MMA competitor, age = 25	Upper body $\dot{V}O_2max$ (ml·kg·min^{-1}) Pre = 40.35, Post = 45.96; Lower body $\dot{V}O_2max$ Pre = 54.96, Post = 56.75; Upper body peak power (W·kg^{-1}) Pre = 798 W·kg, Post = 841; Lower body peak power Pre = 914, Post = 934; MHR (beats·min^{-1}) Pre = 183, Post = 191	Upper (14%) and lower (4%) body $\dot{V}O_2max$, upper body peak power (5.4%), lower body peak power (2.2%) and MHR (4%) increased after 8 weeks of MMA training supplemented by a specific S&C program. Authors suggest use of Wingate anaerobic test (WAnT) to monitor adaptations to training for MMA competition. *Nb. S&C = strength and conditioning; MHR = maximal heart rate*
	(de Oliveira et al. 2015)	n = 18 male regional MMA competitors, age = 27.9 ± 5.9	$\dot{V}O_2max$ = 44.22 ± 6.69 ml·kg·min^{-1}; Right hand grip strength = 45.99 ± 8.99 kg; Left hand grip strength = 45 ± 8.5 kg	MMA participants have low $\dot{V}O_2max$ and low handgrip strength in comparison to other combat sports such as wrestling, boxing, karate and Brazilian jiu jitsu.
	(Marinho et al. 2016)	n = 8 male MMA competitors, age = 31 ± 5	Body mass index (BMI) = 26 ± 3.3 kg·m^{-2}; body fat = 11.8 ± 6.2 kg and 13.4 ± 5.6%; muscle mass = 69.6 ± 4.6%; flexed arm hang = 35 ± 10s; relative squat strength = 0.84 ± 0.1 kg·kg^{-1}; relative bench press = 1 ± 0.2 kg·kg^{-1}	MMA participants display high lean body mass, excellent upper body muscular endurance and low levels of relative strength.
	(Antonio et al. 2018)	n= 15 male professional MMA competitors, age = 28.4 ± 4.4	Bone mineral content (BMC) (kg) = 3.9 ± 0.52; Bone mineral density (BMD) (g·cm^3) = 1.57 ± 0.1	BMC and BMD measured using DXA scanning. MMA participants display higher BMD than other sports (including track and distance athletics, swimming, American football and stand up paddling), with no significant differences to American football players. *Nb. BMC = bone mineral content; BMD = bone mineral density; DXA = dual energy x-ray absorptiometry*
3: Predictors of performance				
Performance	(Baker and Schorer 2013)	n = 1,468 professional MMA competitor records and profiles	Southpaw (left handed) winning % = 64 ± 20.4 Orthodox (right handed) winning % = 62.6 ± 21.3 No statistically significant difference	No indication of lateral preference influencing success in professional bouts
	(Miarka, Del Vecchio, Camey, et al. 2016)	n = 645 professional MMA rounds	Total strike attempts ES between winners and losers: 1st round = -0.20, 2nd round = -0.25, 3rd round = -0.21; Advances to half guard, side control, mount and back mount all significantly different (≤0.05) in favour of bout winner (with exception of mount in 1st round).	Winners and losers distinguished by the numbers of total strikes, submissions and positional improvements *Nb. ES = effect size*
	(Miarka, Del Vecchio, Brito, et al. 2016)	n = 202 professional MMA bouts (n = 101 participants classified as 'home', n = 101 classified as 'away')	Total strikes attempted: Home = 37.3 ± 23.9; Away = 46.4 ± 26.3; Head strikes attempted: Home = 21.5 ± 15.1; Away = 26.5 ± 16.2; Low intensity ground time (s): Home = 13.8 ± 6.2; away = 5 ± 0.1.	No effect of 'home vs away' in determining winner or loser, but some effect on numbers of strikes attempted and landed.

	(Miarka, Coswig, et al. 2016)	n = 174 professional female MMA rounds	Time (s) spent in low intensity standing combat by round for bout ending methods: Split decision = 160.4 ± 83.6; Unanimous decision = 158.4 ± 87.6; KO/TKO = 44.8 ± 38.8; Submission = 42.1 ± 44.1. Total combat time(s) by round for bout ending methods: Split decision = 300.7 ± 0.3; Unanimous decision = 300 ± 0.4; KO/TKO = 154.4 ± 95.2; Submission = 204.2 ± 96.6.	Winners and losers distinguished by striking and grappling actions in bouts that ended via strikes or submissions, distinguished by standing strikes only in bouts that ended via decision.
	(Kirk 2016a)	n = 474 professional MMA bouts	Shorter competitors ranked higher in FlW (ω^2 = 0.14); Shorter competitors ranked in the middle in WSW (ω^2 = 0.2); Shorter competitors more likely to have competed for/won a world title in FW (ω^2 = -1.3) and FlW (ω^2 = -0.95)	Negligible effect of stature and wingspan on rankings, isolated to small number of divisions. *Nb. ω^2 = omega squared effect size*
	(Kirk 2016b)	n = 278 professional MMA bouts, bout winner's age = 29.79 ± 4.3; bout loser's age = 30.79 ± 4.3.	Bout winner stature (cm): Won by strikes = 181.4 ± 9; won by submission = 177.3 ± 8.3; won by decision = 177.1 ± 8.6. Bout loser stature (cm): Lost by strikes = 180.7 ± 8.2; lost by submission = 176.9 ± 8.5; lost by decision = 176.5 ± 9.1. Bout winner age: Won by strikes = 30.59 ± 4.8; won by submission = 28.44 ± 3.4; won by decision = 29.68 ± 4. Bout loser age: Lost by strikes = 31.8 ± 4.4; lost by submission = 29.19 ± 4.1; lost by decision = 30.6 ± 4.1.	Taller participants and participants with a longer armspan more likely to lose due to strikes, older participants more likely to lose in general, but when bout winner is older it is most likely due to decision. No other effects of anthropometry better than moderate found (n = 278 bouts).
	(James, Robertson, et al. 2017)	n = 234 professional MMA bouts.	% of competitors winning after achieving >4 significant ground strikes = 80.4%, increased to 84.9% when takedown accuracy >25%; 0.850 significant ground strikes per minute = 91.5% chance of winning, increased to 91.5% when strikes >4.19 per minute.	Decision tree used to determine grappling and technique accuracy determine success in professional competitive MMA bouts.
	(Miarka, Brito, and Amtmann 2017)	n = 584 professional MMA bouts	Probability of winning bout if achieved more than opponent: Head strikes landed = 14.8%; Successful takedowns = 76.79%; Offensive passes = 66.7%; Chokes attempted = 69.67%	Distance head strikes landed, guard passes and successful takedowns most contribute to winning a bout.
	(Miarka, Brito, Dal Bello, et al. 2017)	n = 2,814 professional MMA rounds	Time keeping distance (s) sig. different to than other divisions: FW = 131.4 ± 89.9; HW = 179.2 ± 93.4; LW = 163.4 ± 88.4. Clinch time without attack (s) sig. greater than other divisions:	Performance in MMA divisions distinguished by different frequencies of actions in both standing and grounded positions, with 'rest' time being a key difference between divisions.

			FlW = 11.4 ± 10.1; WW = 12.6 ± 13.	
	(Miarka et al. 2018)	n = 678 professional MMA bouts, 1,564 rounds	% of KO/TKO by round: 1st = 63.5%, 2nd = 58.1%, 3rd = 64%; % of submissions by round: 1st = 30.3%, 37.2%, 3rd = 0.5%.	Lower time spent in low intensity striking with increased forcefulness of actions in grounded positions in first two rounds increase likelihood of winning. *Nb. KO = knockout, TKO = technical knockout*
	(Brito et al. 2018)	n = 54 MMA competitors tested positive for PEDs in post bout testing, 2001-2014	Bouts won by PED competitors = 34 (60%); Androgenic steroids = 55%, psychotropic = 27%, thermogenic/diuretic = 9%, opioids = 9%;	Competitors who tested positive for PEDs and bout winners displayed greater time spent in high intensity movements than bout losers. No differences between PED competitors and non-PED competitors in terms of technical variables or likelihood of winning. *Nb. PED = performance enhancing drug*
	(Kirk 2018a)	n = 461 professional MMA bouts	Divisions where bout winners/losers can be distinguished by: striking only (BF_{10} = 399-10) = HW; by striking (BF_{10} = 791,661 – 7) and moderately by grappling (BF_{10} = 75-7) = LHW, MW, FW, BW, WBW, WSW; by striking (BF_{10} = 3.533e^{+6} – 221) and grappling (BF_{10} = 17,100 – 50): WW, LW, FlW.	Technical differences between winners and losers distinct between divisions, with some differences having moderate to weak predictive relationships to anthropometry in HW, WW, LW and FW.
	(Kirk 2018b)	n= 100 professional MMA competitors in each division from HW - BW, each division split into 5 ranking groups (RG).	Divisional age: HW = 32.8 ± 5.3; LHW = 31.3 ± 4.4; MW = 31.4 ± 4.4; WW = 30.8 ± 4.1; LW = 30.1 ± 3.4: FW = 29.6 ± 3.9; BW = 29 ± 4.1 Cross divisional RG age: RG1 = 32.3 ± 4.4; RG2 = 30.5 ± 3.9; RG3 = 30.1 ± 4.1; RG5 = 29.9 ± 4.7	As divisional weight increases, so too does participant age (with a decisive BF_{10}) with general trend repeating across each RG. Competitors in RG1 are older than all other RG (decisive to strong BF_{10}) with general trend repeating across each division. MW displays a moderate correlation between age and rank.
	(Monson et al. 2018)	n = 1,284 professional MMA competitors	Stature (cm) = 178.3 ± 8.51; Armspan (cm) = 182.55 ± 10.22; Stature-to-armspan ratio (S:W) = 1.02	S:W found to predict success in MMA based on winning %. <1% (R^2 = 0.008) of winning % variance predicted by S:W.
	(Santos et al. 2018)	n = 45 professional male MMA competitors, assessed twice, 10 years apart (M1 and M2)	Differences between time points: Strikes landed: M1 = 22[12, 34], M2 = 18[18, 31.7]; strikes attempted: M1 = 41[24.5, 62], M2 = 35[21, 48]; takedowns attempted: M1 = 1[0.1,2], M2 = 1[0,2]	The variables most associated with winning in MMA changed from 2000-2014 with successful body and head strikes becoming more associated with winning. Head strikes attempted, total strikes attempted, and submissions attempted became less associated with winning. *Nb. Result shown as median[interquartile range]*
	(dal Bello et al. 2019)	n = 304 professional MMA rounds	Bouts ending in decision = greater freq. of takedowns attempted per round (ES = 0.13); Bouts ending in KO/TKO = lesser freq. of submissions attempted per round (ES = 0.15-0.30); Bouts ending in submission = greater freq. of sweeps per round (ES = 0.27)	The type and frequency of grappling techniques (takedowns, sweeps and submission attempts) used directly affects the outcome of the bout (unanimous/split decision, submission or KO) (n = 304 rounds). *Nb. ES = effect size, KO = knockout, TKO = technical knockout*
	(Miarka et al. 2019)	n = 779 rounds from professional MMA bouts which ended in rounds 3 – 5.	Low intensity combat: 3rd round = 75%; 4th round = 84%; 5th round = 79%; Freq. of strikes attempted: 1st round = 39.5 ± 17.6; 2nd round = 46.1 ± 21.9; 3rd round = 46.1 ± 27	Activity profiles of bouts ending in the 3rd, 4th or 5th rounds are significantly different to bouts which end in rounds 1 or 2, indicating differing training requirements.

Athlete	(James, Beckman, et al. 2017)	n = 29 male semi-professional (HL n = 15, age = 29.5 ± 2.2) and amateur (LL n = 14, age = 26.6 ± 7.95) male competitors	Jump squat time to peak force at 50% BM load(s): HL = 0.718 ± 0.209; LL = 0.898 ± 0.169 (ES = -0.86); Jump squat mean RFD ($W \cdot kg^{-1} \cdot s^{-1}$) at 50% BM load: HL = 143.03 ± 51.28; LL = 104.82 ± 25.73 (ES = 0.93); Jump squat peak power ($W \cdot kg^{-1}$): HL = 44.45 ± 7.54, LL = 38.47 ± 6.74 (ES = 0.78); Jump squat peak velocity ($m \cdot s^{-1}$): HL = 3.06 ± 0.33, LL = 2.81 ± 0.33 (ES = 0.72)	Maximal lower body neuromuscular capabilities distinguish between high-level (based on number of wins being ≥50% of verified competition record) and low-level performers. No differences in reactive strength index, 1RM bench press strength or relative peak force measured using isometric mid-thigh pull (IMTP). Results used to suggest that success is related to lower body neuromuscular force capabilities and training should be aimed towards improving this area. *Nb. 1RM = one repetition maximum*
	(James et al. 2018)	n = 15 professional male MMA competitors, split into HL (n = 7, >50% professional wins, MMA training age = 6.14 ± 0.71) and LL (n = 8, amateur bouts only, MMA training age = 4.31 ± 1.53).	Differences between groups: 20M sprint: ES = -0.49[-1.39, 0.49]; 10M sprint: ES = -0.18[-1.11, 0.76]; Yo-Yo distance covered: ES = 0.57[-0.37, 1.5]; Repeat sprint ability: ES = small to moderate (-0.2 - -0.61) differences in times at each sprint interval	10 and 20M sprint times, repeat sprint ability, and Yo-Yo Intermittent Recovery test results distinguish between professional/semi-professional and amateur competitors to a small effect size or better in favour of the HL group. *Nb. ES = Cohen's d[90% CI]*
	(Peacock et al. 2019)	n = 7 professional, male MMA participants; age = 27.2 ± 3.4; mass = 77.3 ± 0.3 kg; stature = 180.7 ± 4.4 cm.	Sleep latency correlated to: Vertical jump (r = -0.787), Prowler push time (r = 0.776), $\dot{V}O_2max$ (r = -0.860). Heart rate recovery correlated to: Sleep latency (r = -0.739), Sleep efficiency (r = -0.891), Sleep onset variance (r = 0.710). Number of missed sessions correlated to: Sleep latency (r = -0.789), Sleep onset variance (r = 0.788)	Sleep quality may directly affect physiological performance measures and training attendance amongst MMA participants.
	(de Azevedo et al. 2019)	n = 11 male MMA participants (age = 27.6 ± 4.3, mass = 83.5 ± 7.8 kg)	Repeat punch protocol onto force plate, intervention group consumed 5 $ml.kg^{-1}$ caffeine, control group consumed placebo.	No differences in punch force or frequency between groups.
4: Experimental testing of key performance predictors				
Training	(Bodden et al. 2015)	n = 25 male semi-professional MMA competitors, age = 24.31 ± 4.46, split into INT group and CON group	FMS scores pre: INT = 13.25 ± 0.87, CON = 13.23 ± 0.8; Week 4: INT = 15.17 ± 1.21, CON = ~13.4 (not specified) Week 8: INT = 15.33 ± 1.43, CON = ~13.34 (not specified)	Training intervention (corrective FMS exercises performed 4 times a week for 8 weeks for INT group) can improve FMS scores of MMA participants. *Nb. FMS = Functional Movement Screen*
	(Kostikiadis et al. 2018)	INT group n = 10 male professional MMA competitors, age = 28.9 ± 4.2; CON group n =	Post intervention changes ES in favour of INT group: Est. $\dot{V}O_2max$ = 0.69; Bench press 1RM = 0.82;	Specific S&C programme alongside MMA training significantly improves estimated $\dot{V}o_2max$, 1RM strength, CMJ height and power, SJ height and 10M sprint in comparison to control group (regular self-selected training alongside MMA training). *Nb.ES = Hedge's g, CMJ = countermovement jump, 1RM = one repetition maximum*

		7 male professional MMA competitors, age = 25.7 ± 5	Back squat 1RM = 1.17; Dead lift 1RM = 1.63; CMJ height = 0.70; CMJ power = 0.70; 10m sprint time = 0.54	
	(Chernozub et al. 2018)	n = 30 male MMA competitors, age = 21 ± 1.2, split into two groups n= 15 based on using a striking based approach (STR) or a wrestling (WRE) based approach to bouts.	Bench Press 1RM (kg) pre: STR = 68.2 ± 3.7, WRE = 68.1 ± 2.3; 3 months post: STR = 99.2 ± 9.3, WRE = 83.8 ± 4.9; 6 months post: STR = 105.8 ± 7.4, WRE = 95 ± 6.4. Serum cortisol (C) (nmol·L^{-1}) pre: STR = 184.8[100,263], WRE = 197[109,269]; 3 months post: STR = 275[200, 311], WRE = 12[2,43]**; 6 months post: STR = 250[144, 276], WRE = 98[69, 166]**	Significant differences in serum C and bench press 1RM found between groups distinguished by combat style after a power training programme designed specifically for their combat style. No details of training programme provided. *** Results as reported by authors in table appear to differ to results in figures displaying supposedly same data. May be some errors due to pre-publication translation in original paper.* *Nb. C results reported as median[interquartile range]; 1RM = one repetition maximum*
	(Peacock et al. 2018)	n = 12 male professional MMA competitors, age = 25.2 ± 2.3	BESS pre = 11.9 ± 31; post = 10.8 ±2.8; Sit and reach (cm) pre = 17.4 ± 4.2, post = 18.8 ± 4.3	Balance and flexibility improved over the course of 6-week MMA training period incorporating Tai Chi movements, no control group for comparison *Nb. BESS = Balance error scoring system*
	(Vecchio et al. 2019)	n = 6 MMA participants and 10 kickboxing participants split into intervention group = 10 (INT age = 25.2 ± 1.8, mass = 76 ± 7.2 kg, stature = 178.1 ± 7.1 cm) and control group = 6 (CON age = 29 ± 2, mass = 79.8 ± 11.9 kg, stature = 177.7 ± 5.7 cm). Unclear how MMA participants are split between groups.	Post 6-week strength and power training program: Within INT group changes: cross punch force (W) = likely increase, roundhouse kick force (W) = likely increase, vertical jump (cm) = likely increase. No within CON group changes found. Between INT and CON differences: INT likely greater changes than CON for cross punch force and 5RM squat (kg).	6-week strength and power training program caused likely* increases in punch, kick and lower limb force production in comparison to CON group only completing regular sport specific training. **Nb. Inferred from magnitude-based inferences (MBI) and 90% confidence intervals (90%CI).*
5: Determinants of key performance predictors	No studies found			
6: Efficacy studies	No studies found			
7: Barriers to uptake	No studies found			
8: Implementation studies	No studies found			
No ARMSS Category				
Training	(La Bounty et al. 2011)	N/A#	Narrative review of MMA research at time of publication in relation to strength and conditioning research	S&C considerations for MMA based on findings from other combat sport and general S&C research *Nb. S&C = strength and conditioning*
	(Schick et al. 2012)	N/A#	Narrative review of MMA research at time of publication in relation to strength and conditioning research for female athletes	S&C considerations for female MMA participants based on findings from other combat sports and general S&C research
	(Tack 2013)	N/A#	Narrative review of MMA research at time of publication in relation to strength and conditioning research	S&C considerations for MMA based on findings from other combat sport and general S&C research
	(James et al. 2013)	N/A#	Narrative review of MMA research at time of publication in relation to strength and conditioning research for basing conditioning on W:R and metabolic requirements of sport	Suggested training structure based on W:R studies in MMA and general S&C research *Nb. W:R = work-to-rest ratio*
	(Mikeska 2014)	N/A#	Narrative review of MMA research at time of publication in relation to	Metabolic conditioning program based on findings from other combat sports and general S&C research

			strength and conditioning research for field based metabolic conditioning	
	(James 2014)	N/A#	Narrative review of MMA research at time of publication in relation to strength and conditioning research for injury prevention	S&C injury prevention recommendations based on MMA injury studies and general S&C research.
	(Earnshaw 2015)	N/A#	Narrative review of MMA research at time of publication in relation to strength and conditioning research	Recommendations for the content of an MMA S&C mesocycle based on general S&C research
	(Harvey 2018)	N/A#	Narrative review of MMA research at time of publication in relation to HIIT training	Details the development of a potential MMA specific HIIT protocol (MMASIT) encouraging researchers and practitioners to test the validity of the protocol. *Nb. HIIT = high intensity interval training*
Nb. #No experimental cohort used				