AN EVALUATION OF COACHING AND TRAINING PRACTICES IN MIXED MARTIAL ARTS: A MIXED METHODS APPROACH

by

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Thesis Abstract

Mixed martial arts (MMA) is a body mass (BM) regulated combat sport, permitting the use of striking and grappling actions in standing and grounded positions, in order to achieve victory over a single opponent. Contests are conducted over 3 x 3 min or 3 – 5 x 5 min rounds following rules codified in 2002 in the United States of America (USA) and now broadly accepted globally. Despite the recent development of the sport, MMA is an established event with 4,000+ ranked professional male and female athletes worldwide and 100+ amateur national governing bodies registered with the International MMA Federation (IMMAF). Despite this rapid growth, there is a scarcity of data regarding the training methods, practices and effects of training for MMA competition. This includes an absence of studies examining the backgrounds, beliefs and practices of professional MMA coaches; the durations, internal loads, external loads and fatigue effects of MMA technical/tactical training; and the effects of MMA training on athlete physiology. As such, existing suggestions for MMA athlete preparations are mostly unevidenced, with the requirements of the sport itself not currently being characterised within the literature. Therefore, the aim of this thesis was to evaluate the current coaching and training practices that are used to prepare MMA athletes for competition. This was completed using a pragmatist mixed methodology to provide recommendations for future models of athlete support and development, as well as stimulating future research.

Study 1 aimed to explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition. To achieve this, 9.5 hours of semi-structured interviews with four full time MMA coaches were conducted to provide a dialectic understanding of the MMA context. This understanding informed the quantitative training load data reported further in this thesis. Following reflexive thematic analyses, four higher order themes were identified: 1) Evolving coaching in an unknown world: MMA coaches have developed their practice via experiential and peer learning in the absence of formal MMA coach education or support. Such peer learning appears to reduce when coaches become club owners with established capital; 2) Constrained early explorers: MMA coaches have a dual aim of producing competitive athletes whilst providing sessions that will appeal to the majority of their club members who are recreational participants. This simultaneously enables and restricts provision for their athletes; 3) Training camp dictated by external factors: The length of time provided for competition preparation is dictated largely by independent private event promoters, meaning competition preparation may often be sub-optimal; 4) Monitoring of load and improvements is subjective and led by folk pedagogies: MMA coaches rely on 'coach's eye' and personal relationships with their athletes to determine changes in fatigue and skill in a reactive manner. This again means competition preparation may be suboptimal. The unique and rapid growth in the popularity of MMA has resulted in coaching structures and practices that may not be supporting optimal athlete development or preparation.

On the basis of qualitative findings from Study 1, the aim of Study 2 was to quantify the internal training loads of MMA training practices that are used to prepare participants for competition. A mixed sex cohort of fourteen international amateur and professional MMA participants were observed completing their regular training for eight consecutive weeks without intervention. The training durations, loads and fatigue related effects of their normal practices were recorded. Seven athletes were training for competitive bouts whilst the remaining seven were not. Training duration, internal load (sessional and segmented RPE), strain, weekly monotony, fatigue, reaction time, sleep quality and soreness did not change within or between weeks. Between weeks monotony supported little variance in weekly training load. There were no differences in any variable between participants who competed and those who did not with the exception of the final week before the bout, where an abrupt step taper in training duration and load occurred, leading to no between group differences in fatigue markers. These data report the internal load intensity estimates of MMA training categories for the first time. Training intensity distribution corresponding to high, moderate and low was 20, 33 and 47%, respectively. Only striking sparring and wrestling sparring displayed statistical weekly differences in duration or load. It was concluded that periodisation of training load is largely absent in MMA training, as is the case within and between weekly microcycles.

Whilst Study 2 detailed the internal loads of MMA training practices, the aim of Study 3 was to quantify the external loads of MMA training practices that are used to prepare participants for competition. A mixed sex cohort of twenty international amateur and professional MMA athletes were observed for two consecutive weeks without intervention. External load was measured via Catapult Optimeye S5 accelerometers (Playerload) for the full duration of each session, with the corresponding internal load (sessional and segmented RPE) also being recorded. Absolute and relative external load was found to differ between training categories. Despite these distinctions, overall daily external training load did not change between days, leading to a flat loading pattern and reflecting the internal load findings from Study 2. Predictive relationships were found between internal and external training loads, providing support for the use of Playerload in conjunction with RPE to measure the training load of MMA participants preparing for competition. These data provide the external load intensity estimates of MMA training categories for the first time and may be used to appropriately plan training loads during technical/tactical sessions in MMA.

Following the results of Studies 2 and 3, Study 4 aimed to determine the physiological adaptations and changes in body composition that arise from completing a typical six-eight week training period that is used to prepare participants for competition. A cohort of nine male professional and international amateur MMA athletes completed a laboratory-based testing battery six-eight weeks before official bouts and again one week before. The participants displayed statistically relevant reductions in BM, fat mass and fat free mass following the training camp. In terms of performance measurements, no statistically relevant changes were found in maximal muscular force for squat, bench press or prone row exercises. Neither were there any changes to $\dot{V}O_2max$. Only isometric midthigh pull force was found to improve, though this was only a moderate effect. The data supported no improvement in impulse as measured by squat jump, countermovement jump and reactive strength index. MMA athlete's force, impulse and aerobic capacity are lower than many other sporting events, including other combat disciplines. In addition to the loss of fat free mass during training camp, these results suggest MMA training is sub-optimal for the physiological preparation of athletes for competitive performance. It may be recommended for MMA training to be supplemented by specific strength and conditioning interventions to provide sufficient stimuli for adaptation to support athletic performance.

On the basis of Study 4 reporting an absence of positive physiological changes during an MMA training camp, Study 5 aimed to examine the effects of a supplementary high-intensity aerobic training intervention (completed alongside traditional MMA training practices) on aerobic capacity and indices of competition-specific performance. Therefore, this case study applied a seven-week treadmill-based high intensity interval training intervention to a male MMA participant without altering their technical/tactical training. A laboratory testing battery conducted pre and post intervention demonstrated improved submaximal running economy with reduced $\dot{V}O_2$, heart rate, energy expenditure and O_2 cost. There were no improvements in stroke volume or O_2 delivery, as evidenced by no changes in O_2pulse or $\dot{V}O_2max$. Economy adaptations were therefore most likely due to improved neuromuscular efficiency resulting from this participant completing running based aerobic training for the first time. These physiological adaptations resulted in a 4% improvement to their velocity at $\dot{V}O_2max$. This may have manifested as more consistent movement with less exertion in simulated sparring bouts conducted pre, mid and post intervention. These results coincided with a 4% reduction in BM. The intensity and volume of this intervention do not appear to have been sufficient to cause cardiovascular adaptations in a trained participant. Neuromuscular adaptations may have occurred as a result of the participant undertaking a running-based training intervention for the first time.

In summary the presented data provide an evaluation of the current coaching and training practices that are used to prepare MMA athletes for competition, whilst documenting the durations, loads, intensities and effects of MMA training for the first time. The findings of this thesis provide impetus for MMA coaches to work with sport and exercise professionals to plan MMA training programs within and without training camps. This should aim to provide technical/tactical training load undulations and supplementary strength and conditioning to ensure sufficient physiological stimuli to cause positive performance related adaptations. Researchers are also encouraged to realign MMA investigations to be conducted with the Applied Research Model for the Sport Sciences to provide findings that better support the coaches and practitioners working with MMA athletes.

Declaration

I declare that the work in this thesis, which I now submit for assessment and defence on the programme of study leading to the award of Doctor of Philosophy is entirely my own. No portion of the work referred to in the thesis has been submitted for another degree or qualification of this or any other university or other institute of learning. All attempts have been made to ensure that this work is original and does not, to the best of my knowledge, breach any copyright laws. The work of authors and organisations that have provided sources of data, information or evidence have been fully acknowledged within the text.

Publications and Presentations

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Kirk, C., Clark, DR., Langan-Evans, C., Morton, JP., *An exploratory case study examining the training loads and effects of mixed martial arts competition preparation* (Oral presentation and abstract), BASES Conference 2019, 19th-20th November 2019, Leicester

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List of Abbreviations

1RM – one repetition maximum

βm – muscle buffering

ω^2 - omega squared effect size

A:R – activity-to-recovery ratio

ARMSS – Applied research model for the sport sciences

a-$\dot{V}O_2$diff – arterial-venous oxygen difference

AU – arbitrary units

beats·min^{-1} – beats per minute

BF – Bayes factor

BJJ – Brazilian jiu jitsu

BM – body mass

BMD – bone mineral density

BMI – body mass index

BW - bantamweight

cm – centimetre

cm·kg^{-1} – centimetre per kilogram of body mass

CMJ – countermovement jump

CO_2 – carbon dioxide

CR10 – category ratio 10 scale

CRT – choice reaction time

CRTCorr – choice reaction time correct responses

CTE – chronic traumatic encephalopathy

CV – coefficient of variation

CWL – chronic weight loss

d – Cohen's d effect size

DJ – drop jump

DLRT – Deary-Liewald reaction time test

DXA – dual energy x-ray absorptiometry

EMG – electromyography

EUR – eccentric utilisation ratio

FES – fight exposure score

FFM – fat free mass

FM – fat mass

FlW – flyweight

FW – featherweight

GCT – ground contact time

$g \cdot cm^3$ – grams per centimetre cubed

GPP – general physical preparation

GXT – graded exercise test

HIIT – high-intensity interval training

H:L – high intensity to low intensity ratio

HR – heart rate

hrs – hours

HW – heavyweight

ICC – intraclass correlation coefficient

IMMAF – International Mixed Martial Arts Federation

IQR – interquartile range

JZS – Jeffrey-Zellner-Siow prior

$kcal \cdot day^{-1}$ – kilocalories per day

$kcal \cdot min^{-1}$ – kilocalories per minute

kg – kilogram

$kg \cdot kg^{-1}$ – kilogram per kilogram of body mass

$km \cdot h^{-1}$ – kilometres per hour

KO - knockout

LHW – light heavyweight

$L \cdot min^{-1}$ – litres per minute

LW – lightweight

m – metre

min(s) – minute(s)

MMA – mixed martial arts

$mg \cdot dl^{-1}$ – milligrams per decilitre

$mg \cdot ml^{-1}$ – milligrams per millilitre

$ml \cdot beat^{-1}$ – millilitres per beat

$m \cdot s_{GCT}^{-1}$ – metres per second of ground contact time

$\mu g \cdot L^{-1}$ – micrograms per litre

$mmol \cdot L^{-1}$ – millimoles per litre

$ml \cdot kg \cdot km^{-1}$ – millilitres per kilogram of body mass per kilometre

$ml \cdot kg \cdot min^{-1}$ – millilitres per kilogram of body mass per minute

$mOsmol \cdot kg^{-1}$ – millismoles per kilogram of body mass

ms - milliseconds

NFOR – non-functional overreaching

NGB – national governing body

$ng \cdot dl^{-1}$ – nanograms per decilitre

O_2 - oxygen

OTS – overtraining syndrome

$\dot{Q}$ - cardiac output

PLd_{ACC} – accumulated Playerload

$PLd_{ACC} \cdot min^{-1}$ – accumulated Playerload per minute

PSQI – Pittsburgh Sleep Quality Index

RED-S – relative energy deficiency in sport syndrome

RER – respiratory exchange ratio

RFD – rate of force development

RMR – resting metabolic rate

RPE – rating of perceived exertion

RSI – reactive strength index

RTG – regular training group

RWG – rapid weight gain

RWL – rapid weight loss

R_{χ} – rank-biserial correlation effect size

s – seconds

S&C – strength and conditioning

SD – standard deviation

SEff – sleep efficiency

SIT – sprint interval training

SJ – squat jump

sRPE – sessional rating of perceived exertion

segRPE – segmented sessional rating of perceived exertion

SQF – short questionnaire of fatigue

STG – specific training group

S:W – stature to wingspan scale

SV – stroke volume

T – Kendall's Tau-b correlation coefficient

TMA – time motion analysis

TKO – technical knockout

UFC – Ultimate Fighting Championship

$U \cdot L^{-1}$ – units per litre

U_{sg} – urine specific gravity

$\dot{V}CO_2$ – rate of carbon dioxide production

$\dot{V}_E$ – minute ventilation

$V_E \cdot \dot{V}CO_2$ – ventilatory equivalent of carbon dioxide production

$V_E \cdot \dot{V}O_2$ – ventilatory equivalent of oxygen consumption

$\dot{V}O_2$ – rate of oxygen consumption

$\dot{V}O_2max$ – maximal aerobic capacity

$v\dot{V}O_2max$ – velocity eliciting maximal aerobic capacity

VT – ventilatory threshold

W - Watts

$W \cdot kg^{-1}$ – Watts per kilogram of body mass

WSW – women's straw weight

WW - welterweight

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Chapter 1 - Introduction to Mixed Martial Arts

1.1 Background

Mixed martial arts (MMA) is a combat sport in which competitors engage each other using kicks, punches, elbows and knees along with grappling manoeuvres to overcome their opponent. Participants compete in designated body mass (BM) categories (colloquially termed weight divisions) that are intended to promote fair and safe competition between opponents of similar physical morphology. Male categories range from flyweight (maximum BM = 56.7 kg) to heavyweight (maximum BM = 120.2 kg). Whilst a superheavyweight category (unlimited BM) exists, it is rarely used in practice. Female categories range from atomweight (maximum BM = 47.6 kg) to lightweight (maximum BM = 70.3 kg). Bouts consist of 3 x 5 min rounds (5 x 5 minute rounds for championship bouts or bouts deemed to be of significance) for professionals and 3 x 3 min rounds for amateurs (IMMAF, 2017; James et al., 2016; Kirk, 2018a; NJSAC, 2002). 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). It is common practice for competitors to manipulate their BM via rapid weight loss (RWL) followed by rapid weight gain (RWG) in the 48-24 hours (hrs) prior to competition (Barley et al., 2018; Langan-Evans et al., 2017). This is done to achieve a great enough BM to provide a perceived advantage over the opponent, with RWL/RWG occurring to a magnitude of ~8 - 15% BM (Kirk et al., 2020b).

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), and became a codified sport with the 2002 adoption of the 'unified rules' (NJSAC, 2002). MMA has rapidly increased in popularity and participation since this, as highlighted by the 2016 sale of UFC for $4 billion, just 16 years after being bought for $2 million (Rovell and Okamoto, 2016). Presently, there are 4,000+ male and female professional competitors worldwide (Fightmatrix, 2022), with the International MMA Federation (IMMAF) consisting of 100+ national governing bodies across five continents (IMMAF, 2019). As a result, IMMAF now host annual continental and global amateur tournaments for adults (21+ years), juniors (18-21) and youths (12-18) respectively (IMMAF, 2021a).

Owing to such increased participation there has been rapid growth in the number of independent training centres, gyms and coaches. However, many of these practitioners appear to move into coaching as a means of financially supporting their own competitive fighting careers rather than as a primary vocation (Spencer, 2012). 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). In contrast to this development, however, there is evidence that MMA coaches do not view engagement with scientific research as important to their role (Bujak et al., 2013). Consequently, research into this population of athletes and the efficacy of coaching methods used is nascent, a point highlighted by several authors (Andreato and Branco, 2016; Del Vecchio and Franchini, 2013; Kirk, 2018a; Lenetsky and Harris, 2012).

MMA participants require a high level of technical skill across the striking-grappling spectrum in order to be successful in competition (James et al., 2019, 2017b; Kirk, 2018a). Due to bouts consisting of repeated high impulse actions interspersed by regular periods of relative recovery (Del Vecchio et al., 2011; Kirk et al., 2015a), it has been suggested that participants should conduct interval training alongside their technical training in order to maximise anaerobic energy resynthesis (Harvey, 2018; Jay, 2013). Post competition lactate concentrations ranging between 10 – 20 mmol·L^{-1} (Amtmann et al., 2008; Coswig et al., 2016a) and post simulated competition lactate values ranging from 9 – 12 mmol·L^{-1} (Kirk et al., 2015a; Petersen and Lindsay, 2020) provides evidence of this significant anaerobic contribution to energy in MMA. Due to the potential maximal length of a bout (9 – 25 mins), however, it may be the case that MMA would be better characterised and trained as a high-intensity aerobic endurance event (Draper and Marshall, 2013). Though data in support of this is limited, simulated MMA bouts have recently been shown to elicit >90% maximal heart rate (HR) at the end of each round (Petersen and Lindsay, 2020). The specific energy system ratios of MMA are yet to be measured, meaning estimations of energy requirements are reliant on data from related combat sports. Direct gas analysis used during simulations in other such sports estimated 60-70% of participant energy requirements are met through aerobic metabolism (Campos et al., 2012; Crisafulli et al., 2009; Davis et al., 2014; Ghosh, 2010; Rodrigues-Krause et al., 2020). Regarding muscular strength, successful and unsuccessful participants may be distinguishable by their lower body force production (James et al., 2017a). Therefore, it remains likely that MMA athletes are required to train multiple, potentially conflicting, aspects of technical and physiological performance in order to be successful.

When training for such multi-faceted activities, it is understood that balancing training induced stress and psychobiological recovery-adaptation (Sands et al., 2016) is a key determinant of athletic improvement and the avoidance of non-functional overreaching (NFOR) and overtraining syndrome (OTS) (Kellmann et al., 2018; Kreher and Schwartz, 2012; Meeusen et al., 2013; Soligard et al., 2016). Of equal importance is the need to provide a great enough training stimulus to elicit the required physiological adaptations and skill acquisition (Borresen and Lambert, 2009; Viru and Viru, 2000). Despite this, there is currently limited information regarding the coaching practices, loads and subsequent physiological effects of MMA training. The few extant training studies provide only short term, meso-macro level data over one - five weeks (Coyne et al., 2020; Uddin et al., 2020), or are retrospective discussions of training conducted a decade prior to publication (Jukic et al., 2017).

In the absence of such knowledge, it is difficult for coaches and support personnel to accurately determine how to safely and effectively prepare an athlete for MMA competition from a physiological perspective. To this end it is imperative that research provides an understanding of the training and coaching methods currently used in MMA, and what effect these have on the physiological performance of the participants. This would provide the foundation to enable the development of training-based interventions and coaching frameworks to assist coaches in efficiently developing robust performance athletes.

1.2 Aims and Objectives of the Thesis

In sports with under-developed foundational knowledge, and in sport sciences in general, Bishop (2008) proposed that research should be conducted within the Applied Research Model for the Sport Sciences (ARMSS). Consisting of eight interacting stages, ARMSS provides a framework for a sport's requirements and practices to be understood before developing and rigorously testing interventions that may be applied to support the coaches and athletes involved. This framework may provide results that are based firmly on cumulative knowledge and may ensure sport science is more focused and integrative, which should result in applicable findings and avoid '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; Eisenmann, 2017; Verhagen et al., 2014), ARMSS provides a more detailed structure of the cumulative steps of the evidence gathering process. Given the aforementioned paucity of data from MMA training and coaching practices, ARMSS may offer a suitable construct to conduct foundational work into this sport.

The structure of the following thesis is therefore guided by the principles of the ARMSS as proposed by Bishop (2008). The overall aim of this thesis is to evaluate the current coaching and training practices that are used to prepare MMA athletes for competition. In using a mixed methods, pragmatist research methodology, it is hoped that the present thesis will serve to provide recommendations for future models of athlete support and development, as well as stimulating future research.

This aim will be achieved through the following objectives:

1. To explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition. This will be achieved using a qualitative methodology via completion of Study 1 (Chapter 3) and sits within ARMSS Stage 1 – Defining the problem.

2. To quantify the external and internal training loads of MMA training practices that are used to prepare participants for competition. This will be achieved through the completion of Study 2 (Chapter 5) and Study 3 (Chapter 6), both of which sit within ARMSS Stage 2 – Descriptive research.
3. To determine the physiological adaptations and changes in body composition that arise from completing a typical six - eight week MMA training period that is used to prepare participants for competition. This will be achieved through the completion of Study 4 (Chapter 7) and sits within ARMSS Stage 2 – Descriptive research.
4. To examine the effects of a supplementary high-intensity aerobic training intervention (completed alongside traditional MMA training practices) on aerobic capacity and indices of competition specific performance. This will be achieved through the completion of Study 5 (Chapter 8) and sits within ARMSS Stage 3 – Predictors of performance.

Chapter 2 - Literature Review: A Call to ARMSS

2.1 Chapter Rationale

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. As discussed in Chapter 1, MMA is one such sport where this is the case. To improve the quality of data produced by sport science, Bishop (2008) proposed the ARMSS. Consisting of eight interacting stages (Table 2.1) 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, findings are 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; Eisenmann, 2017; Verhagen et al., 2014), 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 present literature review was conducted as a structured narrative review of our current understanding of the physiological and physical demands of MMA training and competition to provide rationale for the following thesis, and to develop the aforementioned aims and objectives.

2.2 Categorising MMA research within the ARMSS model

Studies included in this review were acquired 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, injuries, concussion, CTE, chronic traumatic encephalopathy, weight cutting, rapid weight loss. 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 were 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 project supervisors. 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);
- Characteristics of injuries and concussions in MMA (any article that describes acute and/or chronic injuries sustained by MMA participants);
- Characteristics of body mass manipulation in MMA (any article that is related to the rapid weight loss and rapid weigh grain practices of MMA participants).

These themes were chosen from common areas of sports science research and areas of concern around combat sport athlete preparation (Ruiz, 2017). In total, 134 unique articles were found that fit into the ARMSS. Table 2.1 details the distribution of these articles in each ARMSS stage. An additional 9 articles were retrieved that are related to MMA performance but do not fit in any ARMSS stage. Each article included in the following review is summarised in Appendix A.

Table 2.1 – 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.	**16**
	2 Descriptive research (hypothesis development) Studies that describe what is currently occurring in the field, cross-sectional studies and methodological studies.	**84**
	3 Predictors of performance Studies to identify which factors are most likely to affect performance. Should include replication studies.	**29**
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. 9 additional performance related publications do not fit into any stage of the ARMSS model.

2.3 ARMSS Stage 1: Defining the Problem

Stage 1 research is currently lacking in MMA, despite calls for work of this kind to be conducted (Andreato and Branco, 2016; Lenetsky and Harris, 2012). 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, 2010a, 2004), as has a lack of data regarding training injuries (Lockwood et al., 2018). Of greater concern is the underdeveloped research into the negative, potentially fatal health effects of pre-competition RWL/RWG in this population (Coswig and Del Vecchio, 2016; Langan-Evans et al., 2017). Whilst the details of each of these studies are discussed in other sections of this chapter, 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 such research may have negative implications for the applicability to practice of much of the data discussed in this chapter.

2.4 ARMSS Stage 2: Descriptive Research

2.4.1 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 impulse 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 2.2. 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 2.3). These data tend to suggest that MMA competitors have relatively moderate $\dot{V}O_2max$, hand grip strength, muscular endurance, relative strength, vertical jump and linear sprint speed when compared to other combat and non-combat sports (Argus et al., 2012; Bosquet et al., 2007a; Guidetti et al., 2002; Lockie et al., 2018). Only one study (Plush et al., 2021b) provides detailed $\dot{V}O_2$ characteristics of MMA participants in the form of ventilatory thresholds (VT_1 and VT_2), with others reporting maximal capacities only. In terms of anaerobic capacity, international standard MMA competitors have been found to have inferior average power (8.3 ± 0.32 W·kg^{-1}) and inferior power at lactate threshold (12.2 ± 0.9 W·kg^{-1}) to equivalent athletes from judo, association football and athletics (Mekhdieva et al., 2021). 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.

Table 2.2 – Example anthropometrical and body tissue distribution data of MMA competitors

Study	n	Stature (cm)	Body mass (kg)	Fat mass (kg)	Fat mass (%)	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	
(Plush et al., 2021b)	6				17 ± 11***			

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

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 have 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, $\dot{V}O_2$max and rate of force development (RFD) (UFC, 2021, 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 protocols for each of these indices, reducing the opportunity for comparison, benchmarking or replication.

Table 2.3 – Example physiological and physical assessment data for MMA competitors

Study	n	$\dot{V}O_2$max ($ml \cdot kg \cdot min^{-1}$)	Hand grip strength (kg)	1RM squat (kg)	1RM relative bench press ($kg \cdot kg^{-1}$)	CMJ (cm)	Relative CMJ ($cm \cdot kg^{-1}$)	SJ peak power ($W \cdot kg^{-1}$)	SJ (cm)	Standing broad jump (cm)	10m sprint (s)	Upper body peak power ($W \cdot kg^{-1}$)
(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 = 62.75 ± 4.9, Post = 60.5 ± 5.1 (trials 12 months apart)					Pre = 0.63 ± 0.4, Post = 0.59 ± 0.1 (trials 12 months apart)		Pre = 40.3 ± 3.8, Post = 36.2 ± 3.6 (trials 12 months apart)			
(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 et al., 2017a)	29				HL = 1.21 ± 0.18, LL = 1.07 ± 0.2			HL = 44.45 ± 7.54, LL = 38.47 ± 6.74				
(Plush et al., 2021b)	6	54.1 ± 13.8 (VT_1 = 37.9 ± 11.1; VT_2 = 48.8 ± 12.5)				26 ± 6.5						

*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; VT = ventilatory thresholds*

2.4.2 Assessment of MMA Training Loads

In terms of training load assessment, there are large gaps in our knowledge. Two attempts have used participant questionnaires (n = 18 and 32 respectively) to understand how competitors prepare for bouts (Amtmann, 2010a, 2004). Both instances found that training in MMA has wide variations in frequency and type (one – seven strength and conditioning sessions, three – twelve 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 (S&C) 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) = 3,653 AU during a nine-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 and researchers 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). Uddin et al. (2020) observed n = 6 MMA professional athletes for the final five weeks before competition. sRPE in this group ranged between 3,852 ± 738 – 4,635 ± 1,067 AU until the week of competition when sRPE = 2,871 ± 433 AU. Coyne et al. (2020) also suggested internal load delineations for what could be considered a 'hard' training day (sRPE = 890 ± 383 AU) and an 'easy' training day (sRPE = 520 ± 244 AU). None of these articles, however, describe the specific content or training modes of the sessions themselves, nor how S&C was incorporated alongside the participant's technical/tactical 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., 2015b). 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.

2.4.3 Physiological adaptations to MMA Training

Alm and Yu (2013) observed a reduction in squat jump (SJ) and countermovement jump (CMJ) relative to BM after twelve months of MMA training (Alm and Yu, 2013). These results are limited, however, as they were conducted with five participants being tested in the first instance and only four being tested in the second instance due to injury. As such, this 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 eight-week training period demonstrated increased $\dot{V}O_2max$ 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 four-week strength and conditioning program. Further details of this study are discussed in section 2.6 of this chapter.

2.4.4 Physical and physiological demands of MMA competition

2.4.4.1 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 min rounds (Kirk et al., 2015a). This demonstrates the external load of one MMA simulated bout may be comparable to those of a single Australian rules football match (Mooney et al., 2013), but greater than those experienced during elite netball matches (Cormack et al., 2014) and by defenders in association football matches (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 min round, there was 2-3 mins of activity, which generally reduced as the round and the bout continued. Activity-to-recovery ratio (A:R) ranged between 9:1 – 6:1, when taking the 1 min break between rounds into account. When excluding the 1 min break, A:R was 1:2 – 1:4. This may represent a mistranslation in the published article, however, given the expectation that 'R' would increase relative to 'A' when including the 1 min inter-round break. The briefest category recorded was high intensity standing (9 ± 8 s), with the longest being low intensity groundwork (21 ± 19 s). 'Recovery' 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 this 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 A: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 A: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., 2015a). When comparing these results it becomes clear that actions in MMA are intermittent, with differing requirements for participants of different divisions and sex (Antoniettô et al., 2019; Del Vecchio et al., 2015). 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., 2017a).

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 aforementioned subjective manner in which ‘recovery’ and ‘activity’ have been identified in each of the named studies. 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.

2.4.4.2 Internal Load of MMA competition

Data regarding internal load is presented in Table 2.4. Such data demonstrate that MMA seems to induce physiological responses within the same ranges as other contact (association football) and non-contact (endurance running and sprinting) sports (Klapcinska et al., 2001; Lippi et al., 2004; Nunes et al., 2012; Paccotti et al., 2005). These responses appear to be comparable regardless of whether it is official or simulated competition with the exception of cortisol. This suggests differing metabolic demands and muscle damage between the two modes, a finding mirroring data from other combat sports (Bridge et al., 2018, 2009). Whilst the medium term (24 – 48 hrs post) metabolic and muscle damage responses have not been fully determined, it appears that muscle damage markers may peak 24 hrs after competition but return to baseline within 48 - 96 hrs (Souza et al., 2017; Wiechmann et al., 2016). Only a single study reports HR data from simulated competition, finding that MMA bouts elicit >90% maximal heart rate (HR) at the end of each round (Petersen and Lindsay, 2020). The specific movements, techniques and tactical approaches that bring about these responses in training or competition are yet to be identified. 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 2.4 – Summary of internal load measures of MMA technical training, official competition and simulated competition

Study	Mode	Variable measured	Pre	Post	24 hours post	48 - 96 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., 2015a)	Simulated competition	Lactate (mmol·L^{-1})	2.7 ± 1.46	9.25 ± 2.96 ↑		
(Coswig et al., 2016b)	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 et al., 2016a)	Official competition	Creatine kinase (U·L^{-1})	221 (median)	237 (median) ↑		
		Lactate (mmol·L^{-1})	4 (median)	16.9 (median) ↑		
	Simulated competition	Creatine kinase (U·L^{-1})	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^{-1})	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^{-1})	169 ± 70	230 ± 116 ↑	226 ± 75 ↑=	
(Wiechmann et al., 2016)	Official competition	Creatine kinase (U·L^{-1})	236 ± 190	367 ± 254 ↑	829 ± 753 ↑↑	222 ± 135 =*
		Myoglobin (µg·L^{-1})	29 ± 5	210 ± 122 ↑	92 ± 27 ↑↓	35 ± 11 =*

*Nb. 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; ↑/↓/= on Post and 48-96 hours post measurements indicate either increase/decrease/no practical change from Pre measurements; * = measurements taken 96 hours post; RPE = rating of perceived exertion.*

2.4.4.3 Injuries

Studies related to mechanisms of injury in MMA are limited. Biomechanical analysis has been used to suggest that takedowns produce similar forces on the cervical spine as a car crash, resulting in a high chance of whip lash amongst this population (Kochhar et al., 2005). The four takedowns used in this study are not those commonly used in MMA however. Injury rates and types are comparable to other combat and contact sports, but crucially, there is too little longitudinal data to make recommendations regarding athlete preparation and/or protection (Bledsoe et al., 2006; Scoggin III et al., 2010; Seidenberg, 2011). In-competition injuries most commonly occur to the head (66.8 - 78% of injuries), with lacerations being the most common (36.7 - 59.4% of injuries) (Lystad et al., 2014). Head injuries in elite competition (UFC) are more common in the greater BM divisions, with a concomitant reduction in upper limb injuries. Also in this study, males were found to suffer more injuries per athlete exposure (54·100) in comparison to females (30·100) (Fares et al., 2019). Bout losers may be 2.4 times more likely to suffer an injury than bout winners, with the likelihood of injury increasing for either participant by 4.2% with each minute of competition (Ngai et al., 2008). Bout winners and losers may be particularly distinguished by the number of injuries to the eye and region around the eye (62.8% of participants suffering an eye injury lost their bouts) (Fliotsos et al., 2021).

Participant questionnaire responses found lacerations (37.3%), concussions (20.8%) and contusions (16.5%) to the arms, neck and head are the most frequent injuries sustained in MMA training and/or competition (Ji, 2016). How training injury rates compare to other combat sports is unclear, but it is estimated that MMA was responsible for more admissions to US emergency rooms (16,541) in the period 2008 – 2015 than Brazilian jiu jitsu (BJJ) (12,538) and judo (10,102) respectively (Stephenson and Rossheim, 2018). Rainey (2009) and Jensen et al. (2016) both estimated that over 3 times as many injuries occur in training (77.9%) than in competition (22.1%). Absent from the literature is discussion of training specific mechanisms or causes of treatable injuries. Though individual medical case reports exist (Fields et al., 2008; Lee et al., 2015; Sims and Spina, 2009; Slowey et al., 2012), these only explain isolated incidents without any context of training load, previous injury or lifestyle factors.

2.4.4.4 Concussions

The nature of MMA as a combat sport means head trauma due to strikes is inevitable. The KO rate in UFC bouts between 2006 - 2012 was 6.4 per 100 athlete exposures, with TKO being 9.5 per 100 athlete exposures (Hutchison et al., 2014). Bout winners (2) and losers (47) differ in the number of concussions reported, with this prevalence being greater in amateur (32) than professional (17) bouts

(Ross et al., 2021). Post KO strikes are unique to MMA, with losing participants suffering a further 2.6 ± 3 strikes to the head in the 3.5 ± 2.8 s between a KO occurring and the bout being ended (Hutchison et al., 2014). Additionally, Lockwood et al. (2018) estimated an MMA competitor can suffer an average of 6.2 in-competition KO/TKOs in a career. Though incidences of loss of consciousness in MMA (4.2%) appear to be less than observed in boxing (7.1%) (Karpmman et al., 2016), such incidences have been estimated at 16.5 per 1,000 athlete exposures (Ngai et al., 2008). More recent research, however, suggests concussions may be more common than this, being measured at 14.7 per 100 minutes of bout exposure (Curran-Sills and Abedin, 2018) and 15.9 - 16 per 100 athlete exposures (Fares et al., 2020; Hutchison et al., 2014). When reported as suspected concussions per minute of competition, MMA (0.085 concussions·min^{-1}) may feature a greater frequency of concussions than boxing (0.047 concussions·min^{-1}) (Bernick et al., 2021). Though training data are limited, MMA participants may experience a similar number of head impacts in sparring as boxers, with similar peak angular and peak linear acceleration of the head in response (Jansen et al., 2021). Accordingly, MMA participants display microstructural brain damage related to chronic traumatic encephalopathy (CTE) to a similar extent as seen in boxers (Shin et al., 2013). Such brain damage leads to reduced memory, processing speeds and white brain matter volume in MMA participants compared to healthy controls, with none of these changes correlating to self-reported measures of injury (Mayer et al., 2015). Whilst the number of competitive bouts alone cannot be used as a direct predictor of this damage (Shin et al., 2013), these changes may be related to a competitor's 'fight exposure score' (FES). This proposed metric is the product of a competitor's total number of bouts and their average number of bouts per year (Bernick et al., 2015, 2013; Mishra et al., 2019). A lower age of first exposure to combat sports may also be causative of reduced hippocampus volume alongside increased incidences of depressive symptoms and impulsivity (Bryant et al., 2020).

The onset of CTE in MMA has been linked to degradation of the blood brain barrier due to repeated concussive and sub-concussive impacts experienced in competition and likely more frequently in training (O'Keeffe et al., 2019). Unfortunately, such training-based concussions are less widely examined. Heath and Callahan (2013) reported ~15% of 119 participants stated they had suffered a KO in training (3.2 ± 4.9 KOs per participant). A training-based TKO had occurred to ~33% of this sample (3 ± 3.8 TKOs per participant). The number of KOs experienced was also moderately correlated to the number of mins spent sparring each week. Of concern was the highly reported subjective ratings of concussion, with only 13% of participants seeking medical attention and roughly half returning to training within two days of the concussive incident (full cohort = 5.6 ± 11.7 days). A recent survey of combat sports coaches (37.1% involved in MMA) and athletes (38.6% involved in MMA) revealed that only 5.7% of coaches understood that concussions may occur without loss of consciousness. Additionally, only 14.3% of coaches looked for information regarding evaluation or management of concussions. Of the athletes in this sample 41% stated they returned to full training within 1 week of a diagnosed concussion (Follmer et al., 2020). Evidence also exists that fighters themselves are not aware of having been concussed due to not understanding what constitutes an occurrence. Prior to being given the definition of a concussion, 16.7% of international standard female amateur competitors reported having been previously concussed. After being given the definition, this proportion increased to 30.6% (Kristensen et al., 2021). This passive approach to training-based head trauma may explain the relatively high number of MMA bout cancellations due to pre-competition neuroimaging abnormalities (24%) (Curran-Sills, 2018).

2.4.4.5 Body Mass Manipulation

BM manipulation via RWL prior to weigh-in followed by RWG in the 24 hrs leading to the bout is a nearly ubiquitous practice in MMA (Gann et al., 2015; Murugappan et al., 2021). MMA participants tend to lose more total BM overall (9.8 ± 7.9 kg, ~12%), more in the two weeks leading up to competition (5.6 ± 3.1 kg, ~7%), and also more 24 hrs prior to the weigh-in (3.4 ± 1.9 kg, ~4%) than competitors in related sports such as boxing, wrestling and BJJ. Total BM losses do, however, tend to be over a longer period in MMA (27 ± 24 days) than most other sports (Barley et al., 2018; White and Kirk, 2021). Methods used are a combination of energy restriction (13 – 59% of participants reporting skipping one-two meals a day) and activities designed to bring about extreme hypohydration. These include: fluid restriction (38 - 86% of participants), training in plastic clothing (13 – 63% of participants), training in saunas (13 - 76% of participants) and excessive fluid consumption for 7-10 days followed by fluid restriction in the final 72 – 48 hrs (50 – 67% of participants) (Andreato et al., 2014; Barley et al., 2018; Connor and Egan, 2019; Hillier et al., 2019; Matthews and Nicholas, 2017; Ribas et al., 2017; Santos-Junior et al., 2020). This final method is known as 'water loading' and is proposed to cause renal hormone responses to increase urine output (Reale et al., 2018). The relative influence of these methods has been highlighted in a n = 1 case study reporting overall BM loss = 18.1% (14.5 kg). Of this BM, 9.3% (7.3 kg) was lost in the final 24 hrs prior to weigh-in via hypohydration. Post weigh-in RWG = 10.6 kg, a pattern the participant identified as being 'regular' for them (Kasper et al., 2018).

These methods are mostly prescribed and monitored by MMA coaches (72% high involvement; 29 – 48.1% of participants listed these as a key influence) or training partners (64% high involvement; 3.7 - 50% of participants listed these as a key influence). Females and amateurs appear to be more reliant on their coach's advice (females = 48.1%, amateurs = 38.6%) (Hillier et al., 2019). The involvement of medical professionals or trained dieticians, on the other hand, is rare (0 - 16% high involvement), or seen as unimportant (57% of participants listed these as having the least influence) (Barley et al., 2018; Hillier et al., 2019; Park et al., 2019; Ribas et al., 2017). Female competitors do show a greater tendency to utilise a dietician than males (female = 29.6%, male = 10.1%) (Hillier et al., 2019). Participants who rely solely on training partners for advice tend to use more RWL methods, suggesting an informal trial and error approach to RWL/RWG (Park et al., 2019)

2.4.4.6 Effects of Body Mass Manipulation

Concern regarding the dangers of RWL/RWG has been growing amongst researchers and practitioners. The influence of severe hypohydration on brain trauma (Kempton et al., 2009) and hormonal changes (Coswig et al., 2015) have been highlighted as potential causes of injury, sickness, kidney disease and occasionally death (Coswig and Del Vecchio, 2016; Crighton et al., 2016; Langan-Evans et al., 2017; Matthews and Nicholas, 2017; Murugappan et al., 2018). Anecdotal evidence indicates that these effects are far from rare (Magraken, 2014). Combat sport athlete's ad libitum rehydration methods do not appear to be effective in returning participants to pre RWL baseline (Alves et al., 2018; Moghaddami et al., 2016). As such, MMA competitors have displayed urine specific gravity (U_{sg}) ≤ 1.021 immediately prior to competing after RWG = 3.4 ± 2.2 kg (4.4% of BM) (Jetton et al., 2013). Similarly, 43% of competitors were severely dehydrated (1,267 ± 47 $mOsmol \cdot kg^{-1}$) following RWL = 5.6 ± 1.4 kg (8 ± 1.8%), with the other 57% classed as dehydrated (1,033 ± 19 $mOsmol \cdot kg^{-1}$). Dehydration (930 $mOsmol \cdot kg^{-1}$) was still evident in 14% of this sample post RWG, despite BM increasing 7.4 ± 2.8 kg (11.7 ± 4.7%) in this period (Matthews and Nicholas, 2017). In terms of physiological effects of this practice, Kasper et al. (2018) reported 24 hrs of severe hypohydration induced hypernatremia (plasma sodium = 148 $mmol \cdot L^{-1}$) and evidence of acute kidney injury (serum creatinine = 177 $\mu mol.L^{-1}$) in a single participant prior to competition.

Though less studied in this population, the energy restriction observed in MMA has been linked to potential onset of relative energy deficiency in sport (RED-S) (Burke et al., 2018). Energy restriction (range 1,300 – 1,900 $kcal \cdot d^{-1}$) by the participant in the aforementioned n = 1 case study led to reduced resting metabolic rate (RMR = -331 kcal from baseline), reduced testosterone (< 3 $nmol.L^{-1}$) and hypercholesterolemia (> 6 $mmol \cdot L^{-1}$) immediately prior to weigh-in (Kasper et al., 2018). How these acute responses equate to chronic effects is unknown. An observational comparison between different sports showed MMA competitors have greater bone mineral density (BMD) (1.57 ± 0.10 $g \cdot cm^3$) than most other groups included in the study (Antonio et al., 2018). Though preliminary, this may indicate the effects of RED-S may be acute in this sport, or the physical impacts of training may offset the BMD reduction commonly caused by this condition. Crucially, longitudinal data of the effects of repeated RWL/RWG on athlete health and RED-S are not available.

2.5 ARMSS Stage 3: Predictors of Performance

2.5.1 Physical and Physiological Characteristics

2.5.1.1 Physiology

Analysis of muscular force production in relation to success in MMA was found in one study (James et al., 2017a). 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 $kg \cdot kg^{-1}$), squat jump (SJ) peak power (HL = 44.45 ± 7.54; LL = 38.47 ± 6.74 $W \cdot kg^{-1}$) and SJ peak velocity (HL = 3.06 ± 0.33; LL = 2.81 ± 0.33 $m \cdot s^{-1}$) between both groups (for other results see Appendix A and Table 2.3). 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 ability. 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.

2.5.1.2 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 author of this thesis. 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. 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, 2018a, 2016a, 2016b). 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.

2.5.1.3 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 (Hunter et al., 2016; Korhonen et al., 2009). 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 (dos 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). 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.

2.5.1.4 Technical Actions of Competition

Table 2.5 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 et al., 2017b), 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 2.6 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 chapter 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., 2019a). 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 (dos 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 2.5 – Summary of key determining factors of successful MMA performance

Study	Mode	Sample	Key determining factor	Other info
(Kirk et al., 2015a)	Simulated competition	6 male participants	Successful takedowns achieved	
(Miarka et al., 2017a)	Official competition	584 professional bouts	Head strikes landed at distance, guard passes, successful takedowns	
(Miarka et al., 2016c)	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 et al., 2016a)	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., 2019a)	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 et al., 2017b)	Official competition	234 professional bouts	Strike and takedown accuracy concomitant with ground strikes landed	
(Stellpflug et al., 2021)	Official competition	5,834 professional bouts	Chokes account for 15.5% of total bout outcomes and 76.2% of submissions. Rear naked chokes = 49.1% of chokes.	
(Follmer et al., 2021)	Official competition	1,903 professional bouts, 1,728 = male, 175 = female	17.3% of male bouts end due to submission, 21/1% of female bouts end due to submission	
(Lane and Briffa, 2020)	Official competition	548 professional bouts	>75% chance of winning if strikes·s^{-1} ≥0.38 (decision) or ≥0.8 (KO/TKO and submission).	Success or otherwise of grappling techniques not taken into account

Nb. KO = knockout; TKO = technical knockout

Table 2.6 – 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)

2.5.1.5 Body Mass Manipulation

There is mixed evidence regarding whether or not the occurrence or magnitude of RWL/RWG can predict success in MMA. Coswig et al. (2018) found RWG had a significant influence on who won competitive MMA bouts, with bout winners regaining ~3% more BM than losers (RWL = 14 ± 4 kg, 7-8% BM). Winning and losing in this instance may be more related, however, to energy intake during the RWL/RWG phases. Winners consumed 745 [103 - 1,104] kcal·day^{-1} during RWL as opposed to losers consuming 303 [159 - 703] kcal·day^{-1}. During RWG winners consumed 5,191 [2,887 - 6,117] kcal·day^{-1} with losers consuming 2,952 [2,166 - 4,722.1] kcal·day^{-1}, indicating that energy intake may have had more influence on success than total BM. A more recent study found no differences between winners or losers in terms of RWG (winners = 8.7%; losers = 8.7%). Bout losers in this cohort did engage in greater RWL than bout winners (winners = 8.6%, losers = 11%), leading to the odds of winning decreasing by 11% with each unit of BM lost (Brechney et al., 2019). This suggests that an appropriately managed BM manipulation strategy has greater influence on winning/losing than RWL/RWG alone. This finding of likely null effect of RWG is supported by analysis of an elite standard cohort (UFC and Bellator MMA) which displayed no statistical difference between winners or losers in terms of post weigh-in RWG or in-competition BM. Notably, participants competed with BM one-two divisions greater than their official weigh-in BM, despite no apparent advantage to be gained (Kirk et al., 2020b). Currently, the only performance level found to be positively affected by RWG in terms of bout outcome is 'national' standard, with no effect at 'elite' or 'regional' levels being reported (Faro et al., 2021). The reason for this difference between standards is currently unclear.

Results regarding the influence of this practice on mood states are conflicted (Andreato et al., 2014; Brandt et al., 2018; Coswig et al., 2018), with similar disparities between studies of physiological performance effects. RWL via dehydration has caused reduced repeat effort performance (timed sled push at 75% of BM over 10 m, 30 repetitions) (Barley et al., 2017), reduced lower body power, impaired sit to stand HR response and reduced cognitive function, with none returning to baseline within 24 hrs (Soolaman et al., 2017). In contrast, arm crank power and blood lactate appear to be unaffected (Mendes et al., 2013). Importantly, however, each of these studies limited RWL to 5% BM. When examined using a cohort that engaged in RWL to a magnitude (~9%) closer to the norm for MMA (Barley et al., 2018), handgrip strength (kg) was significantly reduced post RWL and did not return to baseline post RWG (Alves et al., 2018).

2.6 ARMSS Stage 4 Experimental Testing of Key Performance Predictors

2.6.1 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 six-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 six-week training program, however, is provided in sufficient detail to allow replication. The physiological effects of a four-week MMA specific S&C program 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 S&C sessions (Kostikiadis et al., 2018). Use of the specific S&C program 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%); 10 m sprint (STG = -3.7 ± 1.4%, RTG = -0.4 ± 1.1%).

Further evidence of the effect of S&C 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 three-month 'power' training programme based on their combat style to be completed alongside their technical/tactical training. Upon completion of the program both groups then completed the opposite style's training program for the next three 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 programs 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.

2.7 ARMSS Stages 5-8

As can be seen in Tables 2.1 and Appendix A, there are currently no studies that can be placed in any of the four latter stages of ARMSS. Regarding injuries, concussions and RWG/RWL, no studies have yet occurred that may be placed in stage 4 or above. This is likely due to a causal link between predictors of performance and success not yet being 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. Equally, the link between training and athlete health is currently also unknown.

2.8 MMA 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 S&C models based on data from other combat sports and assumptions of the requirements of MMA (Earnshaw, 2015; La Bounty et al., 2011; Tack, 2013). Other protocols are specific towards injury prevention (James, 2014), female competitors (Schick et al., 2012) or metabolic conditioning (Harvey, 2018; Mikeska, 2014; Ruddock et al., 2021). 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 S&C 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/tactical training to optimise preparation. The author in question presents an MMA specific HIIT protocol to integrate into MMA 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.

2.9 Conclusions, Aims and Objectives

When considering the body of knowledge as presented in the current chapter, it is clear that most MMA research is descriptive in nature and does not follow the 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. Research describing the movements and techniques used in professional competition is more 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. Vitally, there has been no attempt at understanding the sport’s current training practices, either in relation to performance, injuries or RWL/RWG. As such, it is difficult to determine the utility or potential efficacy of any suggested training intervention without knowledge of the day-to-day characteristics of MMA training. These conclusions place the current chapter in stage 1 of ARMSS, defining as it does the current gaps in MMA research. Such an outcome means it would be important at this time to characterise the nature of the sport in terms of the current training practices and their resultant effects. Developing an understanding of how MMA coaches structure and manage the training process, followed by detailing the training itself, will provide a starting point for intervention studies to be conducted that better reflect the day-to-day activities of the sport. Once this is completed, stage 3 and 4 studies may be more appropriately planned and undertaken in future research to better support the growing body of athletes involved.

Based on this conclusion, the aims of this thesis as detailed in Chapter 1 are further developed in the following Thesis Map, which is reviewed and updated with study outcomes following each study chapter.

Thesis Map

Study Aim	Study Type	Objectives
Study 1 – Chapter 3 **Thesis Objective 1** **Study Aim** Explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition	**ARMSS Stage 1: Defining the problem** Qualitative semi-structured interviews	1. Interview professional MMA coaches to explore their training and coaching backgrounds, and how they developed as MMA coaches 2. Explore the structure, aims and focus of MMA coaches practice in preparing participants for competition 3. Explore how MMA coaches attempt to monitor the load-fatigue-adaptation cycle of the participants preparing for competition within their practice.
Study 2 – Chapter 5 **Thesis Objective: 2** **Study Aim** Quantify the internal loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the durations, intensities and internal loads of MMA training categories 2. Record subjective fatigue and soreness response of MMA athletes in relation to these internal loads 3. Determine the intensity and load distribution of MMA training sessions and categories 4. Determine any changes in load, fatigue or soreness when MMA athletes are preparing for competition
Study 3 – Chapter 6 **Thesis Objective: 2** **Study Aim** Quantify the external loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the external loads of MMA training categories 2. Determine the relationship between external and internal loads in MMA training. 3. Determine the distribution of external loads of MMA training categories
Study 4 – Chapter 7 **Thesis Objective: 3** **Study Aim** Determine the physiological adaptations and changes in body composition that arise from completing a typical 6-8 week MMA training period that is used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative laboratory data collection without intervention	1. Record physiological and body composition data of a group of international standard MMA athletes prior to commencing training for competition 2. Record the same physiological and body composition variables upon completion of the training period but prior to pre-competition RWL. 3. Determine the effects of a pre-competition training period on MMA athlete's physiological capabilities and body composition
Study 5 – Chapter 8 **Thesis Objective: 4** **Study Aim** Examine the effects of a supplementary high-intensity aerobic training intervention (completed alongside traditional MMA training practices) on aerobic capacity and indices of competition specific performance	**ARMSS Stage 3: Predictors of performance** Quantitative field and laboratory data collection with training intervention	1. Apply a cardiovascular training intervention to MMA athlete's regular technical-tactical training 2. Determine the effects of training intervention on physiological and body composition measures collected in laboratory 3. Determine the effects of training intervention on bout pacing as measured via body worn accelerometry in simulated competition

Chapter 3 - Study 1: From Early Explorers to Restricted Practitioners - A Qualitative Analysis of Coaching Practices within MMA

3.1 Chapter Rationale

Chapter 2 demonstrated that MMA research is limited regarding the nature, content and structure of MMA training. As such, suggested training interventions that appear in the extant literature are likely based on unevidenced assumptions regarding the current practices of MMA athletes and the environment in which they exist. Athletic training, as a structured and guided practice led by the coach, is centred on the perceived needs of the athlete and the coach simultaneously (Gordon, 2009; Jones and Wallace, 2005). Accordingly, any analysis of an athlete's training practices should be underpinned by an understanding of the coaches responsible for this provision. Therefore, the aim of this study was to gain an understanding of their backgrounds in MMA, what they are trying to achieve with their athletes and how they monitor this process. Such insight cannot be provided by quantitative observation alone. Therefore, a qualitative exploration of what the coach is aiming to achieve, how they believe they are achieving this and how they came to hold these beliefs would enable an in-depth discussion of MMA training. Qualitative analyses would also reveal aspects of contextual factors influencing coaching practice that may be transferable across cohorts, populations and groups to better understand MMA training practices as a whole (Christensen, 2013; Smith, 2018). To achieve this, reflexive thematic analysis following a series of semi-structured interviews with a cohort of MMA coaches using a predominantly inductive, relativist approach was conducted (Braun and Clarke, 2013a). In concert with the quantitative observations in the proceeding chapters, this enables the understanding of the MMA training process from a dialectic stance, whereby the results from both realist and relativist viewpoints are brought into 'dialogue' with each other to provide a fuller contextualisation of the research question (Schoonenboom, 2019)

ARMSS Stage: 2 – Descriptive research

3.2 Introduction

Chapter 2 provided a critical review of our current understanding of the physical, physiological and technical requirements of MMA performance. As is the case with sports of such multifaceted and complex demands, success is likely determined by the effectiveness of the athlete's training practices and their engagement with the coaching process (Cushion, 2010; Lyle and Cushion, 2017). The primary aim of the coaching process is to develop a capable sports performer and is centred on the interaction between the athlete and the coach. This interaction is built on the coach's knowledge of the sport, their knowledge of the athlete and their ability to successfully apply the former to the latter (Gordon, 2009). Therefore, the coaching process is by definition a group practice concerned with outcome goals for a specific individual within the group i.e., the athlete (Côté et al., 1995). Coaching itself may be most appropriately thought of as an umbrella term for a family of roles, tasks and jobs that may be fulfilled to enable athlete success (Côté and Salmela, 1996; Lyle and Cushion, 2017; Rathwell et al., 2014). Which roles are required is subject to the individual athlete's perceived needs, the context of the environment in which the sport exists, and the experiences of the coach themselves (Côté et al., 1995; Lyle and Cushion, 2017). As such, the coach is integral to the coaching process and the training environment as a whole.

Studies regarding the training environments of MMA and other combat sports have focussed almost exclusively on the participants. This tends to be done either through a sociological lens (Spencer, 2014, 2012, 2009; Wacquant, 1992) or by describing the training activities in relatively superficial detail to enable examination of their nutritional practices (Langan-Evans et al., 2020; Morton et al., 2010). Studies examining combat sports coaches have provided analyses of their personal coaching philosophies and psychological approach rather than their specific coaching actions (Gould et al., 1987; Santos et al., 2015). The coaching practices or beliefs underpinning the MMA training environment are, however, not currently documented. Coach knowledge may be attained via experience within the sport, observation of others and formal education (Gordon, 2009). Each of these sources are filtered through the personal and societal contexts in which the coach sits, for example, the specific training environment, coach/athlete career stage or requirements for current performance (Anderson et al., 2004;

Evans, 2017; Jones and Wallace, 2005; Miller and Cronin, 2012). Hence, understanding the individual coach's experiences in MMA and the key influences of their coaching alongside their own practices would give valuable insight to the MMA coaching process. Without such information we cannot appreciate how MMA coaches attempt to apply their knowledge to the improvement of athletic performance, and as such we cannot fully understand MMA training. This insight would provide rich contextual understanding to support the quantitative training data observed and reported in Chapters 5, 6 and 7 of this thesis. In turn this would also enable contextual insight of coach effectiveness as described by Cassidy et al. (2009) as the difference between what the coach 'hopes' is happening, and what is 'actually' happening.

To that end, the aim of this study was to explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition. This will provide a novel and significant description of the training environment to underpin analyses of quantitative field observations of training reported in subsequent chapters of this thesis. To achieve this, a group of professional, full time coaches took part in a series of semi-structured interviews where they discussed their entry into MMA and coaching, their current coaching practices, their aims within their practice and how they monitor the effectiveness of their practice.

3.3 Methods

3.3.1 Participants

Participants were recruited via purposeful and criterion-based sampling (Sparkes and Smith, 2014) following institutional ethical approval (20/SPS/033). This sampling is purposeful because the aim of the current study is to understand the coaching practices of current MMA coaches within the population studied in the following thesis chapters. Participants were recruited using the following criteria: current head coach of an MMA club; must plan and coach a minimum of five MMA training sessions per week to demonstrate an active involvement in MMA athlete development, with a minimum five years experience of coaching female and male adult competitors. Whilst there are currently no recognised MMA coaching qualifications, each of the participants demonstrated qualified competency within combat sports, and awareness of health safety in coaching by fulfilling at least two of the following criteria: a recognised coaching qualification and/or black belt in at least one other sport (kickboxing, boxing or BJJ); formal education in sports science or sports coaching; First Aid and automated external defibrillator (AED) qualified; recognised safeguarding certification and/or Disclosure and Barring Service (DBS) registration. Participants demonstrated knowledge of MMA as a sport and physical activity with each of the following criteria: a minimum of ten years involvement in MMA training; a minimum of five years of coaching national and/or international competitors, at professional, amateur and developmental levels. All participants were made fully aware of the aims of the study and provided informed, signed consent prior to the start of the interviews. Each of the following participants were provided with pseudonyms:

Coach 1 – Ian

Ian is a full time MMA and combat sports coach in his late 40's. He is a former international standard, professional MMA competitor who began training and competing in MMA during its formative years in the late 1990s/early 2000s. He retired from competition in 2010 and set up a combat sports club in his hometown in north-west England. He is the head coach of the club, focussing on teaching kickboxing and boxing for MMA as well as some grappling sessions. He has trained and now employs a small group of coaches in the club who coach several age groups and combat sports disciplines, including MMA. The club itself has ~100 paying members, providing sessions for multiple age ranges from ~6 years up to adult. Adult sessions are provided for novice beginners looking to improve fitness through to ~10 competitive MMA athletes performing at international amateur and regional professional standards. Ian has also worked extensively as a coach at international amateur tournaments. Ian is a qualified kickboxing coach whilst also holding black belts in BJJ and kickboxing.

Coach 2 – Steve

Steve is a current international standard, professional MMA competitor and coach in his early-mid 30s. He began training MMA in the late 2000s and first competed 2010. He is one of two head coaches and owners at an MMA centred combat sports club in north-west England, that has ~120 paying members. He focuses on coaching the competitive MMA team that consists of ~15 athletes. In this role, Steve coaches athletes at regional amateur levels, international amateur level and a small number of national-international standard professional competitors. He has previously coached at international amateur tournaments. Steve also works with a local formal tertiary education provider to run a series of sports coaching qualifications within the club. Based around coaching for MMA and other combat sports, this program has led to a small number of program graduates to be employed as coaches in the club under Steve. Steve holds a BSc (Hons) in Sports Coaching and is a brown belt in BJJ.

Coach 3 - John

John is a full time MMA and combat sports coach and club owner based in north-west England in his mid-50s. He has trained and been involved in MMA since the early existence of the sport in the mid-1990s. John moved to California (USA) in the late 1990s for 8 months to train full time as an MMA competitor, but never formally competed. He established an MMA training group upon his return to the UK that developed into the club he now owns and manages. John is responsible for coaching the club's fight team that is made up of ~20 regional and national amateur competitors as well as international and elite standard professionals. John also coaches at international amateur tournaments. John has trained and now employs a small group of MMA coaches who focus on the club's youth, beginner, and intermediate classes for MMA, BJJ and kickboxing, which make up ~80% of the club's membership. John holds a black belt in BJJ.

Coach 4 – Mark

Mark is a full time MMA coach in his late-40s. A former regional professional MMA competitor, he has owned and operated an MMA club in north-west England since the early 2010s. The club is focussed on youth development with ~40 members and a group of ~8 competitive regional-national amateurs and a smaller number of regional-national professionals. Mark is a former school science teacher and has used this experience to establish links with local schools and tertiary education providers to develop formal post compulsory education courses for 16 - 19 year olds based within the club. Mark works with other clubs in the region to provide a greater pool of training partners for the professional athletes in his club. He is also an active MMA event promoter and holds 2 - 3 events a year consisting of amateur and professional bouts. Mark holds a BSc (Hons) in Sport Science.

3.3.2 Data Collection

Each participant took part in three separate interviews lasting 40 - 80 mins each (mean = 47.3 ± 7.5 mins). Interviews took place via Zoom video chat software (Zoom Video Communications, USA) due to COVID19 restrictions in place during the data collection period. Zoom was also used to record the interviews for post-hoc transcription. Interviews were semi-structured, informed by the question guide in Appendix B and consisted of open and neutral questions informed by training literature and practical experience of the lead investigator in observing MMA coaches in their coaching roles to enable open discussion between two parties (the investigator and the interviewee) with sufficient understanding of the research context to allow meaningful exploration and synthesis to occur (Purdy, 2014; Smith and Sparkes, 2016). Questions were designed to focus on participant's background in MMA, their transition into coaching, and their current practices in coaching competitive and recreational MMA participants. This approach was chosen to facilitate three key outcomes: a) participants would present their own personal opinions on the same topics, allowing a degree of lateral comparability of response; b) allow flexibility within the interview structure for participants to voice novel or unexpected approaches that may be unique to themselves; c) provide a detailed narrative of their personal approaches and beliefs about MMA coaching that would allow contextualisation of quantitative training load data (Chapters 5 and 6). Interviews were reviewed by the researcher after completion, with notes made about further probing questions to be asked in the following interview session. All data were anonymised at the point of transcription (Braun and Clarke, 2013b; Purdy, 2014; Smith and Sparkes, 2016).

Interviews were conducted online instead of in person through necessity. Interviews conducted online produce a different environment and context than face-to-face interviews, which may affect the data (Purdy, 2014; Roberts et al., 2021; Smith and Sparkes, 2016). As such, the following factors were addressed to ensure interviews were conducted in such a way to provide rigorous and robust data in an ethical manner following the recommendation of Roberts et al. (2021): interviews were conducted via password protected video conferencing software with recordings stored on a secure, password protected drive to ensure data safety; participants were offered to be led through a practice session using the video conferencing software before data collection to minimise any technological barriers and increase their comfort in using the software and communicating via video; participants were given the option of using virtual backgrounds or filters at their discretion to protect the privacy of their homes and were asked to schedule interviews at times when family members would not be present; video and audio was recorded to capture body language to ensure non-verbal communication and context was captured for reference during analyses; rapport was established prior to the interviews via the participant recruitment process; ethical procedures were conducted via email and password protected, signed word processing documents prior to the commencement of data collection.

3.3.3 Data Analysis

Transcription of all interviews was completed using Otter.ai transcription software (Otter.ai, Los Altos, USA) followed by manual correction of errors. Transcripts were analysed via reflexive thematical analysis which enabled the identification and interpretation of patterns within the data from realist, relativist and inductive viewpoints (Braun and Clarke, 2019; Braun et al., 2017). Segments of text that were determined to be meaningful to the research aims were coded into themes and compared between interviews and participants. These themes were further analysed and grouped into categories of higher order themes, allowing a schematic of themes to be developed (Figure 3.1). Researcher subjectivity and reflexivity was embedded in this process (Braun and Clarke, 2013a) owing to the author's extensive first-hand experience and knowledge of MMA and its practices. Analyses therefore were both inductive and abductive (Siu and Comerasamy, 2013). To ensure rigor and credibility during these analyses, the following processes were conducted throughout: 1) maintenance of reflective diaries throughout the interview and analysis stages, serving to record thought and decisions throughout, managing subjectivity and providing justification for approaches taken during each interview and throughout the coding process; 2) each participant was given the opportunity to engage in checking the interviews, whereby they were provided the opportunity to review and comment on the interview transcript prior to coding. This allowed checking of the investigator's recording, hearing and interpretation of their sentence structures to avoid misappropriation or misinterpretation. Only minor errors in syntax and participant emphases were corrected during this process; 3) each stage of data analysis was subjected to peer debriefing by the supervisory team as critical friends (Smith and McGannon, 2018), who challenged the analyses conducted by relating findings back to the raw data from their own contextual viewpoint. The aim of this practice was to develop a more nuanced reading of the data with greater reflexivity. This debriefing was also used during the selection of interview participants and interview question themes (Braun and Clarke, 2019, 2013b; Burke, 2017).

3.4 Findings

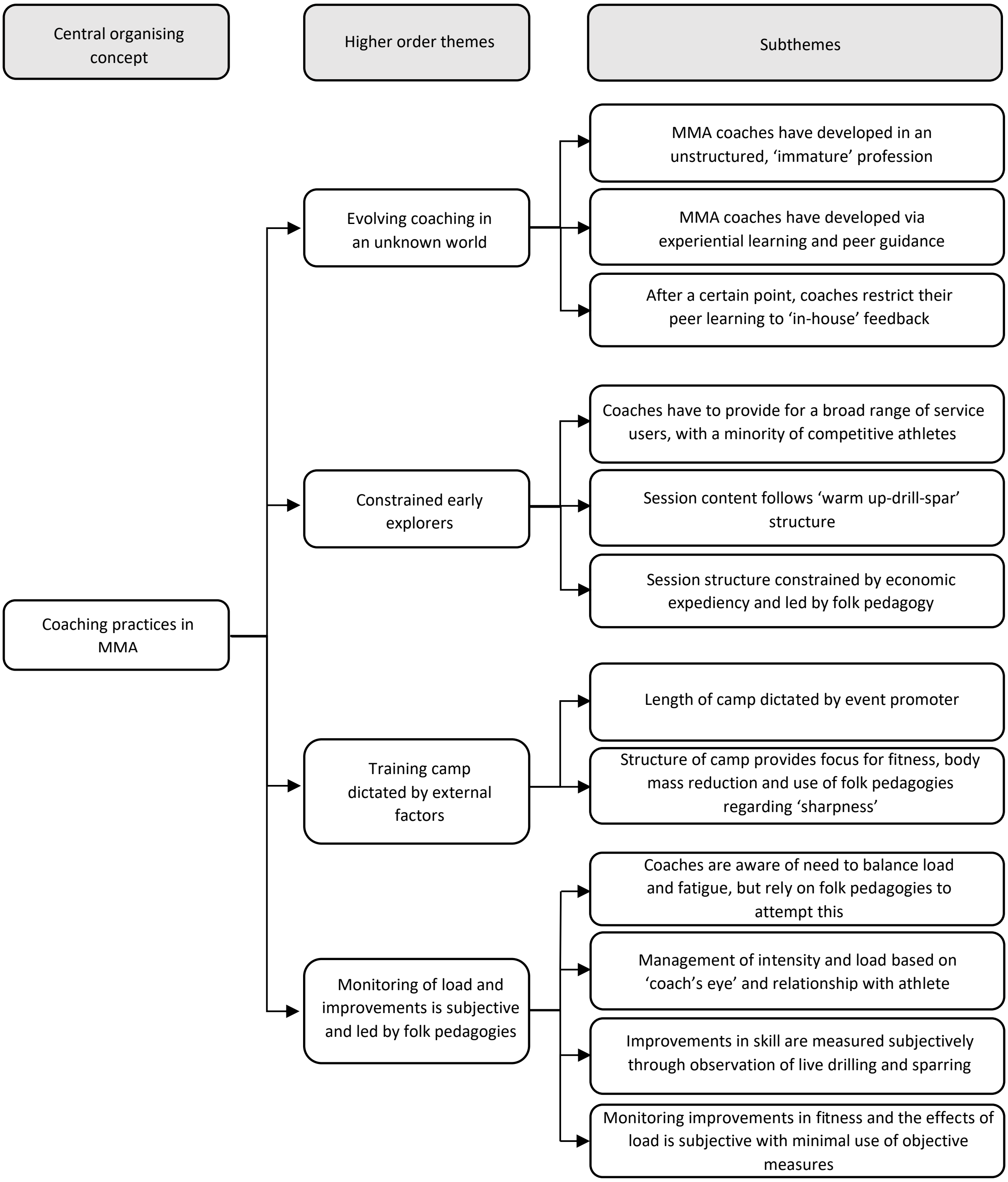

Figure 3.1 – Schematic showing the relationships between the higher order themes and subthemes

3.4.1 Higher Order Theme One – 'Evolving coaching in an unknown world'

The practice and profession of MMA coaching is still in its infancy. Three of the coaches, Ian Mark and John, became involved in MMA during its formative years when the nature and structure of the sport were still in development. The final coach, Steve, entered during MMA's 'boom' period of the late 2000s. Owing to the rapid growth of MMA in this time, the coaches developed their coaching methods through experiential 'trial and error' and peer learning from other MMA and combat sports coaches. However, once the coaches become established within their field, this peer learning appears to have reduced or ceased entirely.

3.4.1.1 Subtheme One – MMA coaches have developed in an unstructured 'immature' profession

Ian, John and Mark became involved in MMA during the 1990s and early 2000s through a general interest in 'traditional' martial arts. In the absence of a formal club or participation structure, each coach travelled to different groups of people with a shared interest to learn.

> Ian: "My ex-wife was training at a karate club and she was pecking my head to go and join. I wasn't that interested, but all the stories she was talking about it didn't sound like karate. She was talking about armbars…So eventually I went down out of interest…Started with that club trained with them, and sort of fell in love with it and started training twice a week, and it was three times a week then it was four times a week, trained with him for about probably about two years and then he closed. I wanted to take it a bit further so I sought out the local - well it wasn't local it was an hour away - the best fight team in in probably the north-west at the time, you know, there wasn't many, in fact there was one"

Each of the older coaches had similar experiences with Mark stating "I couldn't find anything near me…so I had to travel round quite a lot", while John "made the decision to go out to America and train full time" at the age of 21. By the time Steve, the youngest of the coaches, first engaged with MMA, it was more established as a sport in the UK. MMA clubs were now available in his local area with local competitors being 'known' in their regions. Through their informal networks each coach learned the techniques of MMA, shared ideas between training partners and recreated the competition format in a seemingly ad hoc, unstructured manner.

> Ian: "The setup was a lot different back then you know there wasn't a head coach there was no one in charge of the team. We were all just at the same level mixing our knowledge together. So it'd be like, you know, 'Ian you know some boxing, you run a boxing session tonight. Yeah, Alan, you're really good at the ground part you run a ground session tonight'"

> John: "...because people really didn't know how to train back then that much……The MMA training that we did was either sparring, or it was like wall wrestling rounds, that sort of thing really but every day was full on intense, very intense…we used to call them bloody Mondays because they were very, very intense sparring… sort of an old school method really… Who's got more that day? Basically it was that sort of training."

Mark's discussion also hints at the rapid growth of MMA in the early-mid 2000s. By this time Mark was able to find a nearby club with a single coach who was "a fledgling coach himself, but he was definitely a lot more advanced than anybody I'd been coached by". Within this environment, each of the participants experienced one of two motivations for becoming a coach. Ian and John expressed being drawn to coaching as a natural progression from their own competitive career and by noticing potential for the role within themselves.

> Ian: "It seemed like it was a natural progression from athlete now move across to coaching…It appealed to me anyway because I always felt I had a lot to pass on…and it was towards the end of my fight career that I sort of said 'right, I'm going to set up my own place and concentrate on that, rather than myself as an athlete now'".
>
> John: "I was in America, some of the guys commented to me a few times that they thought I was good at doing that already. So, it just was just naturally in me to sort of take the lead on running stuff."

In contrast, the other two coaches appear to have seen it as a financial opportunity either for their own livelihood or to support their own training, with Mark realising "I could take it a little bit more seriously now you know what I mean? I could actually eventually be able to make a living out of coaching" and Steve being clear that "I wanted to coach as well, A) for the passion of it but B) to provide a funding stream for fighting".

3.4.1.2 Subtheme Two – MMA coaches have developed via experiential learning and peer guidance

Owing to the unstructured nature of MMA during each coach's development, much of the learning that took place was via group experience and the open sharing of ideas between training partners and clubs.

> Ian: "When the sport started off we all shared knowledge because no one knew anything…because there wasn't that many on the scene so you knew everyone in the UK…So sharing of knowledge was paramount for us actually learning anything…. I trained at enough gyms and trained all over the world as well, you know training many different coaching styles."
>
> Mark: "My coaching was anything I learned on the Tuesday I taught on the Wednesday. And then there was a couple of guys I knew that were starting something in {NEARBY TOWN} and they asked me to do a bit of coaching from there and said, 'Yeah, no problem'. And so I brought some of the guys from {CLUB TOWN} to {NEARBY TOWN} and we had sort of a joint class going on."

In the absence of any formal coach education or development pathways for MMA, Steve "had about thirteen lads coming just pay £3 to the gym and I'd just coach them for nothing just to get some experience". He acknowledges that his coaching was initially based on how he had been coached up to that point, with improvements coming from experiencing other sports.

> Steve: "…it was all about the micro class. There was definitely no understanding of the macro sort of approach. There was no objective to learning there was simply, you know, moves to learn. That's how I envisioned it, a good coach was someone who has more moves than the next guy....and as that progressed, I started to work with more coaches like my wrestling coach….I had a boxing coach as well….and I noticed the difference with them two to my MMA style coaches, there was always clearly a warm up, there was a lesson objective explained. It was more apparent that the themes will be linked and can become increasingly complex."

Mark has also observed this evolution in other coaches and within his own practice.

> Mark: "*[MMA]* coaches are changing and evolving all the time and that's how I feel about it because at first I would train it a bit like a jiujitsu session but I've certainly changed on that a lot. Now, I try and do as many drills that are realistic to what they'll face in fights, so that when they get themselves in these situations, it's not foreign to them."

Importantly, however, Steve is the only participant who reported being influenced by any formal coach education.

> Steve: "Before I had a coaching degree I'd assess my class on what I taught, so I could already assess how well the class went before I'd taught it based on how good I thought the session plan was…. it was all lightbulbs were going on for me, like I were a coach who used to queue kids up for pads, d'you know what I'm saying? I know what bad coaching looks like, I'm the guy who taught an omaplata *[an advanced grappling manoeuvre]* to beginners. So, you know, I've done it all wrong, but I didn't know I was doing it wrong."

3.4.1.3 Subtheme Three – After a certain point, coaches restrict their peer learning to in-house feedback

The nature of peer learning and feedback appears to change as MMA coaches become more established in their role. Ian compares coaches and training partners he worked with previously being more open to sharing of ideas and methods in the past as opposed to now.

> Ian: "There are some coaches that are very free to share their ideas with you, and there are some coaches that think it's all secret techniques, and they won't be sharing with you. So I'm very free with my ideas, I've had coaches contact me say 'can I come and have a chat with you about you and your kids programme?'... I'm like 'cool, let's chat let's see what we can improve'. And it's the only way you're going to get better is if we're all share ideas of what works and what

> hasn't worked….early on, it was very much: share, and I think probably as it's got bigger it has got a little bit more political."

This reduction in external peer learning is strongly reflected in John's assertion about not requiring external information or assistance, stating his own experience and in-house colleagues are all he requires:

> John: "I've enough experience to know when I don't know something and to go and find out and ask. But because a lot of my job is on technical and lifestyle assessments, I don't really need to speak to someone else.… If I had a question about wrestling, I have a wrestling coach for me to ask, if I have a question about jiujitsu, I have that many jiujitsu black belts I'm friends with I could ask them. But, do I have to go and ask an MMA coach advice about MMA? Very, very, very rarely ever…. I don't need anyone. I'd rather play off my coaches and us work together on stuff than do that."

Mark is less restrictive in his approach to external development but still does not appear to engage with other coaches. He prefers technical tutorial videos and popular science books.

> Mark: "Bits and pieces every now and again, I don't study individual coaches. I do watch a lot of grappling tutorials and things like that. Books wise, I'll read like The Talent Code and Bounce and things like that, coaching manuals…but there's no one person or anything like that that I follow. I just try and pick up little bits and pieces along the way really."

In summary, this theme demonstrates that the infancy and rapid growth of MMA necessitated peer-to-peer, experiential learning on the part of the coaches. Once coaches become established as club owners, however, this peer learning appears to reduce or cease entirely.

3.4.2 Higher Order Theme Two – 'Constrained early explorers'

Each of the coaches have progressed from being an early MMA explorer to becoming owners of independent MMA clubs. This leaves them with two distinct aims of i) providing a viable income for their club and themselves and ii) ensuring their athletes are able to compete successfully. These potentially conflicting aims may constrain the scope and development of their coaching practice in that they must design sessions and 'classes' aimed at the perceived needs of the paying, recreational members. This creates a paradox where the provision of training for competitive athletes, who are the minority in each club, is simultaneously enabled but also restricted by the economic expediency of providing sessions for recreational participants. In order to achieve the dual aims of ensuring the paying customer is satisfied and the athlete is ready for competition, training sessions follow a set 'warm up-drill-sparring' structure. Within these sessions the structure and practice appear to be based on folk pedagogy where session content is guided by unevidenced assumptions regarding the physiological and performance outcomes of training methods used.

3.4.2.1 Subtheme One - Coaches have to provide for a broad range of service users, with a minority being competitive athletes

Each club runs a series of different sessions, often referred to as 'classes' by the coaches. These classes tend to be tiered according to participant experience but with overlap between each tier.

> Steve: "So at the gym now we've got an intro to MMA, an intermediate's and advanced…. Every level is equally important. So, I wouldn't say there's anything more important, we're trying to be family martial arts meets American Top Team *[elite international MMA gym]*…. we might be a bit more passionate about fighting because it's competitive, but if you come in the gym and you look at the way the structure works you got them coming in at 4 *(years old)*, working them up through the fundamental movement skills into the juniors, you know, progressing on to being young adults."

> Mark: "The beginner class is definitely more people that just want to get fit, learn a martial art, and have some sort of a hobby…I get quite a few people who come to the beginner class who are in the 40s and things like that, you know, they've no desire of jumping in a cage anytime soon. And who could blame them?"

This structure does seem to allow some talent identification and development to occur within the club structure and feeds into the amateur competitions available in the UK.

> Mark: "I try and get them to think about wanting to do an inter-club fight…I've probably got maybe 50/50 that want to fight on a show, so not one of the big shows to begin with…guys that do well and want to carry on further then obviously one of the bigger shows."

> John: "In terms of the gym as a business, then of course it's important to keep filling the fundamental classes up. As a professional coach, it's important for me to build new competitors up."

John and Steve are able to employ younger coaches to take the recreational and beginner classes, leaving them to focus on the 'fight team' sessions. Ian also expresses a desire to do this, but the economic realities of being a club owner precludes it.

> Ian: "Priority as a business owner, are your paying members…you've gotta look at *(what)* 80% of our paying members want - they are there as a recreational activity. You're stupid if you then model your business to the 20%. You won't be around very long. And that's the reality of it. Now, the enjoyment is probably at the 20%."

This view is echoed by Mark stating "if I just focussed on out and out fighters, I wouldn't be able to put food on the table". With equal clarity Steve admits "if we started to prioritise the fighters, other stuff will go to shit…If we don't have the paying customers coming in we can't run the gym anyway."

3.4.2.2 Subtheme Two - Session content follows 'warm up-drill-spar' structure

When discussing their training sessions, the coaches utilise a warm-up based around narratives of raising the HR and breathing rate of the people involved. There is also some evidence that mobility drills are being considered whilst using the movements that are to be trained in that particular class.

> Steve: "I usually start the class with a bit of a basic jog round, some stuff to warm up and then we'll usually have some drills down the mat, which will be quite fundamental like singlelegs down the mat, doublelegs down the mat, and constantly focused on biomechanics, posture. And so we'll do some mobility work as well… typically I'll set them up in groups and I'll say 'right three minutes', it starts being a lot more like conditioning sparring almost for the warm up,"

Session structure tends to be based around drills with a focus on open skill, performance specific skills.

> John: "we'll cover some techniques that like we think needs working on from the fundamental range of stuff that we know works. Once we've got that, then we can transfer down to the floor, and we'll do some basic grappling for MMA that sort of stuff. Once we do that, we then implement sparring, from a very light sort of shadow boxing on the feet, with very heavy wrestling and grappling."

Ian highlights that the content and coaching techniques largely depend on the experience of the group in the session.

> Ian: "If I'm teaching beginner level they might do a footwork drill, and I will teach 'this is a jab'…whereas if I'm teaching a much more advanced level that jab might be within the footwork…so it all becomes a lot more merged is not as simple as this the drill this is the technique…my kid's sessions are planned pretty much down to the minute…it's written down exactly how it's taught. The fighter sessions I'm a little bit more free with it, sometimes I'll come in with a plan, and I'll watch how people are finding what my plan is and then I might tweak it"

'Live' drills and sparring are incorporated into sessions, often as a method of 'conditioning', with this taking place "two to three times a week…we might build in some conditioning sparring" according to Steve.

> Mark: "…then they'll do some wall wrestling when they're in a fatigued state, and then we'll do some more exercises and then we'll do some getting up in a fatigued state, then they'll do some more and then they'll roll in a fatigued state"

Ian is keenly aware that the session includes paying, recreational members, so needs to be tailored towards their enjoyment as much as being about improvement of performance capacity.

> Ian: "I add stretching in for the kids, I don't for the adults. That is something that I tend to say to them, 'Look, you're not paying me to teach you to stretch. If you want to stretch do it in your own time'… to get the best technique across to them can sometimes seem boring, compared to what they want to do. So you have to find that right balance"

3.4.2.3 Subtheme Three - Session structure constrained by expediency and led by folk pedagogy

The economics of needing a strong base of recreational, paying members means balancing customer satisfaction and athlete performance is difficult to achieve.

> Ian: "It's difficult when you're dealing with a paying customer. At the end of the day, they're paying for a product. If you're not giving them enough time on their side of things they have every right to complain about that. So you have to get a balance where you're giving your time fairly, just because they're an athlete doesn't make them more important than the person who isn't."

The indication here is that coaching practices are constrained by the expediency of relying on paying customers to make the club and the sessions economically viable. In response, the coaches plan sessions aimed at improving skill and fitness for their athletes as well as being enjoyable for paying members. As described by Mark, sessions "end up with some fitness drills at the end where they'll do something that's hard like some exercises…and then I tell the guys in their own time to do a bit of a stretch to cool down". John discusses how "there's stuff that everyone needs to do…the intricacies that we've noticed that the higher-level athletes needed we implement into our amateur team anyway". This approach appears to be based on folk pedagogy and personal assumptions about the effects of the techniques employed, with little depth of evidence provided.

> Steve: "I always aim for a minimum of 15 minutes live. So the easiest day you'd get is drill for like half an hour, 40 minutes and I go live for 15 minutes. I feel that's the lowest level of intensity I'd go for is 5 x 3 *[minutes]* jiujitsu with punches. A more intense session will be shark tank rounds so you're in a three…winner stay on. So the fittest guy will end up probably doing the most time in."

> John: "*[The]* fight lasts 5 minutes…My professional MMA fighters when they do jiujitsu rounds, they get 3 minutes. And the reason for that is when they get in the cage, and the round starts, it's going to take a minute of feeling out to get the timing on the takedown, then when you get the takedown, how long is it going to take you to get them actually down? How much time do we have left? Average times roughly going to be about 3 minutes."

Following these comments, it can be said that MMA coaches are exploring how to achieve the coaching aims of their athletes under the constraints of providing a service for paying recreational participants. In this, they are led by folk pedagogy and experience-based assumptions about the effects of their training methods.

3.4.3 Higher Order Theme Three – 'Training camp dictated by external factors'

The coaches have external restrictions placed on their mid- and long-term planning, in addition to the aforementioned constraints to their individual training sessions. The amount of time provided for competition preparation is dictated to them by the date of the competition, which the coaches state is decided predominantly by the event promoter. This period of time is referred to as a 'training camp' and consists of more focussed, purposeful training with specific aims related to an upcoming competitive bout. The aims of the 'training camp' depends on the current and target BM of the athlete, their perceived levels of fitness and the coaches perception of which skills they require for the given opponent.

3.4.3.1 Subtheme One - Length of camp dictated by event promoter

Training plans for competition are highly dependent on how much time there is provided before the date of the bout.

> Steve: "{FIGHTER D} comes in and there's a fight there in seven weeks, right? Well, we've got seven weeks. If it's a bit earlier, maybe you know, maybe in November, you say 'right, this next show's in April? Well, we've got twelve weeks.' So we always look at the situation when is this show, or when is this fight being offered….if he's got six weeks, sound let's go."

In spite of this, the coaches do express a preferred length of time that either they or their athletes would have, with Mark stating "a good camp will be eight weeks I would say. That gives the fighter enough time to start to get himself (in shape)" whilst admitting that this target length is not always available: "If we could get eight weeks for them it'd be good". Ian discusses the input of the athlete to his choice of camp length and what they feel is appropriate for them.

> Ian: "It used to be a set length, we used to do eight weeks. Nowadays, I leave a little bit up to the athlete and what makes them feel comfortable, from a mental standpoint. {FIGHTER B} was fit doing a twelve week camp and she was fit doing a six week camp, but in her head she

> was fitter doing a twelve week camp than she was doing a six week camp. Yet, I got better results in her fights if I let her think she'd done a twelve week camp."

Ian, though, also admits that, when not dictated by the date offered by the event promoter, length of training camp is led by 'accepted tradition' within MMA where "I tend to plan (for) that eight to ten week period. Where do you get your eight to ten weeks from? That's just the standard that goes around, there's probably no actual scientific evidence behind that! [laughs] Some do twelve some do six."

3.4.3.2 Subtheme Two - Structure of training camp provides focus for fitness, body mass reduction and use of folk pedagogies regarding 'sharpness'

A key aim of training camp appears to be getting the athlete 'in shape' and down to their target BM. This forms the initial assessment of the athlete when accepting a bout.

> Steve: "What condition is this person in? Are they really heavy? Are they really unfit at the moment? Are they active, is their weight good?"
>
> Mark: "The first initial part we'll look at the opponent….so we've got something to go on from a technical point of view and a tactical point of view. And then it's just about getting my fighter in shape so eight weeks, start off trying to get them as fit as I can, as early as I can. (If) his fitness base is poor, then I need a bit more than eight weeks really".

Alongside this, however, John states he prefers his competitors to not require a long training camp as "the people that are going to make it are the ones that stay ready….I know he's ready to go with three weeks time. He's a professional athlete, he takes care of his stuff". Steve reflects this opinion by using a specific member of his club as an example.

> Steve: "I like a linear twelve weeks early prep, eight week camp, seven weeks is training. For that ten weeks (sic) we're looking at that bell shaped curve, I like that sort of approach… If he's got six weeks, sound let's go. Let's just let's just hit that bell shaped curve now."

In this instance, whilst Steve doesn't provide any detailed explanation as to which training variables are subject to the "bell-shaped curve", or how they are manipulated, he does highlight that "it's about making sure he's not just doing too much volume all the time and not enough intensity, and not enough sport specific stuff". This demonstrates that Steve is attempting to provide some form of short-term periodised plan. Training camp also provides a focus for specific skills that the coaches feel their athlete needs to improve.

> Ian: "I plan to the athlete's skills that they've got, to make them better in what they're going to do, rather than game plan off the fighter that we're trying to guess what they're going to do. So

I tend to plan around where they need to improve or what improvements I want to see in this next fight."

Mark: "Closer to the time I work a lot on escapes. I always tell the guys a couple of weeks before….I want it to be like second nature in their minds, you know, if they get caught in a guillotine they've got to know what to do straight away. If they get caught on their back they've got to look to try and escape same way without having to think about it. So kind of drill that quite a lot just before the fight."

The coaches also indicate that their technical/tactical training forms part of their fitness stimuli, with Mark explaining how parts of sessions are planned to specifically 'exhaust' the participants.

Mark: "Now I try and (use) more of the HIIT, try and focus on getting the heart rate really high and sort of replicate what it's like in a fight really….quite often, we'll do a pre-exhaust where they'll tire themselves fully out and then they've got to fight or they've got to spar or they've got to roll in that fatigued state."

There is also some discussion about attempting to provide overload using the technical/tactical drills, including the use of sparring to demonstrate improvements in technique and/or fitness.

Ian: "It's usually done through drills and live drills. So if I want you to use your underhook to get off the wall and then hit your own takedown…it'll be done under no resistance, work what you're comfortable with and then usually go 'right let's do some resistance drills on that as well'".

Ian is the only coach to provide evidence of planning a pre-competition taper as part of technical/tactical sessions where "the last week it's very, very light, and won't do much really". This apparent taper, however, may be more related to the practices of weight cutting rather than performance peaking, as Mark points out "the last week…you can't really do much conditioning or anything like that it's just a weight cutting week."

This theme therefore demonstrates that whilst the coaches would prefer eight - ten weeks for competition preparation, the length of time provided is dictated by the event promoter. This time is mostly used to ensure the athlete achieves the required BM for competition and increase their fitness through technical/tactical training.

3.4.4 Higher Order Theme Four – 'Monitoring of load and improvements is subjective and led by folk pedagogies'

The coaches understand that training load needs to be modulated during a training camp. The nature of the training environment and the focus of their own practice means they attempt to achieve this via altering the intensity or content of technical/tactical sessions. The effects of this on the athlete's physiological and skill performance is assessed through informal, day-to-day observation of their responses during training sessions.

3.4.4.1 Subtheme One - Coaches are aware of need to balance load and fatigue, but rely on folk pedagogies to attempt this

The coaches display an awareness that training intensity and volume need to be managed over the course of a training camp, demonstrated by Ian explaining that "they'll *(the athlete)* break because they've never been put under pressure. But then you put under them too much pressure they break because they're now overtrained". This tends to be done by altering the content and focus of technical/tactical sessions, using a process Steve calls "tactical periodisation" where eight - ten weeks before a bout sessions may involve "working at 80%, an amber session, we're gonna have a high volume and a moderate intensity". Mark also suggests his chosen training methods change in relation to the competition date where "the last couple of weeks I'll do a lot of escapes from positions and submissions…we'll do some extra stuff for the guys who've got fights coming up, and then the fitness work and stuff like that, we'll set it and sometimes they'll do the outside the class time". Ian discusses his understanding of intensity within his sessions.

> Ian: "I don't think of it as intensity probably, I think of more in the sense of when am I going to introduce sparring, which obviously will be more intense. Now it isn't me thinking I want it to be more intense, it's the fact that I now want you to get fight sharp."

Each of these discussions include the use of terms that suggest the coaches are cognizant of some training load management theory.

> Ian: "You're getting closer and closer to competition so it should become more, more and more competition specific…*(They)* call it the GPP I think don't they? It's just becoming more sport specific, less general more sports specific…becomes more and more close to what you're actually going to be doing on the night. That's why the sparring gets introduced then, my thought process has been any way to try and take them into right 'now we're ready, now we put everything in that we worked'."

3.4.4.2 Subtheme Two – Management of intensity and load based on 'coach's eye' and relationship with athlete

None of the coaches interviewed regularly collect any direct training load or fatigue data. Each relies on their relationship with their athletes and understanding individual moods and responses over time to determine load-fatigue-recovery.

> John: "You have to be able to read the room as a coach. It's very important. Some days we'll go in sparring, and you can like feel in the air that someone's going to get injured. And like you have to be able to cut the sparring short and say, we're only doing three rounds today. And the guy's will be like 'no I need to do more' and I'm like 'you don't'."

> Steve: "We kind of know because we watch the lads train every day. We can kind of look at them, and sometimes I'll come in and say 'Mate look at you, you don't need to train this morning', 'I want to do something', 'Alright well have a jog then, do a like 30 minute jog on 9 kph *(sic)* where you can have a conversation while you're jogging'. It's about understanding what you're looking for."

Ian discusses his memories of competing himself and applies those as a measure of whether or not his athletes have overtrained where "I look back at my career, I always felt bollocksed after the first minute (of a fight) [laughs]. However, I've tweaked it for my athletes, and… I can have a conversation with them in the corner, because they're not knackered, because I've not broke them down in training." The coaches also demonstrate an understanding of the overall effects of fatigue on the person outside of training and performance, enabled by their personal relationships with their trainees.

> John: "There might be a reason for that so I'll be like, 'you look tired today' and then they might turn round and go 'I didn't sleep well last night', or they might turn around and go, 'I haven't eaten this morning, I was in a rush on the way out'. Or maybe they trained too hard yesterday and haven't recovered or sometimes people hold themselves back because they've got another training session that night. There's a multitude of reasons, but we discuss them."

Steve goes onto suggest that using more formal monitoring methods may be beneficial as "this is where tracking wellness can come in better, if we was recording mood and fatigue". Some of the coaches differ in their opinions of how to respond to their perceptions of fatigue changes. John states that he provides periods of rest during training camp.

> John: "So we factor in a three or four day sort of break for them to just take some time, maybe drop the weight a little bit through diet alone, rather than having to fuel themselves for every training session. Sometimes I give people a break just from sparring, still come in do all the technical sessions but I'll make them not spar at all for like a week or two."

Mark, conversely, would prefer his athletes to maintain the intensity of their training outside of training camp as he would "prefer my guys to be to be training all the way through, obviously up the intensity when the fights are announced and stuff, but they should all really be training hard all the way through".

3.4.4.3 Subtheme Three - Improvements in skill are measured subjectively through observation of live drilling and sparring

Improvements in skill, rather than fitness per se, are the coaches' main concern when considering load and intensity management, as John discusses: "Looking for improvements in fitness, is like a bit of a tricky one because that's not what I'm really looking at. I'm looking for, number one, improvements in skill". Observing skill improvements or decrements, however, is discussed as being difficult in MMA as a highly skilled based sport.

> Ian: "That is the hardest thing in MMA! I've thought about this a lot….you can monitor it you can track it….with a sport where you need to jump a certain distance it's easy! Can you jump further?...How do you measure the improvement of a jab? ….At first it's easy because, 'can you throw a jab? No. Can you throw a jab now? Yes. Cool well that's improvement, I can measure that. And the next step is well can you use that jab to land on you know in a live situation? Well now yes, I can. And now you're hitting a point with 'Well, now how do we measure it now?' How do we say that that's getting better? Because now you're in situation where it depends who you are against and stuff."

This inherent difficulty necessitates the use of subjective measures to determine performance improvements, especially during live drills and sparring sessions. This use of 'coach's eye' is used to provide feedback within and between sessions and to determine the content and intensities of subsequent sessions in a reactive manner.

> Steve: "So when me and {OTHER GYM COACH} watch sparring on Friday night, if there's something that might be annoying us like, 'I just watched four MMA rounds done there, two of you shot a takedown. Right, let's get four weeks on boxing-wrestling here, let's get them mixing the takedowns back in'. We'll add the takedowns back in and before you know it, 'four of you got heelhooked this morning. Does no-one know a heelhook defence in here? Right mate bang that in the classes the next three weeks.' So it's very much assess on the go."

3.4.4.4 Subtheme Four - Monitoring improvements in fitness and the effects of load is subjective with minimal use of objective measures

Alongside subjective monitoring of skill, the coaches also use subjective assessments to determine changes in athlete fitness. The use of subjective measures is in spite of their knowledge of other, more objective methods being available.

> Mark: “You'll see it when they start to spar or wrestle sometimes, and they look just a little bit jaded, and then you just tell them ‘you probably need a rest day’.... You can just tell that they're not doing as well against people that they usually do better against. You can see sometimes they just look a little bit like they're a bit off the pace here and it could be they've just done three weeks without a rest day…I don't do the perceived level of exertion and all that anything like that….you can just tell the guys who're putting the effort in.”

Similar to the coaches monitoring of skill, this approach seems to be chosen based on the difficulties associated with load management in a skill-based training environment and the fact that “overtraining is difficult to gauge isn’t it” as opined by Mark.

> Ian: “It's through training. Not only just fight measurements but you're going to look at him during his training sessions, is he generally improving the skill that we want him to improve on? But it's hard to write on the board, pinpoint what that is - how we measure that? Very difficult, it's subjective again.”

Indeed, John is the only coach to discuss using any objective measurement of load or fatigue within their MMA technical/tactical sessions. This is still used, however, in conjunction with subjective measures derived from his personal relationship with the athletes in his club.

> John: “A lot of the fighters wear heart rate monitors in the sessions and stuff as well. I can tell when they're rundown when they're tired when they're grumpy, cranky that sort of stuff from knowing them, if that makes sense. I can check *(HR)* for a full week how the sessions are pushing them, when they should be on rest days,”

In summary, this theme shows that the coaches understand the need to provide changes in load during training camp to avoid what would be recognised as symptoms of overtraining syndrome (OTS). In practice, however, the coaches rely mostly on their own experience and their relationships with the athletes to attempt to influence and monitor changes in training load. There is minimal use of objective measurements of either fitness, load or fatigue to support this process.

3.5 Discussion

The aim of this study was to explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition. This was to provide context for the reading and analysis of quantitative field observations of MMA training reported in subsequent chapters of this thesis. Following reflexive thematic analysis of ~9.5 hours of interviews with four professional MMA coaches, a set of four higher order themes were constructed. These themes demonstrate that the MMA coaches have developed their practice via experiential learning led by peer-to-peer knowledge sharing. The absence of a recognised national governing body (NGB) or coach education pathway has resulted in MMA coaching being underpinned by folk pedagogies, which are reinforced by peer learning becoming ‘in-house’ after the coaches become club owners. Each coach expressed a desire to work primarily with competitive athletes, but this is constrained and simultaneously enabled by the economic expediency of the absolute majority of club members being paying, recreational participants. The competition structure of the sport is largely determined by independent event promotors which sets another layer of constraint onto the coaches’ work, often reducing the training time available to less than that required for an effective training cycle. Influenced by this environment and the absence of external support or formal education, methods of monitoring skill and fitness improvements are subjective, reactive and based on folk pedagogy.

The MMA coaches interviewed revealed that they have not developed along what could be considered a ‘traditional’ coaching pathway. In contrast to other competitive sports, there is no recognised NGB for MMA in the UK (Sport England, 2021). Whilst associations for England, Ulster and Wales have recently been formed with International MMA Federation affiliation (IMMAF, 2021b), each of these bodies are in various stages of applying for recognition as formal NGBs (Spencer, 2021). This means there are no regulated coaching qualifications for MMA (1st4Sport, 2021). Established combat sports such as boxing (England Boxing, 2019) and judo (British Judo, 2021) require NGB certification and licencing before a person can begin coaching. Currently, however, only 54% of all sport coaches in the UK hold formal qualifications (UK Coaching, 2019) and formal coach education appears to have little impact on practice (Ciampolini et al., 2019; Cushion et al., 2003; Harvey et al., 2013) suggesting that such qualifications do not guarantee competency (Duffy et al., 2013). The absence of qualifications, therefore, does not necessarily indicate poor practice on the part of the MMA coaches. Rather, it is evidence they have developed their coaching capital through other means, such as the number of years involved in the sport as competitors and coaches. Capital in this instance being the intangible aspect of a coach’s persona that engenders trust in their knowledge of coaching and the sport itself on the part of the athlete (Blackett et al., 2017; Christensen, 2013). Ian and John’s formative period of experiential learning developed the foundation of their coaching knowledge and application. Similar to what is seen in other sports (McCullick et al., 2016), Mark’s practices share a direct lineage from his own coaches, who were part of the same generation of 'early explorers' as Ian and John. Steve, as the youngest of the coaches, had access to more structured coaching to begin his own competitive career. His coaching was, however, still provided by 'early explorers', providing a traceable, relatively small genealogy of MMA coaches. In the absence of formal, external coach education, this linear process may lead to practices based on folk pedagogy (Olson and Bruner, 1996; Partington and Cushion, 2013). Under folk pedagogy, a practitioner's theories of learning are based on their personal experiences as a learner (athlete) and teacher (coach) processed through the norms of the culture in which they exist (Drumm, 2019; Olson and Bruner, 1996). Such pedagogies provide the 'what' of the coaching activities employed, with their own experiences developing each participant's beliefs around the purposes and outcomes of said activities (Armour, 2004; Harvey et al., 2013).

The coaches' capital and their application of folk pedagogies are ultimately reinforced when they become club owners and hold a perceived position of authority and custodianship within the sport (Taylor and McEwan, 2012; Wacquant, 1992). As a coach gains greater perceived capital, their own definition of effective practice becomes ingrained and less affected by external influence or reflection (Cushion et al., 2003; Sherwin et al., 2017). This may be compounded by the reduction in peer-to-peer learning used by MMA coaches as they become more established. As a result, an orthodoxy of practice in MMA coaching may have become ensconced, thus setting the template for sessions and training periods. Such an effect has been documented previously in other sports (Taylor and McEwan, 2012). As newer coaches follow the 'traditions' set by their coaching predecessors, this orthodoxy of practice becomes entrenched within the culture of the sport itself (Cushion et al., 2003; Duffy et al., 2013; Partington and Cushion, 2013; Taylor and McEwan, 2012). Accordingly, the practices applied by the coaches examined here are likely in keeping with traditions established during the first ~25 years of the sport's existence, having been reinforced across subsequent generations. These traditions developed by the 'early explorers' therefore become default procedures that are applied by newer coaches without critical analysis as to their effectiveness for athlete development. The absence of such critique means the training methods used are unlikely to be grounded in current training and coaching theory (Halson, 2014; Impellizzeri et al., 2018; Jeffries et al., 2021; Kellmann et al., 2018; Turner, 2011).

MMA coaching practice was revealed to be constrained by the economic realities of running a for profit sports club and the competition structure of the sport as a whole. Each of the coaches expressed their main interest or desire to be working with competitive athletes. As club owners, however, each requires a high number of recreational club members in order to maintain business viability. Whilst the athletes in their clubs require voluminous repetition of key skills (Jukic et al., 2017; Massey et al., 2013; Vaittinen, 2017) and 'physical callusing' against pain and soreness (Spencer, 2009), this type of training carries a relatively high injury rate (Ji, 2016; Stephenson and Rossheim, 2018) and therefore is unlikely to be achievable or desirable for anyone who does not wish to compete (Massey et al., 2013). This causes sessions to have dual, potentially conflicting aims of preparing athletes for bouts whilst ensuring paying members are satisfied with their experience and continue to attend. As such, the coaches exist simultaneously across both coaching 'occupations' (participation oriented and performance oriented) and all four coaching 'domains' (beginner, participation, talent and high performance) as recognised by Duffy et al. (2011). The coaches respond by working backwards from which skills they believe are required in MMA competition, but which any recreational participant would also find beneficial. The coaches view this compromise as enabling them to achieve the aims of both sets of club members, with session structure following a simple-to-complex pattern of technical drills leading to sparring and/or fitness drills (Harvey et al., 2013). It is unknown, however, whether this compromise is effective for either group of club members, with athletes unlikely to receive the required physiological stimuli, and recreational participants taking part in potentially monotonous drill activities that by nature carry a high injury risk (Ji, 2016).

Further constraints are placed on MMA coaching practice by the sport's competition structure. Coach consensus for the preferred length of a 'training camp' is eight - twelve weeks. This length of time has precedence for use in MMA (Jukic et al., 2017) and equates to the suggested time for improvement of MMA athlete bio-motor abilities (James et al., 2013; Mikeska, 2014). The actual time provided, however, appears to be mostly dictated by the event promoter and the date they have available for a bout to take place. The coaches reveal that it is common for this time to be shorter than desired. As such, training camp becomes more focussed on providing 'sharpness' and achieving the required competition BM. Athlete preparation is therefore more reactive than proactive, with the coach responses providing potential evidence that such planning is on a micro level only, at the expense of meso/macro planning. Once more, the compromises reached by the coaches to attempt provision for their athletes and paying members, alongside the irregular and externally controlled preparation periods, means the training structure of MMA may not be optimal for competitive athletes (James et al., 2013; Mikeska, 2014).

The coaches demonstrate they are not ignorant of the importance of managing the training load-fatigue response. They also discuss that as technical coaches their main concern is the improvement of skill rather than fitness. This juxtaposes with the coaches also stating a key aim of a training camp is to ensure the athlete is fit enough to compete. This disparity may be related to their admission that changes in skill, fitness and fatigue are difficult to monitor in a multifaceted training environment. Consequently, the coaches revert to focussing on factors closer to their expertise, namely, technical skills (Schempp and McCullick, 2010). Some of the participants in this study did discuss looking to external sources for education regarding training and performance, but these tended to be 'pop-science' materials that may lead to pseudoscientific beliefs being incorporated (Stoszkowski et al., 2020). This is indicated by the use of phrases such as "hit that bell shaped curve" and "pre-exhaust" in relation to athlete fitness. These terms, amongst others, are used by the coaches on a surface level only, without further context. Whilst it is common for coaches across sports to prefer informal rather than formal education (Fullagar et al., 2019; Sherwin et al., 2017; Stoszkowski et al., 2020), these data suggest MMA coaches do not appear to utilise sport science practitioners for advice or information regarding their specific training practices. This reflects previous surveys of MMA coaches' use of sports science (Batra, 2019). Alongside the aforementioned reduction in peer learning, this provides potential for MMA coaches to work within an 'echo-chamber' of ideas lacking critical voices, where pseudoscientific practices may be passed from coaches with high perceived capital to their 'apprentices' with little examination or challenge (Bailey et al., 2018; Cushion et al., 2003; Stoszkowski et al., 2020; Taylor and McEwan, 2012). Such an environment would ingrain the potentially sub-optimal training practices described here, which may not provide peak athletic performance.

The coaches describe using technical/tactical drills to provide progressive overload, with one participant discussing this in relation to the general physical preparation (GPP) model (DeWeese et al., 2015). Such methods are utilised successfully in other sports often via small sided games to induce cardiorespiratory enhancements alongside technical/tactical improvements (Bujalance-Moreno et al., 2019). Whether this approach is successful or not in this instance is unknown due to the absence of objective monitoring of either skill or fitness. The only objective measure used by any of the coaches was HR, which is used to gain a general overview of the training day rather than the effects of any specific training mode. The coaches all expressed knowledge of the existence and purpose of methods such as RPE and wellness monitoring. None made use of these methods, however, despite them potentially providing more contextually useful load-fatigue data than methods such as HR alone (Fox et al., 2018; Thorpe et al., 2016). As such, the MMA coaching environment appears to lack external guidance or critique beyond 'pop-science' sources with a lack of objective monitoring or assessment of athlete fatigue-adaptation. In such an environment there is significant potential for training loads and athlete adaptations to be suboptimal. This may cause an absence of physiological improvements or, in the worst case scenario, onset of non-functional overreaching (NFOR) or overtraining syndrome (OTS) (Kellmann et al., 2018; Kreher and Schwartz, 2012; Meeusen et al., 2013).

In conclusion, due to the infancy of the sport, there is no formal education or coach development provision for MMA. The coaches have attained their capital through their involvement in MMA over many years which is reinforced by their positions as club owners. Once established in these positions, their low levels of continuing peer learning leads to reliance on 'pop-science' and pseudoscience to find ways of achieving their aims. Changes in training intensity and volume are therefore attempted through manipulation of technical/tactical drills and sparring. Lack of objective monitoring means the effectiveness and alterations of these methods are determined by coach and athlete subjective perceptions in a reactive manner only. As a result of these conditions, it would be expected that the training load-fatigue response of MMA athletes would be sub-optimal. The coaches interviewed here viewed management of the load-fatigue-adaptation cycle as being important, but secondary to their role as a coach. Other more pressing aims are designing sessions that could instil the skills needed for competition but also allow recreational members of the public to take part. Such a compromise may reduce the provision of physiological stimuli sufficient for competitive athletes. This is exasperated by the irregular and externally dictated event schedule and the lack of control over the length of the training camp period. Within this environment, it would be difficult to plan and execute a training program that enables weekly changes in training load in keeping with current theory (Halson, 2014; Impellizzeri et al., 2018; Jeffries et al., 2021; Kellmann et al., 2018; Turner, 2011). The result, therefore, would likely be no changes in weekly training load or fatigue leading to no changes in physiological markers of fitness in the medium-long term. Accordingly, there is a pressing need to describe the current training practices of MMA athletes in terms of durations, loads and resultant fatigue to characterise the load-response of participation in this sport.

3.6 Chapter Summary

- MMA coaches have developed via experiential and peer guided learning. In lieu of formal qualifications they have accrued coaching capital by the amount of time spent engaged in MMA and become established upon opening their own MMA club, at which point peer learning and critique becomes reduced to 'in-house' feedback.
- MMA coaching practice is constrained by the economic expediency of requiring recreational paying members, as well as the promoter dictated competition structure. This causes training sessions to be designed around conflicting aims and competition training periods to be less than those desired by the coaches.
- Whilst coaches understand the need for physiological preparation, their knowledge is based on technical/tactical improvement. The absence of external support or continuing education therefore leads to training potentially based on pseudoscientific folk pedagogies to attempt to achieve both aims.
- There is an absence of objective physiological or skill monitoring in MMA training, meaning training practices are unlikely to match current training theory regarding the load-fatigue-adaptation cycle.

End of Study 1 Thesis Map

Study Aim	Study Type	Objectives	Outcomes
Study 1 – Chapter 3 **Thesis Objective 1** **Study Aim** Explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition	**ARMSS Stage 1: Defining the problem** Qualitative semi-structured interviews	1. Interview professional MMA coaches to explore their training and coaching backgrounds, and how they developed as MMA coaches 2. Explore the structure, aims and focus of MMA coaches practice in preparing participants for competition 3. Explore how MMA coaches attempt to monitor the load-fatigue-adaptation cycle of the participants preparing for competition within their practice.	1. MMA coaches developed via experience and peer learning. Peer learning reduces when they become club owners 2. Sessions must cater both to competitive athletes and recreational participants simultaneously. 3. Training practices are led by folk pedagogy potentially underpinned by pseudoscience with minimal evidence of objective monitoring of athlete load-fatigue-adaptation.
Study 2 – Chapter 5 **Thesis Objective: 2** **Study Aim** Quantify the internal loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the durations, intensities and internal loads of MMA training categories 2. Record subjective fatigue and soreness response of MMA athletes in relation to these internal loads 3. Determine the intensity and load distribution of MMA training sessions and categories 4. Determine any changes in load, fatigue or soreness when MMA athletes are preparing for competition	
Study 3 – Chapter 6 **Thesis Objective: 2** **Study Aim** Quantify the external loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the external loads of MMA training categories 2. Determine the relationship between external and internal loads in MMA training. 3. Determine the distribution of external loads of MMA training categories	
Study 4 – Chapter 7 **Thesis Objective: 3** **Study Aim** Determine the physiological adaptations and changes in body composition that arise from completing a typical 6-8 week MMA training period that is used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative laboratory data collection without intervention	1. Record physiological and body composition data of a group of international standard MMA athletes prior to commencing training for competition 2. Record the same physiological and body composition variables upon completion of the training period but prior to pre-competition RWL. 3. Determine the effects of a pre-competition training period on MMA athlete's physiological capabilities and body composition	
Study 5 – Chapter 8 **Thesis Objective: 4** **Study Aim** Examine the effects of a supplementary high-intensity aerobic training intervention (completed alongside traditional MMA training practices) on aerobic capacity and indices of competition specific performance	**ARMSS Stage 3: Predictors of performance** Quantitative field and laboratory data collection with training intervention	1. Apply a cardiovascular training intervention to MMA athlete's regular technical-tactical training 2. Determine the effects of training intervention on physiological and body composition measures collected in laboratory 3. Determine the effects of training intervention on bout pacing as measured via body worn accelerometry in simulated competition	

Chapter 4 - Quantitative Studies General Methods

This chapter describes the quantitative data collection and statistical analysis methods used throughout the rest of this thesis. Methods discussed are the general methods shared between chapters, whilst the chapters themselves provide the methods specific to that particular study.

4.1 General Methods for Studies 2 and 3

4.1.1 Experimental Design

Data collection for Studies 2 and 3 utilised a cross-sectional cohort observational design to record the regular training of competitive MMA participants without intervention following institutional ethical approval (19/SPS/007). All MMA training sessions were attended in person by the author for the purposes of data collection. Training content data was recorded using a bespoke hand notation system developed through a six-week period of pilot testing at a single MMA club. Recorded training modes and categories were initially chosen based on the author's extensive experience in MMA training and academic awareness of related scientific research. These were then refined further and added to, based on observations of training modes and categories that did not fit those originally defined, and alongside regular discussions with the club coach who confirmed agreement. The final hand notation sheet may be viewed in Appendix C. Due to the nature of MMA training sessions, the numbers of people training in addition to the study cohort ranged from 5 – 40 people per session. This included competitive MMA athletes not involved in the study and non-competitive participants training for fitness and recreation. Only the activities of study participants were recorded.

Duration of each session in its entirety, as well as duration spent in each of the training categories was recorded to the nearest whole minute, inclusive of rest periods, using a handheld stopwatch. Categorisation of specific drills was confirmed by the club coach at the end of each session to ensure accurate researcher interpretation. Sessions were videorecorded for post session review to check data accuracy using a tripod-based camcorder (Panasonic SDR-H81, Osaka, Japan). Where study participants were completing different training sessions simultaneously, or where individual participant session timings differed, these were recorded on the same sheet using annotations to clearly delineate between participant activities and timings. The majority of sessions (84%) took place in the evening between the hours 16:00 – 21:00, with 16% of sessions taking place between the hours 09:30 – 13:00. Strength and conditioning (S&C) sessions external to technical sessions were recorded via self-reporting by each participant using a bespoke, paper based personal training diary returned to the researcher on a weekly basis. For the purposes of this thesis, S&C is defined as any non-technical/tactical training conducted for the purposes of causing non-sport specific neuromuscular or cardiorespiratory adaptations (Serrano and Galpin, 2019). As such, any technical/tactical training conducted within MMA training sessions with the intention of improving sport specific fitness were quantified and described separately to S&C.

4.1.2 Participants

Participants for these studies were recruited based on the following inclusion criteria: aged ≥ 16 years at the commencement of data collection; taken part in ≥ 4 amateur or professional MMA bouts; taken part in at least one amateur or professional MMA bout in the eighteen months prior to commencement of data collection; be actively training in MMA with the intention of competing in an MMA bout within the six months post data collection. Participants were recruited from four separate, unaffiliated MMA clubs, with each club being observed in turn over different nine-week periods. Study 2 reports data from the entire nine-week period. Study 3 reports data from weeks 4 and 5 of this period. An initial cohort of twenty-five participants was recruited for these studies (age = 23.2 ± 5.3 years) consisting of nineteen males and six females. At the time of data collection nineteen participants were classified as amateur, with six of these competing internationally in IMMAF events. The remaining thirteen amateurs were competing at a national standard at the time of data collection. Since completion of data collection, five of the amateur participants have turned professional and are competing nationally. Six of this initial cohort were classified as professional at the time of data collection, with three competing internationally and three competing nationally. Following recruitment, three participants were injured during their regular training and were unable to complete data collection. Two participants became non-compliant after Week 1. The data of these five participants was removed from both Study 2 and Study 3. Further, one participant was removed from training by their coach after showing signs of overtraining. One participant removed themselves from the study for personal reasons. Four participants were deemed to not be actively training in MMA or showed low compliance with data collection (< 3 training sessions attended in ≥ 3 weeks). The data of six these participants were removed from Study 2, but each completed the required data collection protocols to be included in Study 3.

4.1.3 Data Collection

Unless stated otherwise, each of the following procedures were conducted for nine consecutive weeks: week 0 was designated for participant familiarisation and reliability testing; weeks 1 – 8 was the formal data collection period. During Week 0 participants were familiarised with the interpretation and reporting of rating of perceived exertion (RPE), how to complete their short questionnaire of fatigue (SQF) and CR10 soreness rating questionnaire, how to complete their S&C training diary and ask any questions they may have about the procedures. Each Week 0 training session was attended by the author and all data was recorded in keeping with the protocols detailed below, to ensure participants were familiar and consistent with the procedures. Particular attention was taken ensuring participants understood the timing requirements and specific anchoring statements of the Foster sessional RPE 0-10 (Foster et al., 2001), SQF (Chatard et al., 2003) and CR10 soreness (Boonstra et al., 2016) scales to ensure data accuracy and validity. No Week 0 data was included in data analysis except for reliability testing of several variables via two-way mixed effects intraclass correlation coefficient ($ICC_{(3,1)}$) and coefficient of variation (CV = standard deviation / mean). The acceptance threshold of $ICC_{(3,1)}$ was set at ≥ .700 (Field, 2018; Koo and Li, 2016). Acceptance level of CV was set at ≤ 15% (Haff et al., 2015; Shechtman, 2013).

4.1.4 Training Content, Duration and Load

4.1.4.1 Internal Load

The content of each MMA related training session was recorded in terms of duration spent in each of the training categories defined in Table 4.1. The perceived intensity of each training category and the session overall was measured by asking each participant individually to record RPE using the Foster sessional RPE 0-10 scale (Foster et al., 2001) 10 - 30 mins after the end of the entire training session (Uchida et al., 2014). Participants were instructed to record RPE on their own, away from coaches, other participants and the author to avoid external influence. Participants were instructed to rate the intensity of the session overall and each category based on their own combined sensations of cardiorespiratory strain, muscular strain, physical impact, physical discomfort and difficulty of skill completion to provide an undifferentiated RPE (Foster et al., 2001; Haddad et al., 2014; Haile et al., 2016b). RPE was only collected for categories trained in that session and was measured in arbitrary units (AU). RPE was also used post hoc to delineate each category into one of the following intensity zones as applied previously: low (RPE $\leq$ 4); moderate (RPE 5 - 6); high (RPE $\geq$ 7) (Lovell et al., 2013; Seiler and Kjerland, 2006). Internal load for the full training session was calculated via sessional RPE (sRPE) using the following equation (Foster et al., 2001):

sRPE (AU) = RPE * session duration (mins)

Weekly monotony was also calculated using the following equation (Foster et al., 2001):

Weekly monotony (AU) = daily mean sRPE / daily sRPE standard deviation

This equation was modified to calculate between weeks monotony as follows:

Between weeks monotony (AU) = weekly mean sRPE / weekly sRPE standard deviation

Weekly strain was calculated using the following equation (Foster et al., 2001):

Strain (AU) = total weekly sRPE * monotony

Training load for each category was calculated via segmented sessional RPE (segRPE) (Haile et al., 2016b), using the following equation:

segRPE (AU) = RPE * category duration (mins)

RPE scale anchoring procedures were completed during Week 0. Briefly, these procedures involved each participant completing the RPE recording procedures as described above. Each participant was then immediately asked to compare that session to other similar Week 0 sessions by the author asking questions such as “If we compared your rating of today’s wrestling drills to your rating of yesterday's wrestling drills, would you change your rating of either?" and "How does this session compare to the least and most intense sessions of this type you've completed recently? Where would you place those sessions on the RPE scale?", thus enabling memory and exercise anchoring procedures to take effect (Haile et al., 2016b).

Table 4.1 - MMA training category definitions used during data collection

Training Category	Definition
Warm up	Any drill or session content specifically aimed at preparing participants to take part in physical activity
Striking drills	Any drill consisting of repetition of coach determined striking movements (boxing and/or kickboxing) in groups for the purpose of skill enhancement and/or attainment
Wrestling drills	Any drill consisting of repetition of coach determined wrestling movements (taking opponent to the ground or moving yourself from a grounded to a standing position) in groups for the purpose of skill enhancement and/or attainment
BJJ drills	Any drill consisting of repetition of coach determined submission grappling movements (either gaining a dominant grounded position or causing the opponent to submit to joint locks and/or chokes) in groups for the purpose of skill enhancement and/or attainment
Striking sparring	Live rounds of open skill sparring (boxing and/or kickboxing) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.
Wrestling sparring	Live rounds of open skill sparring (taking opponent to the ground or moving yourself from a grounded to a standing position) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.
BJJ sparring	Live rounds of open skill sparring (attempting to submit or attain/hold a dominant position over opponent) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.
MMA sparring	Live rounds of open skill sparring (full MMA rules) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.
Circuit training	Any section of a session using repeated MMA skills or muscular endurance exercises for a coach specified time with the intention of improving fitness rather than skill enhancement/attainment.
S&C	Any session or section of a technical session used to improve athlete strength, power or endurance.

Definitions made in agreement with independent MMA coach during pilot testing; Occasions where session sections could fit into more than one category (i.e., striking drills to set up a wrestling takedown) the session coach was asked to state which of the categories they intended the section to be more aimed towards. BJJ = Brazilian jiujitsu; MMA = mixed martial arts; S&C = strength and conditioning

4.1.4.2 External Load

For two consecutive weeks during the data collection period, external load was measured via Catapult Optimeye S5 100Hz tri-axial accelerometers (Catapult Innovations, Australia) for the full duration of each training session. The units were worn in the manufacturer's harness, sized to ensure a tight fit on each participant, with the unit positioned around the T3-4 vertebrae (McLean et al., 2018).

To ensure reliability of results, each participant was assigned their own individual unit calibrated to the manufacturer's specifications each morning of testing, adhering to established guidelines for the use of accelerometry in sport (Malone et al., 2017). The switch on and switch off times of each unit were recorded during each session. The units were used to record absolute external load (Playerload = PLd_{ACC}) and relative external load (accumulated Playerload per minute = $PLd_{ACC}\cdot min^{-1}$) of each training session and each training category included within each session (both in AU). PLd_{ACC} has previously been found to be reliable (ICC = .794-.984; CV = 2.4-7.8%) for the measurement of MMA movements (Hurst et al., 2014). To better understand the external loads of different types of training within categories, the following sub-categories were highlighted via researcher observation and coach confirmation, with only external load being collected at this level:

i) striking drills = boxing; kickboxing; strikes with takedowns/sprawls. ii) wrestling drills = open space; against wall; with strikes. iii) BJJ drills = positional; submission. iv) sparring = boxing; kickboxing; wrestling; BJJ; BJJ with strikes; MMA.

4.2 General Methods for Studies 4 and 5

4.2.1 Cardiorespiratory Performance

A treadmill-based graded exercise test (GXT) was conducted to determine participant $\dot{V}O_2max$ ($L\cdot min^{-1}$ and $ml\cdot kg\cdot min^{-1}$), ventilatory thresholds (VT_1 and VT_2, both $L\cdot min^{-1}$ and % of $\dot{V}O_2max$), O_2pulse ($ml\cdot beat^{-1}$) and velocity at $\dot{V}O_2max$ ($v\dot{V}O_2max$, $km\cdot h^{-1}$). Participant's HR ($beats\cdot min^{-1}$) was collected using a Polar H10 HR sensor (Polar Electro, FINLAND). Breath-by-breath gas analysis was conducted throughout using a Cortex Metalyser 3B (Cortex Medical, GERMANY) having previously been demonstrated to be a reliable collection tool for this task via ICC = .969 ($\dot{V}O_2$), .964 ($\dot{V}CO_2$) and .953 ($\dot{V}_E$) respectively (Meyer et al., 2001). After being equipped with the breathing mask participants remained stationary on the treadmill for 2 mins of normalisation. The treadmill was then started at 6 $km\cdot h^{-1}$ with treadmill speed being increased by 1 $km\cdot h^{-1}$ every 3 mins until 12 $km\cdot h^{-1}$ was reached. At this point treadmill speed was maintained for 2 mins after which it was increased by 2 $km\cdot h^{-1}$ every 2 mins until 16 $km\cdot h^{-1}$ was reached. From this point treadmill speed remained at 16 $km\cdot h^{-1}$ but incline was increased by 1% every 1 min (Langan-Evans et al., 2020). As a laboratory specific protocol, there is an absence of reliability data for this specific protocol. It has been designed, however, to ensure sufficient time at each stage to enable steady state to be achieved by participants who are not accustomed to treadmill-based exercise or testing, such as the participants included in this thesis. As such, lower intensity stages are of longer duration to allow respiratory fluctuations to stabilise, with shorter stages at higher intensities to avoid muscular fatigue causing premature exercise cessation (Cooke, 2009). Participants were instructed to continue running until they reached volitional failure or until a plateau in $\dot{V}O_2$ occurred (increase < 2 ml·kg·min^{-1}) despite increased intensity. $\dot{V}O_2$max was identified post hoc as the highest 30 s average achieved during the final stage of the test when RER > 1.15, and HR was within 10 beats·min^{-1} of the participant's predicted HRmax (Cooke, 2009). All relevant participants reached $\dot{V}O_2$max according to these criteria. VT_1 and VT_2 were estimated post hoc via visual inspection of the plots using minute ventilation (V_E) ventilatory equivalents following data treatment and analysis recommendations provided by Keir et al. (2021). VT_1 was defined as the first increase in $V_E \cdot \dot{V}O_2$ without a concomitant increase in $V_E \cdot \dot{V}CO_2$. VT_2 was defined as the first sustained increase in $V_E \cdot \dot{V}CO_2$ (Seiler and Kjerland, 2006). Both VT_1 and VT_2 were confirmed via concurrent inflections on $V_E/\dot{V}O_2$ and $\dot{V}CO_2/\dot{V}O_2$ plots (Keir et al., 2021). O_2pulse (ml·beat^{-1}) was calculated post hoc as a proxy for stroke volume (SV) and O_2 extraction at the end of each incremental stage using: $\dot{V}O_2$ (L·min^{-1}) / HR * 1000 (Sheykhlouvand et al., 2016).

4.3 Statistical Analyses for Studies 2 - 5

All data were assessed for normality via Shapiro-Wilk test for normality ($p \geq .05$) and visual examination of frequency distribution and/or Q-Q plots. Inference in each of the following tests was based on the calculation of Bayes factors (BF), to provide support for either the hypothesis (BF_{10}) or the null hypothesis (BF_{01}) respectively. The following thresholds were used for each BF: 1 - 2.9 = anecdotal; 3 - 9.9 = moderate; 10 - 29.9 = strong; 30 - 99.9 = very strong; ≥ 100 = decisive. Due to default priors being used, BF robustness checks were performed (Dienes, 2014; van de Schoot and Depaoli, 2014; van Doorn et al., 2019; Wagenmakers et al., 2018). Where a result was found to cross a threshold, both thresholds are reported (Wetzels and Wagenmakers, 2012). For brevity, p values are not reported in the text, but any result found to support a hypothesis ($BF_{10} \geq 3$) was also found to have acceptably low probability of type 1 error ($p < .05$).

Effect sizes were applied as follows: Omega squared (ω^2): very small ≤ .01; small ≤ .06; medium ≤ .14; large > .14 (Kirk, 1996). Cohen's d: small ≥ .2; moderate ≥ .6; large ≥ 1.2; very large ≥ 2 (Hopkins, 2002). R_x thresholds were set at: trivial ≤ 0.09; small ≥ 0.1; moderate ≥ 0.3; large ≥ 0.5; very large ≥ 0.7 (Cureton, 1956). Correlation (T) and regression (R^2) thresholds were set at: trivial ≤ 0.09; small ≥ 0.1; moderate ≥ 0.3; large ≥ 0.5; very large ≥ 0.7; nearly perfect ≥ 0.9; perfect = 1 (Hopkins, 2002). Statistical analyses specific to each study are described within each chapter. Each named statistical test was completed using JASP 0.16 (JASP Team, NETHERLANDS), with data presented as mean ± SD unless stated otherwise.

Bayesian analyses were specifically chosen to compare the strength of the hypothesis against the null hypothesis and vice versa using the observed data (Kruschke and Liddell, 2018a; Lambert, 2018; Morey et al., 2016). Under a Bayesian paradigm, existing beliefs or predictions regarding the phenomena being studied are represented by the prior distribution on the effect size. Observed data are then used to produce the posterior distribution on the effect size. The resultant BF indicates to what extent the posterior distribution fits the observed data more than the prior distribution (Dienes, 2014; Kruschke and Liddell, 2018a; Kruschke, 2010a). This contrasts the comparison of observed data to hypothetical repeat trials as is the case in frequentist analyses (Field, 2018; Kruschke, 2010b; Morey et al., 2016). The strength of Bayesian inference is therefore based on the prior used in each analysis (Dienes, 2014; Lambert, 2018). As such, power analyses in a frequentist sense are not applicable to Bayesian methods, with the BF itself representing the strength or otherwise of the evidence. In the case of this thesis, default informed priors were used as recommended for such analyses where there is little existing evidence to support a predicted effect (Kruschke and Liddell, 2018b; Wagenmakers et al., 2015). Use of Bayesian analyses in this way removes the expectation for data to fit a parametric distribution as required of frequentist paradigms, as each datum and group are compared to the chosen prior individually and update the posterior distribution accordingly (Dienes, 2014; Kruschke, 2015, 2010b). In turn, this removes the requirement for data transformation, outlier removal, sphericity or equality of variance between groups, as these factors do not affect the comparison of the posterior distribution to the prior distribution (Kruschke and Liddell, 2018a; Kruschke, 2015). Accordingly, observed data are not retroactively altered to fit a specific model as seen in frequentist analyses. To further ensure credibility of analysis results and to provide data for type 1 error checks, however, non-parametric tests have been used when appropriate and available.

Chapter 5 – Study 2: Quantification of the Content, Internal Load and Fatigue of MMA Training

5.1 Chapter Rationale

Chapter 2 demonstrated that MMA research is underdeveloped and has not been conducted following a systematic framework. As such, there is little foundational data regarding the nature, structure or content of the MMA athlete training process. Therefore, any suggested training interventions are potentially based on assumptions without evidence. Chapter 3 showed that MMA coaches have developed their practices through experiential learning under sports specific constraints. With this lack of available training data and coaching practices potentially based on folk pedagogies, it may be the case that MMA training patterns do not follow those recommended by current training theory in terms of manipulation of training intensity, duration and load to bring about specific physiological adaptation (Turner, 2011; Turner et al., 2015). Due to the lack of published data regarding the training practices and subsequent effects of MMA it is currently unknown whether this population follows such training theory. Therefore, the aim of this study was to quantify the internal training loads of MMA training practices that are used to prepare participants for competition and the effects these practices have on athlete fatigue.

ARMSS Stage: 2 – Descriptive research

5.2 Introduction

Chapter 2 demonstrated that success in MMA is likely dependent on a range of technical and tactical skills (James et al., 2019, 2017b; Kirk, 2018a) underpinned by a combination of aerobic and anaerobic physiological capabilities (Kirk et al., 2015a; Petersen and Lindsay, 2020). As a result, the need to appropriately balance a multitude of potentially conflicting technical and physical focused training sessions, coupled with the requirement to 'make weight' for competition, clearly outlines the challenge and importance of formulating a well-structured and periodised training plan. The success or otherwise of such a plan is dependent on the management of training load and fatigue in a manner that leads to optimal adaptation (Kellmann, 2010).

Training loads are categorised as the physical actions the athlete completes (external load) and the resulting physiological responses to these actions (internal load) (Halson, 2014; Impellizzeri et al., 2005; McGuigan, 2017). It is the internal load responses that cause mal/adaptation(s) and the proceeding performance outcomes (Borresen and Lambert, 2009; Jeffries et al., 2021; Viru and Viru, 2000). Fatigue is characterised by an acute and/or chronic reduction in performance capacity which may be followed by positive adaptations and performance outcomes with appropriate recovery (Impellizzeri et al., 2018; Kellmann, 2010). In order to achieve optimal timing of load and recovery, the training and fatigue patterns of the sport must be quantified (Halson, 2014). Chapter 3 revealed that whilst the MMA coaches interviewed understood the need to balance training load, this understanding was on a surface level only owing to a lack of continuing education or external support. Their ability to modulate the load-fatigue-adaptation cycle is reduced further by the external constraints placed on their practice by the competition structure of MMA and the economic realities of running a private club. Accordingly, the coaches relied on subjective methods of monitoring training load and fatigue amongst their athletes.

Training load can be assessed in applied practice via post training RPE which quantifies the gestalt of acute peripheral and central responses to exercise (Foster et al., 2017, 2001; Haile et al., 2016a; Slimani et al., 2017b). Fatigue in response to training load may last a few minutes to several days (Ament and Verkerke, 2009; Kellmann et al., 2018). The sensation of fatigue is due to an array of interdependent, co-affecting systemic changes that occur during exercise and the subsequent recovery period (Burke et al., 2004; Chuckravanen et al., 2018; Rohlfs et al., 2005; Waldron and Highton, 2014). Directly observing this centrally mediated fatigue is therefore invasive and time-consuming. As such, proxy measures of fatigue are recommended in the field (Halson, 2014). Such measures include mood (Nassi et al., 2017), sleep (Gupta et al., 2017), perceived effort and/or exertion (Martin et al., 2018), post training muscle soreness (Fletcher et al., 2016) and reaction times (Draper et al., 2010; Nederhof et al., 2007). Whilst some of these measures may be classified as subjective, due to their multifactorial nature, they may well be superior to more objective measures in applied settings (Coyne et al., 2018; Saw et al., 2016; Thorpe et al., 2016).

In contrast to traditional endurance sports (Guellich et al., 2009; Seiler, 2010) and team sports (Anderson et al., 2016; Moreira et al., 2015), a detailed understanding of habitual training practices of MMA athletes has not yet been established. Indeed, reports to date are limited to retrospective questionnaires (Amtmann, 2010a, 2004) and a case-study account in which a participant was preparing for a now defunct rule set and competition format (Jukic et al., 2017). More recent studies do provide the subjective weekly load of MMA pre-competition training (Uddin et al., 2020) and suggest training load ratings for 'hard' and 'easy' days (Coyne et al., 2020). However, neither of these studies describe how these loads are achieved, the intensities of training methods, or how training is modified prior to a bout. Additionally, it is unclear if or how training practices are manipulated in those athletes who are actively engaging in BM manipulation before competition (Brechney et al., 2019; Kirk et al., 2020b). As such, current MMA training practices and the training-recovery-adaptation requirements of the sport have not been adequately quantified (Impellizzeri et al., 2018). This omission makes it difficult to determine which training methods, loading strategies and recovery protocols are most appropriate for this population (Kellmann, 2010).

Therefore, the aim of the study was to quantify the internal loads of MMA training practices that are used to prepare participants for competition. To this end, a cohort of experienced MMA athletes was observed completing an eight-week training period. Quantification of training duration, load and associated fatigue and soreness within and between each weekly microcycle was achieved, as was the frequency and intensity of each specific training activity completed. Owing to the ubiquitous and extreme BM manipulation practices highlighted in this population (Brechney et al., 2019; Murugappan et al., 2021), training durations and loads may differ during specific competition preparation periods. Therefore, a secondary analysis was performed to ascertain if training practices differed between those athletes who were preparing for competition versus those with no upcoming contest. In accordance with traditional periodisation strategies, it was hypothesised that training load would be periodised within and between weekly microcycles and that different training patterns would be completed by athletes actively preparing for competition.

5.3 Methods

5.3.1 Participants

A cohort of fourteen competitive MMA participants from four individual MMA clubs volunteered to take part in this study following institutional ethical approval. During data collection seven participants had competitive bouts, whilst the other seven did not. Of the seven who competed, two were involved in professional, national standard bouts, two took part in amateur, national standard bouts, with the remaining three competing in amateur, regional standard bouts. Participant descriptive data is reported in Table 5.1. Training duration and internal load data were collected following the procedures established in Chapter 4. For details of the time of day of sessions, please refer to Chapter 4.1.1.

Table 5.1 – Participant descriptive data

Participant No.	Age (years)	Sex	Stature (cm)	Habitual Body Mass (kg)	Competed ?	Pre-bout mass loss (kg and %)	Division Weigh-in Limit (kg)
1	21	M	178	73	Y	7.2 (9.9%)	65.8
2	17	M	176	76	Y	10.2 (13.4%)	65.8
3	26	M	177	81	Y	10.7 (13.2%)	70.3
4	18	M	186.5	72	Y	10.8 (15%)	61.2
5	21	M	162.5	64	Y	7.3 (11.4%)	56.7
6	19	M	188.4	84	Y	6.9 (8.2%)	77.1
7	23	M	173.5	73	Y	7.2 (9.9%)	65.8
8	20	F	163	66	N	-	61.2
9	24	M	178	75	N	-	65.8
10	16	F	157	72	N	-	65.8
11	25	M	166.5	66	N	-	56.7
12	31	F	164	57	N	-	52.2
13	20	F	161.5	78	N	-	70.3
14	29	F	163	60.5	N	-	56.7
Total Cohort Means	22 ± 4.4	-	171 ± 9.9	71.3 ± 7.7	-	-	-
Bout means	20.7 ± 3.1	-	177.4 ± 8.6	74.7 ± 6.5	-	8.6 ± 1.8 (11.6 ± 2.4%)	-
No-bout means	23.6 ± 5.3	-	164.7 ± 6.6	67.8 ± 7.6	-	-	-

Nb. M = male; F = female; kg = kilograms; cm = centimetre; Y = yes; N = no

5.3.2 Fatigue and Soreness

Immediately after recording RPE data for the final training session of each day, participants completed a paper-based short questionnaire of fatigue (SQF) to record their perceived fatigue and wellness (Chatard et al., 2003), with the sum of the responses to each question providing a daily total fatigue score for each participant. The weekly mean of each daily score was calculated to provide a weekly fatigue score (AU) for each participant. The timings of training sessions confounded the calculation of test-retest reliability, but SQF reliability has previously been reported as CV = 2.1% (Elloumi et al., 2012). A bespoke, paper-based questionnaire recorded participant's perceptions of soreness for the following body regions: head and neck; shoulders and arms; upper torso (upper back and chest); lower torso (lower back and hips); legs. Ratings were based on the following CR10 scale: 0 = no pain; 1-3 = mild discomfort/stiffness (defined as not interfering with normal function); 4-6 = moderate discomfort (defined as some interference with normal function); 7-9 = noticeable pain (defined as unable to perform normal function); 10 = maximal pain (Boonstra et al., 2016; Lau et al., 2015; Serlin et al., 1995). These body areas were chosen in keeping with the body regions most associated with injuries in MMA competition and training (Ji, 2016). The soreness questionnaire was completed immediately after the SQF and determined weekly mean soreness for each body region (AU). Completion of both questionnaires took < 5 mins in total. For non-training days, participants were provided a blank set of SQF and soreness questionnaires and were asked to complete these at least 60 mins before bed. Completed forms were collected from the participants on a weekly basis.

5.3.3 Reaction Time

Prior to the first training session of each week participants completed a Deary-Liewald choice reaction time test (DLRT 3.1, University of Edinburgh). Participants were required to press either 'Z', 'X', ',' or '.' in response to a **X** appearing in one of four corresponding boxes on the screen at random. Further details of the DLRT have been described previously (Deary et al., 2011), whilst the specific settings used in this study can be viewed in Appendix D. The DLRT was completed on a standard laptop computer (screen vertical refresh rate of 60 Hz) in a quiet room with the participant in a seated, comfortable position. For each DLRT trial participants were provided eight practice trials which did not provide data. Once participants were content they were ready to continue they were provided forty experimental trials. The following variables were recorded for the DLRT: number of correct responses (CRTCorr); mean ± SD time taken to record a correct response (CRT) (ms). Each participant completed the DLRT a minimum of three times and a maximum of four times during Week 0 to calculate reliability of each variable: CRT $ICC_{(3,1)}$ = .854 and CV = 5%; CRTCorr $ICC_{(3,1)}$ = .832 and CV = 3%.

5.3.4 Sleep Quality

Prior to the first training session of each week, each participant's sleep quality, sleep latency and sleep duration was assessed via completion of a paper based Pittsburgh Sleep Quality Inventory (PSQI) questionnaire (Buysse et al., 1989). Participants completed the PSQI in the same quiet room, in a seated position, on their own after completion of the DLRT. The PSQI was used to provide a global score of sleep quality (AU) and rating of sleep efficiency (SEff) as calculated:

SEff (%) = # of hours asleep / # hours spent in bed

Each participant completed the PSQI a minimum of three times and a maximum of four times during Week 0 to calculate reliability via $ICC_{(3,1)}$ (PSQI = .940; SEff = .862) and CV (PSQI = 14%; SEff = 6%).

5.3.5 Statistical Analyses

All data were found to be parametric. Unless stated, the following comparisons were completed using Bayesian repeated measures ANOVA with a default prior r = 0.5, and a default t test with a Cauchy prior as post hoc analysis. Omega squared (ω^2) was calculated as the effect size.

Within week and between week differences in each of the following variables were determined: number of sessions, total session duration, category training duration and sRPE. Between week comparisons of category segRPE, weekly monotony, strain, total fatigue score, PSQI, SEff, CRT and CRTCorr were completed. The duration of time spent in each intensity zone was compared within categories. Between week and between body region differences in soreness was also calculated.

Differences in variables between participants who competed (Bout) and those who did not (No Bout) were determined. As participants competed at different stages of the eight week collection period, groups in this test were compared over a five week period incorporating three weeks prior to the bout (B -3, B -2, B -1), the week of the bout (B 0) and one week post bout (B +1).

Finally, drill-based categories and sparring based categories were grouped and compared in terms of total time and percentage of time spent in each intensity zone. Between weeks monotony was compared between Bout and No Bout. These comparisons were performed using Bayesian independent samples t tests. This was performed using a default Jeffery-Zellner-Siow (JZS) prior = .707 at location parameter = 0 (Wetzels and Wagenmakers, 2012), with Cohen's d effect size using the standard deviation of the mean scores as the denominator. Inference thresholds for each test may be viewed in Chapter 4.

5.4 Results

5.4.1 Quantification of training duration, load, fatigue and soreness between weekly microcycles

There were no differences between the total training duration, sRPE, weekly monotony, strain or fatigue score of any week for the full cohort across all eight weeks (Figure 5.1). The number of sessions completed per participant per week ranged between 3.8 ± 2.9 – 4.8 ± 2.4, with no differences between weeks. Between weeks monotony for the full cohort = 2.3 ± 0.7 AU. Similarly, there were no between week differences in PSQI, CRT, CRTCorr or SEff (Table 5.2). In terms of body region soreness, there were no between week differences (Figure 5.2), but the following post-hoc differences were found between regions: Legs > Head & Neck (BF_{10} = 217); Legs > Upper Torso (BF_{10} = 126,456); Arms & Shoulders > Upper Torso (BF_{10} = 43); Lower Torso > Upper Torso (BF_{10} = 22). There were no differences between regions within weeks.

5.4.2 Quantification of training duration, load and fatigue between groups

Weekly training duration, sRPE and monotony (Figure 5.3) were the only variables found to be different between participants who competed and those who did not, but only in the week of the bout (B 0) and the week immediately post bout (B +1). Between week comparisons were only statistically relevant for training duration (BF_{10} = 13, ω^2 = .04; between groups post hoc BF_{10} = 4) and sRPE (BF_{10} = 11, ω^2 = .13; between groups post hoc BF_{10} = 20) when compared between groups. Weekly monotony was also only different between weeks when accounting for group, but with a medium effect and no post hoc differences (BF_{10} = 315, ω^2 = .09; between groups post hoc BF_{10} = 1). There were no statistically relevant differences in between weeks monotony, strain, total fatigue score, PSQI, SEff, CRT or CRTCorr either between groups or weeks (Figure 5.4).

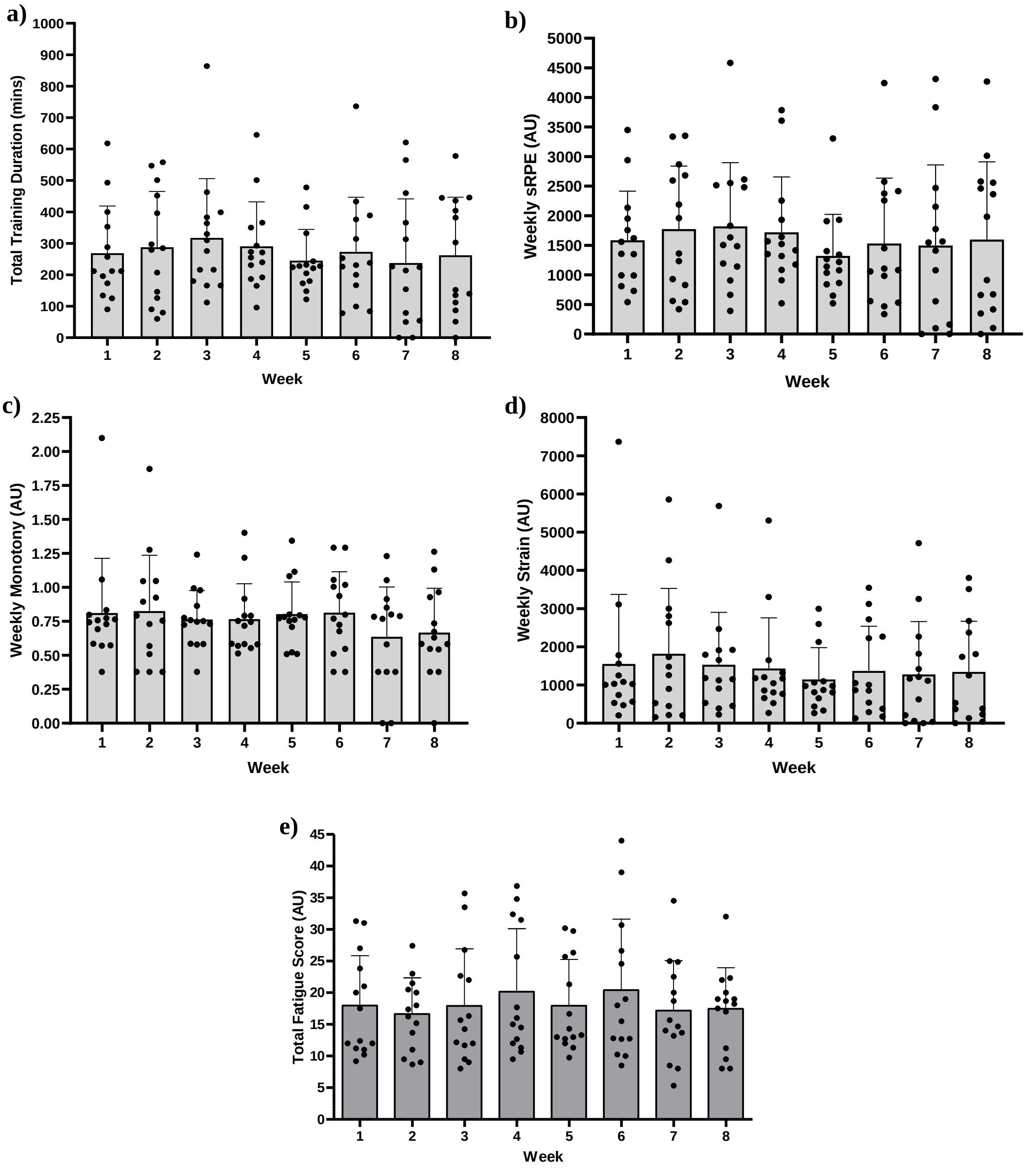

Figure 5.1 - No between week differences in: a) training duration (mins); b) sRPE: c) monotony; d) strain; e) total fatigue score (all AU unless stated). *Nb. Black dots represent individual participants. Error bars = SD*

Table 5.2 – Fatigue response variables by week

Week	1	2	3	4	5	6	7	8
PSQI (AU)	5.8 ± 3.9	6.1 ± 4.3	5.9 ± 3.9	4.9 ± 3	5 ± 3	5.2 ± 3.8	5.9 ± 3.9	5.3 ± 3.6
SEff (%)	86 ± 12	84 ± 12	85 ± 14	90 ± 8	90 ± 7	88 ± 9	84 ± 12	88 ± 10
CRT (ms)	405.7 ± 31.9	404.7 ± 32.2	407.1 ± 28.6	402.7 ± 31.3	420.3 ± 42.5	402.4 ± 29.6	408.7 ± 33.2	398.9 ± 30.5
CRTCorr (count)	37.7 ± 1.8	37.6 ± 1.4	38.1 ± 2.2	37.8 ± 1.8	38.4 ± 1.3	38.4 ± 1.9	37.9 ± 1.6	37.9 ± 1.8

Nb. PSQI = global sleep quality; SEff = sleep efficiency; CRT = choice reaction time; CRTCorr = CRT correct responses

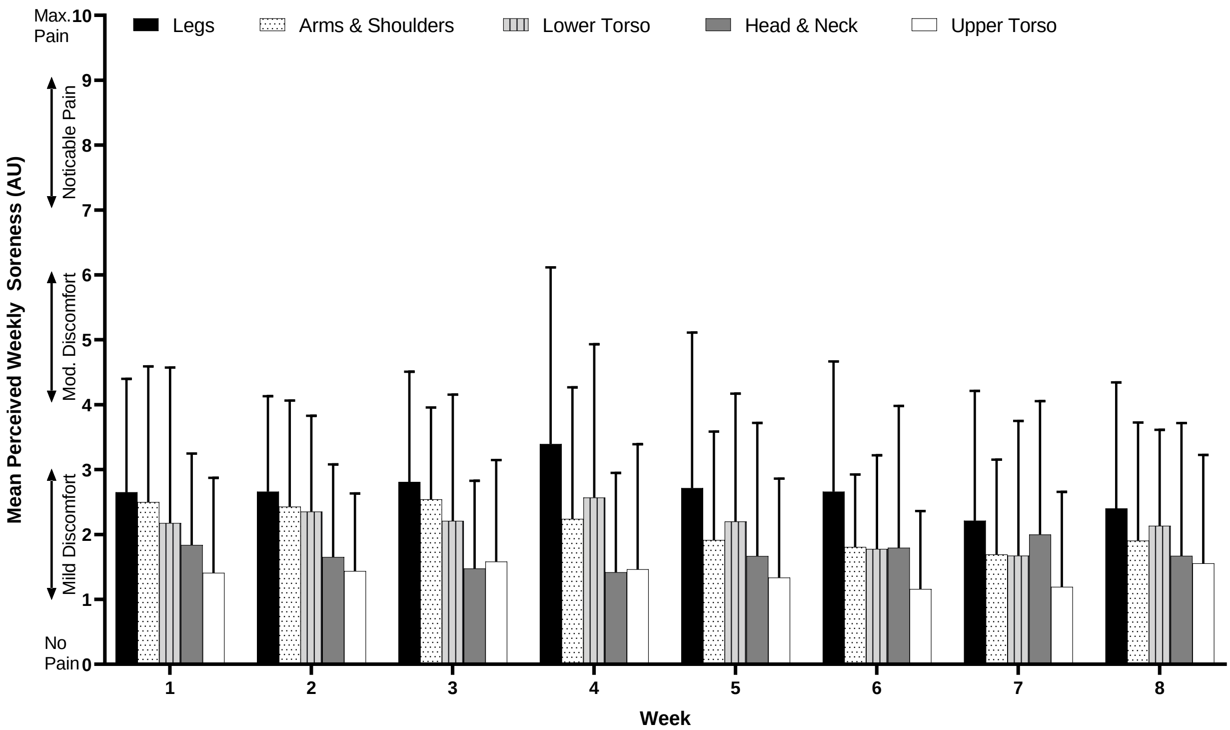

Figure 5.2 - Between and within week comparisons of perceived body region soreness (AU). *Nb. See accompanying text for statistical comparisons between regions. Error bars = SD*

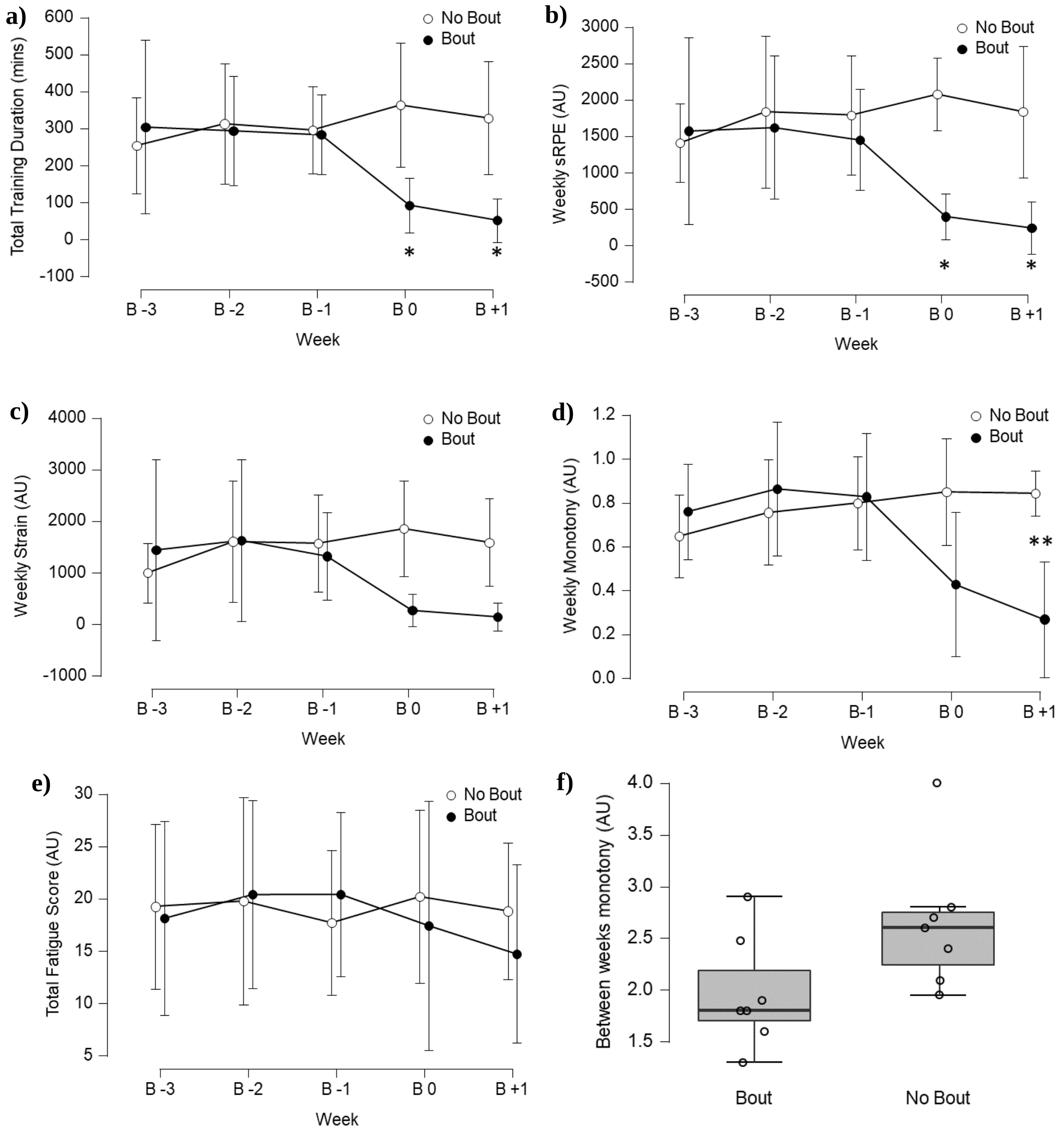

Figure 5.3 - Plots a-e: Between week comparisons of training load variables and fatigue score split by bout and no bout. *Nb. B = weeks before/after bout; * between weeks and between groups differences; ** between weeks differences only; Error bars = 95% credible intervals.* **Plot f: comparison of between weeks monotony between groups.** *Nb. Median [10 – 90%].*

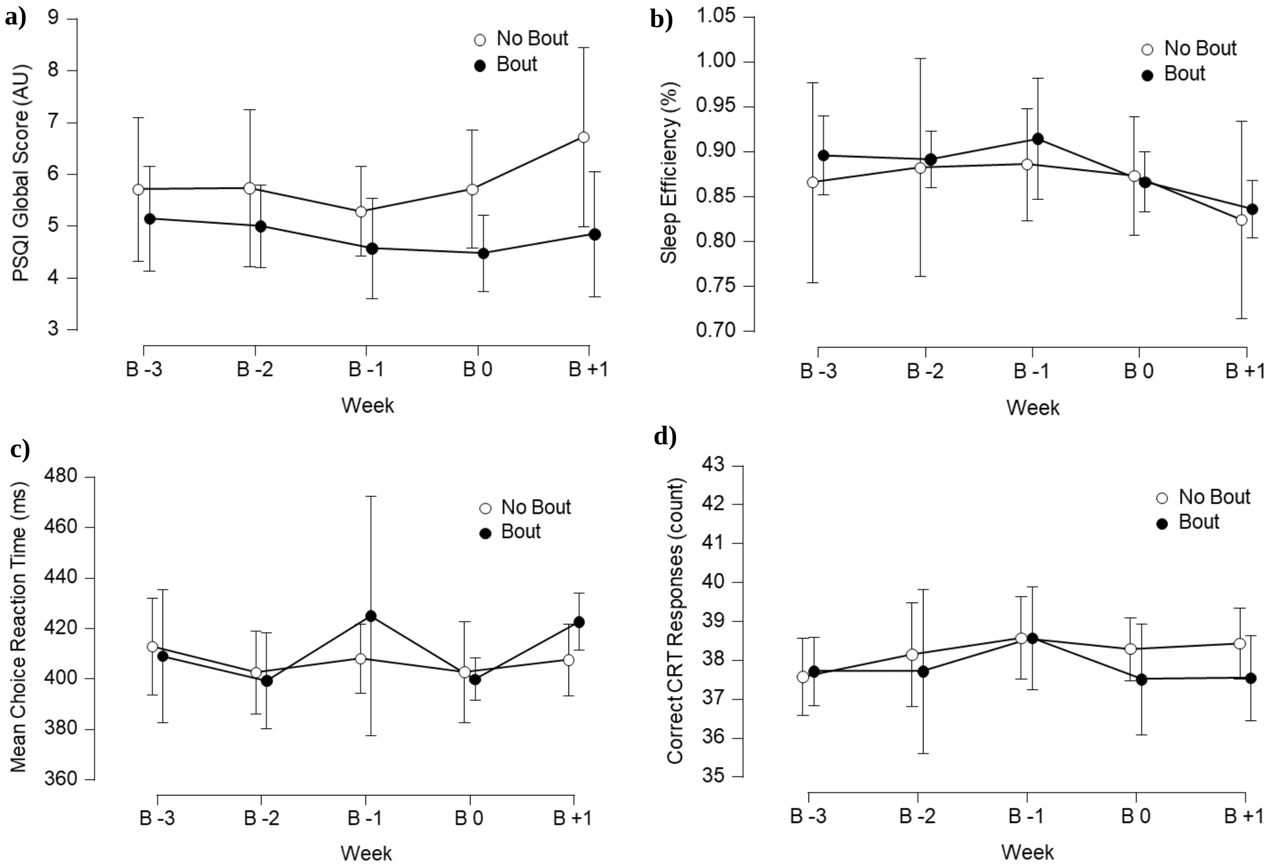

Figure 5.4 – Between week comparisons of perceived and central fatigue variables split by bout and no bout. *Nb. Error bars = 95% credible intervals*

5.4.3 Quantification of training duration, load, fatigue within each weekly microcycle

When analysed across all seven days, there is a clear trend that weekends have decisively lower training durations than Monday-Friday with medium to large effects (Figure 5.5). Week 2 is the only timepoint which displays a less than strong statistical difference between all seven days. When excluding weekends, between day differences largely disappear, with only weeks 1, 3 and 6 displaying greater than anecdotal differences with very small to medium effects. Statistically relevant post-hoc differences were almost entirely between midweek days and weekend days (BF_{10} = 3 – 1,225). Midweek post-hoc differences in training duration were limited to week 1 (Monday > Tuesday BF_{10} = 17; Tuesday < Wednesday BF_{10} = 4) and week 3 (Friday < Monday BF_{10} = 407; Friday < Wednesday BF_{10} = 26). Similarly, there was a consistent statistical difference between the sRPE of midweek days and weekend days with large effects (Figure 5.6). This difference was, however, absent in week 2. Post-hoc differences between sRPE of midweek days and weekend days had range $BF_{10} = 3 – 563$. Monday-Friday between day differences were only found in week 1 (Monday > Tuesday $BF_{10} = 11$) and week 3 (Monday > Friday $BF_{10} = 34$; Wednesday > Friday $BF_{10} = 15$) respectively.

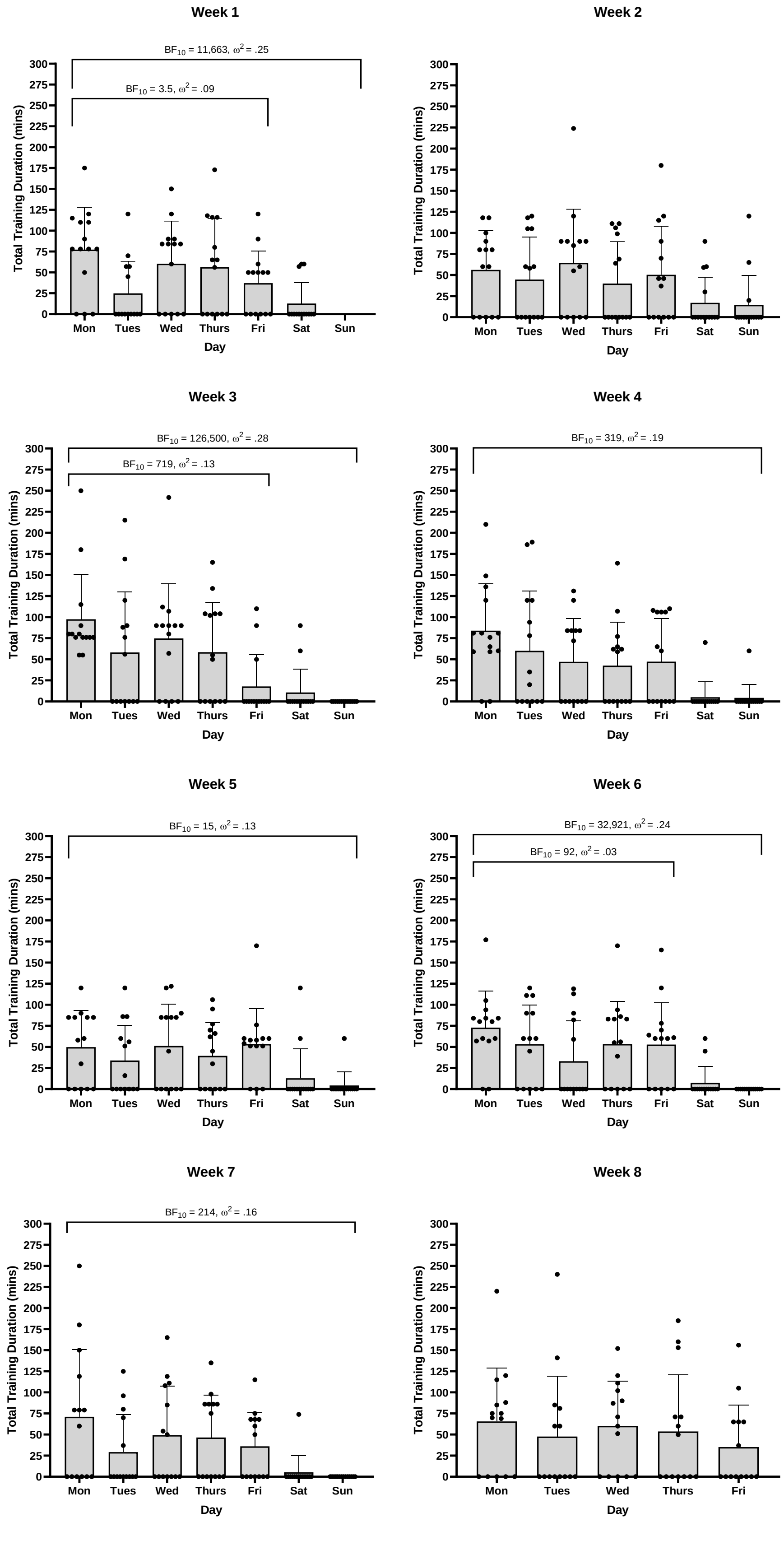

Figure 5.5 - Within week training duration (mins) comparisons. *Nb. Black dots represent individual participants; Error bars = SD*

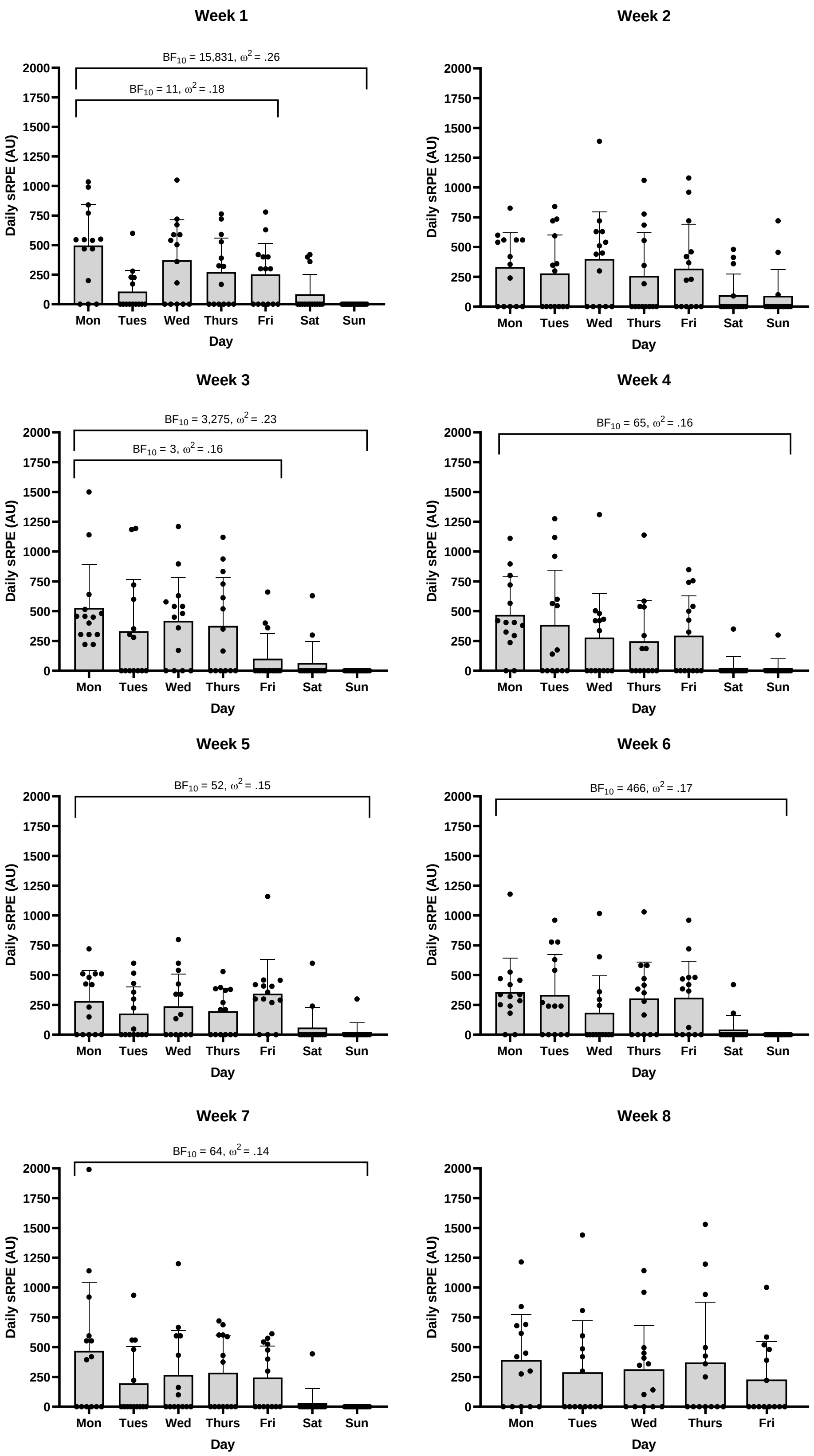

Figure 5.6 - Within week sRPE (AU) comparisons. *Nb. Black dots represent individual participants; Error bars = SD*

5.4.4 Training Category Duration

Table 5.3 and Figure 5.7 displays descriptive data for duration of each training category by week, and the mean duration of each category per session. Between category durations were found to be decisively different with a large effect (BF_{10} = 4.254e^{+113}, ω^2 = .36). Warm-up duration was shorter than all other categories with the exception of wrestling sparring and circuit training (BF_{10} = 6,746 – 1.807e^{+86}). More time per session was spent on striking drills (BF_{10} = 2,970) and BJJ drills (BF_{10} = 216,437) than wrestling drills, with no difference between striking drills and BJJ drills. Within sparring modes, BJJ consisted of longer durations than striking (BF_{10} = 1,683) and wrestling (BF_{10} = 156,504). More time was spent on MMA sparring than striking (BF_{10} = 106,151) and wrestling sparring (BF_{10} = 2.423e^{+6}) and with no difference in comparison to BJJ sparring. More minutes per session tended to be spent on technical drills than sparring (BF_{10} = 7 – 6.599e^{+17}), with the exception of wrestling drills, which had no statistical differences to BJJ sparring or MMA sparring, respectively. Where participants took part in S&C, they were of longer duration than all other categories (BF_{10} = 3.978e^{+8} – 1.807e^{+86}). Only wrestling sparring displayed different durations between weeks (BF_{10} = 12, ω^2 = .13), with week 3 being lower than weeks 2, 5 and 8 (BF_{10} = 8 - 24). Similarly, week 7 had a lower wrestling sparring duration than weeks 2 and 8 (BF_{10} = 3 - 5).

5.4.5 Segmented Sessional RPE of Training Categories

Table 5.3 also displays the weekly mean segRPE for each training category. Decisive differences were found between the segRPE of training categories (BF_{10} = 3.725e^{+128}, ω^2 = .39). Post hoc analyses found warm up to cause lower segRPE than all other categories (BF_{10} = 6.980e^{+9} – 1.335e^{+85}). In terms of technical categories, striking drills produced greater load than wrestling drills (BF_{10} = 14) with no other differences between categories. BJJ sparring produced greater load than striking (BF_{10} = 651) and wrestling sparring (BF_{10} = 992), without any relevant difference to MMA sparring. Wrestling sparring also caused lower load than MMA sparring (BF_{10} = 1.240e^{+6}). There was a general trend for technical drills to cause a greater load than sparring, with striking drills segRPE being decisively greater than striking (BF_{10} = 11,167) and wrestling sparring (BF_{10} = 25,578). BJJ drills also induced greater loads than striking sparring (BF_{10} = 21,540) and wrestling sparring (BF_{10} = 24,453).

Only MMA sparring was found to elicit statistically greater loads than wrestling drills (BF_{10} = 217). Strength and conditioning segRPE was found to be greater than all other categories (BF_{10} = 14 - 1.335e^{+85}). Wrestling sparring load was found to differ between weeks (BF_{10} = 5, ω^2 = .11), due to week 3 segRPE being lower than weeks 2, 5 and 8 (BF_{10} = 4 – 34). Striking sparring segRPE also differed between weeks (BF_{10} = 3, ω^2 = .11). In this category week 3 had lower load than weeks 1, 2 and 8 (BF_{10} = 6 – 504). Week 8 also had lower striking sparring segRPE than weeks 1, 2, 5 and 7 (BF_{10} = 6 – 1,430). Finally, week 6 was lower than week 5 (BF_{10} = 3) whilst week 7 was lower than week 6 (BF_{10} = 6).

5.4.6 Training Category Intensities

When analysing RPE as an estimate of training category intensity (Figure 5.8a), there were decisive differences with a large effect between categories (BF_{10} = 1.168e^{+134}, ω^2 = .40). Warm-ups were of lesser intensity than all other categories (BF_{10} = 1.882e^{+9} – 2.245e^{+64}). Within drill-based categories wrestling was found to be more intense than striking (BF_{10} = 5) and BJJ (BF_{10} = 59). Striking sparring was perceived to be of lower intensity than wrestling (BF_{10} = 137) and MMA sparring (BF_{10} = 986). BJJ sparring was also less intense than MMA sparring (BF_{10} = 10) with no other between sparring category differences. All drill categories were recorded as lower intensity than all sparring categories (BF_{10} = 2,436 – 7.723e^{+21}). Circuit training caused a greater RPE than all categories with the exception of BJJ, wrestling and MMA sparring (BF_{10} = 12 – 7.918e^{+26}), whilst S&C was more intense than all categories with the exception of wrestling sparring, MMA sparring and circuit training (BF_{10} = 15 – 3.271e^{+49}).

5.4.7 Training Intensity Zones

MMA related total training durations were categorised as 47% at low intensity, 33% at moderate intensity and 20% at high intensity. Figure 5.8b displays the mean duration of time spent in each intensity zone for each MMA training category. Drill based categories consisted of greater amounts of total time at low intensity in comparison to sparring based categories across all eight weeks with a very large effect (BF_{10} = 8-12, d = 3.1). Though there was a large effect between drill based and sparring based categories in terms of mean duration per session at low intensity, the evidence for this was only moderate (BF_{10} = 3, d = 2.2). Post-hoc ANOVA differences were found between durations spent at low and high intensities in warm up (BF_{10} = 155,619), BJJ drills (BF_{10} = 228), wrestling sparring (BF_{10} = 3) and MMA sparring (BF_{10} = 10). BJJ drills also displayed post-hoc differences between moderate and high intensities (BF_{10} = 9), with striking sparring having differences between low and moderate (BF_{10} = 37). Figure 6c shows the percentage of time spent in each intensity zone for each MMA category. The percentage of total time spent in low intensity was greater in drill categories than sparring categories (BF_{10} = 23-37, d = 4.1). The only differences between drills and sparring at high intensity was in the percentage of total time spent in this zone (BF_{10} = 11, d = 3.3).

Table 5.3 - Category duration (mins) and segmented sessional RPE (AU) per week and mean per session.

	Week	1	2	3	4	5	6	7	8	Category Means
Warm Up	**Duration**	10.2 ± 4.2 (11%)	11.2 ± 4.6 (11.4%)	9.5 ± 4 (9%)	10.2 ± 4.5 (10.7%)	10.4 ± 3.6 (10.9%)	10 ± 7.3 (11.1%)	7.8 ± 3.7 (8.8%)	10.9 ± 4 (11.8%)	10 ± 4.7
	segRPE	28.9 ± 20.2	36.7 ± 23.2	31 ± 22.3	28.1 ± 21.4	30.4 ± 16.2	32.8 ± 31.9	26.7 ± 18.1	39.7 ± 19.7	31.8 ± 22.3
Wrestling Drills	**Duration**	18.3 ± 11.9 (13.1%)	17.1 ± 11.8 (6%)	21 ± 11.9 (11.3%)	29.7 ± 14.8 (15.1%)	19.5 ± 12.4 (9.9%)	17.5 ± 16.5 (8.1%)	18.9 ± 10.8 (11%)	19.5 ± 11.6 (10.6%)	20.3 ± 13
	segRPE	86.4 ± 59.6	76.8 ± 59.4	116.9 ± 86.8	136.1 ± 69.2	78.7 ± 47.8	80.9 ± 91.6	87.3 ± 50.6	105.5 ± 73	97.4 ± 70.3
Striking Drills	**Duration**	33 ± 18.9 (29.6%)	30.1 ± 18.3 (27.6%)	32.3 ± 21.5 (29%)	21.3 ± 16.1 (19.8%)	30.7 ± 19.8 (29.9%)	29.9 ± 20.8 (32.4%)	27.3 ± 23.5 (24.3%)	26.8 ± 20.9 (23.3%)	29.1 ± 20
	segRPE	152.4 ± 99.2	149.7 ± 111.3	125.5 ± 99	82.7 ± 70.9	135.5 ± 101.6	127.1 ± 100.1	128.9 ± 137.1	130.6 ± 107.3	128.8 ± 104.2
BJJ Drills	**Duration**	24.7 ± 15 (10.3%)	27.7 ± 14.7 (12.1%)	31.2 ± 14.8 (16%)	27.4 ± 11.9 (11.5%)	38 ± 9.4 (13.5%)	39.6 ± 14.7 (13.5%)	30.6 ± 15.9 (16.7%)	27.6 ± 18.3 (17.7%)	30.1 ± 15.2
	segRPE	106 ± 97.5	107.3 ± 70.7	122.8 ± 55.7	124.7 ± 65	121.1 ± 55.9	136.4 ± 52.5	120.6 ± 80.6	109.9 ± 73.5	117.8 ± 69.5
Striking Sparring	**Duration**	14.5 ± 2.6 (5.2%)	14.3 ± 3.7 (4.2%)	11.3 ± 1.9 (2.9%)	14.7 ± 11.3 (9.3%)	15.9 ± 9.4 (6.4%)	9.7 ± 4.2 (4.2%)	14.8 ± 5.6 (6.1%)	8.4 ± 3.3 (3.3%)	13.1 ± 7.1
	segRPE [b]	83 ± 15.6	90.3 ± 39.3	51.8 ± 11	85.4 ± 73.2	103.6 ± 69.6	53.7 ± 25.8	88.8 ± 35.4	43.42 ± 18.41	75.7 ± 49.1
BJJ Sparring	**Duration**	23.7 ± 7.7 (7.8%)	21 ± 19 (12.2%)	20.6 ± 14.1 (14.2%)	22.8 ± 13.6 (10.9%)	16.5 ± 9.8 (8.4%)	14.5 ± 6.8 (7.7%)	19.3 ± 9.9 (9.9%)	15.8 ± 8.1 (8.2%)	19.3 ± 12.4
	segRPE	157 ± 79.3	128.1 ± 121.8	126.6 ± 85	137.9 ± 124.5	89.3 ± 69	88.8 ± 54.5	118.1 ± 74.7	98.1 ± 70.2	117.5 ± 89.9
Wrestling Sparring	**Duration [a]**	11.1 ± 5.4 (4.6%)	17.5 ± 11.5 (5.6%)	8.1 ± 5 (5.4%)	10.2 ± 6.3 (6.1%)	19.7 ± 17.5 (6%)	10.2 ± 7.9 (2.9%)	7.6 ± 2.5 (2.3%)	13.8 ± 6.2 (4.9%)	11.5 ± 8.6
	segRPE [b]	70.5 ± 37.9	118.9 ± 78.4	50.8 ± 36.3	67.6 ± 40.8	103 ± 81.3	68.9 ± 66.3	55.7 ± 23	99.6 ± 66.4	74.4 ± 55.8
MMA Sparring	**Duration**	27.7 ± 18 (7.4%)	18.7 ± 13.5 (5.5%)	18.8 ± 2.1 (1.9%)	21.3 ± 5.1 (3.8%)	21.1 ± 6.1 (5.7%)	16.6 ± 13.2 (5.6%)	29.6 ± 13.1 (7.1%)	19.3 ± 11 (5%)	21.4 ± 12.4
	segRPE	181.3 ± 135.3	142 ± 126.5	111.8 ± 12.8	150.5 ± 42.9	132.4 ± 40.3	102.3 ± 80.6	210.3 ± 127.7	143.5 ± 99.5	146.1 ± 99.3
Circuit Training	**Duration**	10.3 ± 6.9 (1.2%)	10.1 ± 6.1 (2.1%)	11.3 ± 11 (0.9%)	5* (0.2%)	22.3 ± 19.7 (2.3%)	9 ± 1.4 (0.6%)	0 (0%)	9.8 ± 9.2 (1.3%)	11.5 ± 9.5
	segRPE	70.3 ± 49.3	65.4 ± 37.3	58.3 ± 53.5	50*	157 ± 138	47 ± 32.5	0	81.5 ± 82.8	77.3 ± 67.6
Strength & Conditioning	**Duration**	53.3 ± 7.5 (9.5%)	50.6 ± 15.5 (13.3%)	61.7 ± 16 (9.5%)	42.2 ± 31.8 (12.6%)	45.2 ± 18.7 (9.1%)	50 ± 19.9 (13.9%)	45.2 ± 19.8 (13.9%)	55.6 ± 29.1 (14.3%)	49.8 ± 21.5
	segRPE	360 ± 121.9	343. ± 158.1	411.7 ± 160.1	301.9 ± 247.9	333 ± 193.6	311.6 ± 187.2	343.1 ± 200.5	383.8 ± 184.2	344.4 ± 181.9

*Nb. Duration data shown as within week group mean ± SD minutes and (% of total weekly training time spent in category); * only one occurrence of this category in this week;* a = *strong BF_{10} and medium ω^2 between weeks;* b = *moderate BF_{10} and medium ω^2 between weeks; RPE = rating of perceived exertion (AU)*

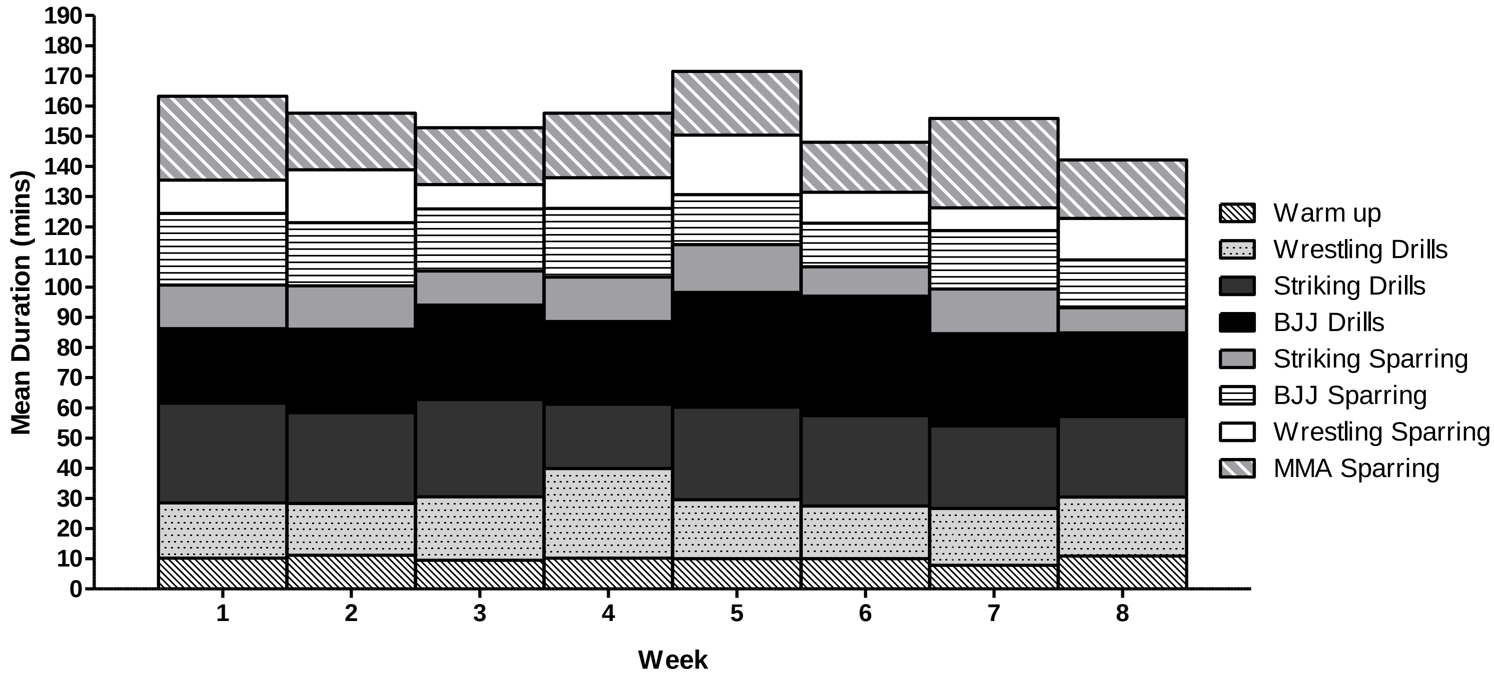

Figure 5.7 - Mean category duration (mins) by week

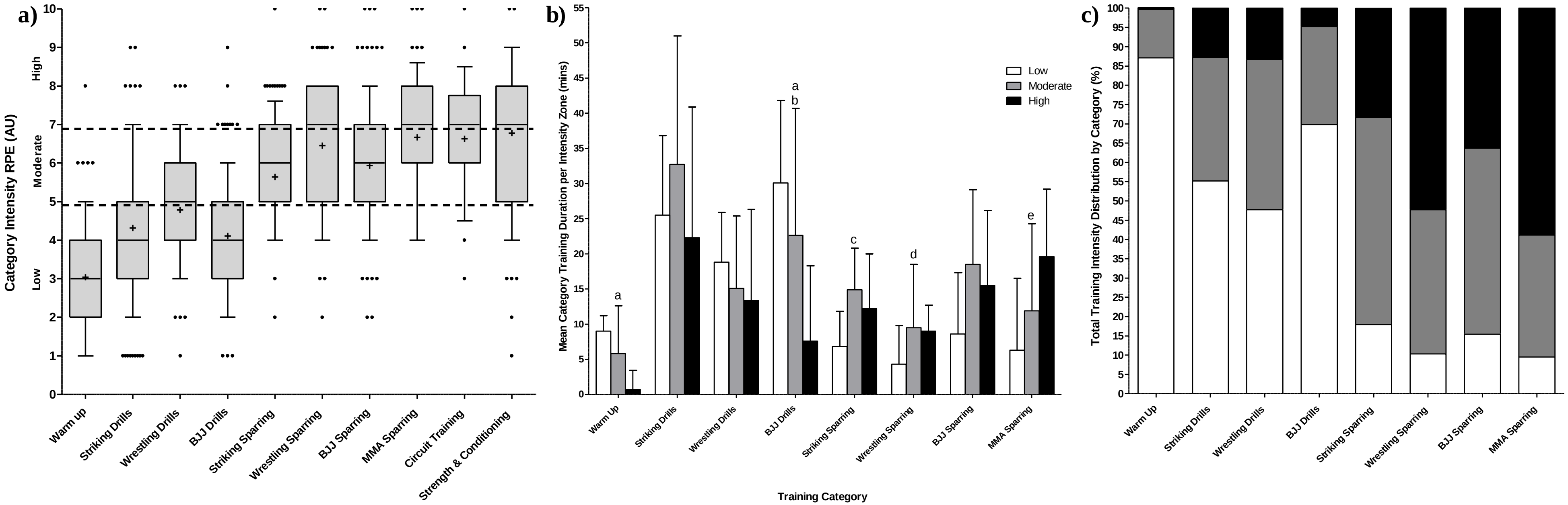

Figure 5.8 - a) Median [10 – 90%] rating of perceived exertion per category (AU); b) Mean time spent in each intensity zone per MMA training category (mins); Error bars = SD; c) Percentage of total time spent in each intensity zone per MMA training category.

Nb. 6a: Dots show outliers in each category; + = category mean. 5b: a = decisive post-hoc differences between low and high intensity; b = moderate post-hoc differences between moderate and high intensity; c = very strong post-hoc differences between low and moderate intensity; d = moderate post-hoc differences between low and high intensity; e = strong post-hoc differences between low and high intensity.

5.5 Discussion

This study reports for the first time the typical training load and periodisation strategies employed by MMA athletes over an extended period. In contrast to the hypothesis, limited evidence of training periodisation within or between weekly microcycles is reported. Additionally, differences in training load practices between athletes preparing for professional or amateur competition and those in normal training only occurred in the final week before competition, largely reflective of reduced training duration. Related to this limited evidence of periodisation, no changes in ratings of fatigue or soreness throughout the eight-week observational period were found. From a practical perspective, the study provides novel data by reporting the perceived intensities associated with the full spectra of training activities habitually completed by MMA athletes. As such, these data may provide a platform to develop subsequent sport specific training periodisation strategies thus enabling training load undulation, functional overreaching and physiological adaptation to occur (Turner, 2011).

Despite the well evidenced role of training load periodisation (Turner, 2011), the training observed in the present cohort of athletes did not change between weekly microcycles. Reported here for the first time, the weekly training duration of ~3-6 hours per week is less than that reported in judo (Papacosta et al., 2013) and boxing (Halperin et al., 2016), and only half the weekly duration reported in non-combat sports (Guellich et al., 2009; Moreira et al., 2015). Each of these sports use changes in training duration to manipulate overall load, a method that appears to be unused in this cohort resulting in no changes in weekly load. It may be that MMA coaches are constrained in planning session duration around the expectations of their paying customers rather than the needs of their competitive athletes, who were in the minority in the observed sessions. In this light, MMA coaches may require more specialised methods of load manipulation to account for this relatively unique circumstance. Methods developed should allow competitive participants to experience overloading but still allow recreational participants to train alongside them. The absence of periodisation is also apparent during competition preparation, where effective tapering strategies were absent. Over the five comparable weeks, the only reduction in training duration or load was seen in the week of the bout. Rather than employing an exponential taper over the final fourteen days (Turner, 2011) participants reduced training load by more than 2/3 in an abrupt stepwise manner seven days prior. With no comparable reduction in fatigue markers the week of the bout or the week after, it is possible that this approach did not improve athlete readiness or performance. This result is supported by recent data from another research group who also found that MMA training load is only reduced in the week of the bout (Uddin et al., 2020). In addition to extreme 'weight cutting' seen in our cohort and MMA competitors in general (Brechney et al., 2019; Kirk et al., 2020b), it is more likely that performance would have been impaired. Though no direct performance data was collected, evidence from boxing suggests that a taper of ten days or fewer causes a reduction in combat sport performance until several days after competition (Halperin et al., 2016).

Planned within week undulation of load and duration is a common practice in individual sports without regular competition to achieve overall weekly training fluctuations (Agostinho et al., 2017; Halperin et al., 2016; Stellingwerff, 2012). The absence of this practice in the presented data results in the static load between weeks and may also explain the lack of changes in fatigue. Comparisons to other sports show daily sRPE of MMA is low (Algrøy et al., 2011; Weaving et al., 2018) and most days would be classed as 'easy' according to the arbitrary definition recently suggested for MMA (Coyne et al., 2020). The daily load provided therefore may not be great enough to cause sufficient strain to bring about fatigue beyond the acute stage, reducing the likelihood of optimal fatigue-recovery-adaptation (Kellmann et al., 2018). Equally, the minimal training at weekends may be deliberate to allow post-training soreness and fatigue to dissipate enough to remain mild-moderate in the long term (Halson, 2014; Kellmann, 2010). Whilst this reduces the chances of NFOR/OTS it is also unlikely to be sufficient to cause the desired physiological adaptations and therefore improve performance (Impellizzeri et al., 2018). Effective periodisation of training duration and load structure specific to the needs and environment of MMA may allow coaches to plan training with sufficient daily variation to maintain health and improve performance.

The lack of changes in body region soreness may have a number of explanations. Due to repeated physical impact of MMA, participants may be conditioned against the effects of such strain on musculotendon soreness (Gomes-Santos et al., 2019; Naughton et al., 2018). This repeated exposure may also have caused a 'normalising' of perceived soreness as 'part of the sport'(Fletcher et al., 2016), resulting in higher individual thresholds for 'moderate discomfort' and 'noticeable pain'. Though this cohort displayed similar lower body soreness to rugby players (Tavares et al., 2018), this occurred without the elevated soreness to the upper torso or head and neck regions that is common to impact and grappling inclusive sports (Tavares et al., 2018). Due to anecdotal experience and extant injury data (Ji, 2016), this result was unexpected and may indicate purposeful planning on the part of coaches to minimise soreness by keeping overall training load low (Weaving et al., 2018). As the effects of MMA on musculotendon structures are currently unknown, determining the effects of different MMA training loads, durations and practices on this aspect of athlete preparation may be an important area of research moving forward.

Given MMA is a complex sport with multiple conflicting training demands, the need for coaches to ensure their athletes are sufficiently trained in each technical area is reflected in the training category data. BJJ drills had the longest average duration, with the shortest being wrestling sparring. MMA sparring caused the greatest average training load overall, and the highest or second highest training load in 6 of the 8 weeks. Striking drills was the second most load inducing category overall and was the greatest or second greatest load inducing category in five of the eight weeks with the second longest average duration. Despite these weekly variations in category durations, only one was statistically relevant. This absence of weekly changes in category use likely contributes to the static weekly and daily loads reported. Coaches do, however, appear to attempt to manage intensity and load within sessions. Though wrestling sparring and MMA sparring were perceived as the two most intense categories, the former had the second shortest average duration, with the latter being of relatively moderate duration. Conversely, the categories displaying the longest average durations - striking drills and BJJ drills - were also the two least intense. This indicates that coaches are cognizant of too much high intensity work in one session and the negative associated consequences (Cadegiani and Kater, 2017; Hill et al., 2008). It does appear though that this is led by pre-conceived notions of category intensities. More time being spent on BJJ sparring than striking sparring, for example, may be evidence that coaches perceive BJJ to be lower intensity. According to the data presented here, these two categories are actually of equal intensity and spending more time on BJJ sparring leads to a greater overall load from this category. Additionally, though striking drills are generally low perceived intensity, the high amount of time spent training this category leads to the highest average time spent at moderate intensity, and an equal amount of high intensity time as MMA sparring. It therefore appears that planning training duration based on anecdotal conceptions of category intensity may not be adequate for balancing training demands. Equally, attempting to train each category to the same extent each week may be the cause of the static weekly training load and fatigue observed.

The current cohort of MMA athletes perceived 80% of their training time as low-to-moderate intensities with 20% as high-intensity. This may be an appropriate split for these athletes considering the physiological responses to these intensity zones (Algrøy et al., 2011). However, little of the training conducted at low intensity was performed at steady-state, owing to these sessions consisting of skill orientated, intermittent drills with prolonged rest periods, likely reducing the aerobic adaptations from these sessions (Guellich et al., 2009; Seiler, 2010). Compounding this is the low number of S&C sessions reported by this cohort (63 out of 405 individual sessions), none of which could be qualitatively described as steady-state or aerobic endurance. Given MMA training alone is insufficient at improving aerobic or anaerobic performance (Kostikiadis et al., 2018), in-bout reductions in pacing are to be expected (Kirk et al., 2020a). Though the intensity distribution observed here may potentially be appropriate for the unique physiological requirements of combat sports, the absence of supplementary conditioning across the cohort in general likely negates its effectiveness.

Based on the presented data, therefore, it may be possible to plan session content and intensity on a weekly basis. In this hypothetical structure, it may be the case that low load weeks consist entirely of striking and BJJ drills, with only one day of wrestling drills or wrestling sparring. High load weeks might consist of one day of striking or BJJ drills, with several days of wrestling, BJJ and MMA sparring. This would allow clear delineation between weeks of high, moderate and low load, enabling functional overreaching to occur followed by restitution weeks (Turner, 2011). This process may elicit the physiological improvements associated with spending <10% of weekly and total training time at high intensity (Gottschall et al., 2020), alongside the performance benefits of shock or overloading weeks (Aubry et al., 2014). This may allow different weeks to focus more time on specific categories to equalise the balance between skill transfer and physiological adaptation (Gabbett et al., 2009), whilst still satisfying the aforementioned duration expectations of paying customers. The category intensity ratings provided here may allow coaches to start planning training in this manner and researchers to more accurately quantify training responses.

It should be noted that these data were recorded from clubs in one region of the UK and as such may not be generalisable across the MMA population. There is, however, recent evidence that pre-competition periodisation is also absent amongst MMA athletes in other regions of the UK (Uddin et al., 2020). Equally, sociological studies conducted in North America reveal a similar pattern of competitive athletes training in the same sessions as recreational participants and having to organise their own S&C externally to the club (Spencer, 2012). This indicates that the training concerns highlighted here may be common amongst MMA participants. This study only includes internal load measures without external load being quantified. Chapter 6 addresses this by using reliable technology (Hurst et al., 2014) to determine the external load of MMA training and its relationship to internal load measures. Studies should also be conducted to determine effects of different tapering strategies on both performance and weight making prior to competition. It is of key importance to note, however, that physiological requirements of and responses to MMA competition are largely unquantified. This leaves a void in the planning of training due to a lack of known physiological targets to be achieved. Investigations of the direct internal and external load of MMA competition should be therefore prioritised in order to make optimal use of the data presented here.

In summary, the typical weekly and daily training load and periodisation strategies employed by MMA athletes is reported for the first time. In contrast to the hypothesis, there was limited evidence of training periodisation within or between weekly microcycles. Additionally, differences in training load practices between athletes preparing for competition and athletes engaged in 'normal' training was limited to the final week before competition and was abrupt and stepwise, largely due to reduced training duration. There were no observable changes in ratings of fatigue, soreness, sleep or reaction time throughout the eight-week observational period, or prior to bouts. From a practical perspective, this study provides intensity classifications for MMA training categories which may be used to manipulate weekly load and pre-competition tapers. Using these data, researchers should work with coaches to determine the optimal loading and tapering strategies to ensure appropriate physiological fatigue-recovery-adaptation alongside skill learning for competitive MMA athletes.

5.6 Chapter Summary

- MMA training does not appear to be periodised between or within weekly microcycles.
- Pre-competition tapers are stepwise 1 week prior to a bout, leading to no reductions in fatigue markers
- Each MMA training category may be distinguished by intensity and internal load, with 20% of training spent at high intensity.
- Though coaches appear to modulate training category durations, this is done in a manner that leads to equal loads per day.
- The external load of MMA training is still unknown and is addressed in Chapter 6.

End of Study 2 Thesis Map

Study Aim	Study Type	Objectives	Outcomes
Study 1 – Chapter 3 **Thesis Objective 1** **Study Aim** Explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition	**ARMSS Stage 1: Defining the problem** Qualitative semi-structured interviews	1. Interview professional MMA coaches to explore their training and coaching backgrounds, and how they developed as MMA coaches 2. Explore the structure, aims and focus of MMA coaches practice in preparing participants for competition 3. Explore how MMA coaches attempt to monitor the load-fatigue-adaptation cycle of the participants preparing for competition within their practice.	1. MMA coaches developed via experience and peer learning. Peer learning reduces when they become club owners 2. Sessions must cater both to competitive athletes and recreational participants simultaneously. 3. Training practices are led by folk pedagogy potentially underpinned by pseudoscience with minimal evidence of objective monitoring of athlete load-fatigue-adaptation.
Study 2 – Chapter 5 **Thesis Objective: 2** **Study Aim** Quantify the internal loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the durations, intensities and internal loads of MMA training categories 2. Record subjective fatigue and soreness response of MMA athletes in relation to these internal loads 3. Determine the intensity and load distribution of MMA training sessions and categories 4. Determine any changes in load, fatigue or soreness when MMA athletes are preparing for competition	1. MMA training does not appear to be periodised between or within weekly microcycles. 2. Pre-competition tapers are stepwise 1 week prior to a bout, leading to no reductions in fatigue markers 3. Each MMA training category may be distinguished by intensity and internal load, with 20% of training time spent at high intensity.
Study 3 – Chapter 6 **Thesis Objective: 2** **Study Aim** Quantify the external loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the external loads of MMA training categories 2. Determine the relationship between external and internal loads in MMA training. 3. Determine the distribution of external loads of MMA training categories	
Study 4 – Chapter 7 **Thesis Objective: 3** **Study Aim** Determine the physiological adaptations and changes in body composition that arise from completing a typical 6-8 week MMA training period that is used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative laboratory data collection without intervention	1. Record physiological and body composition data of a group of international standard MMA athletes prior to commencing training for competition 2. Record the same physiological and body composition variables upon completion of the training period but prior to pre-competition RWL. 3. Determine the effects of a pre-competition training period on MMA athlete's physiological capabilities and body composition	
Study 5 – Chapter 8 **Thesis Objective: 4** **Study Aim** Examine the effects of a supplementary high-intensity aerobic training intervention (completed alongside traditional MMA training practices) on aerobic capacity and indices of competition specific performance	**ARMSS Stage 3: Predictors of performance** Quantitative field and laboratory data collection with training intervention	1. Apply a cardiovascular training intervention to MMA athlete's regular technical-tactical training 2. Determine the effects of training intervention on physiological and body composition measures collected in laboratory 3. Determine the effects of training intervention on bout pacing as measured via body worn accelerometry in simulated competition	

Chapter 6 - Study 3: Quantification of the External Loads of MMA Training

6.1 Chapter Rationale

Chapter 5 detailed the internal training loads and associated fatigue response of MMA training sessions and categories for the first time. Internal loads are the athlete's physiological responses to the external loads placed upon them by their physical actions (Jeffries et al., 2021). Therefore, in order to understand the training process, both internal and external loads must be recorded. Currently, there is no validated method of measuring external load in MMA. Previous studies have used accelerometry for this purpose in simulated competition (Kirk et al., 2015a), but not in the athlete's normal training. Accordingly, this study aimed to quantify the external loads of MMA training sessions and categories via torso mounted accelerometry and determine these loads relationship to the corresponding internal load.

ARMSS Stage: 2 – Descriptive research

6.2 Introduction

Understanding an athlete's response to training plays a key role in optimising performance and minimising fatigue (Halson, 2014). This process requires differentiation between external loads placed on the athlete during training and the subsequent internal load i.e., the athlete's physiological response (Impellizzeri et al., 2018; Jeffries et al., 2021). As no single method has been identified that can accurately predict the athlete's training dose-response (Bourdon et al., 2017), a combination of internal and external load measurements is recommended (Wing, 2018). The sport specific physical demands of certain events can render load measurement difficult or impractical in an applied setting. MMA would be an example of such a sport given the unique movement requirements of the distinct training categories used. It would, therefore, be important for practitioners and researchers to understand how to appropriately program the loads of these different categories both within and between weeks (Turner, 2011).

Chapter 5 presented novel data showing MMA training consisting of a static within and between week training load, resulting in no changes to markers of fatigue over an eight-week period. It was concluded that MMA coaches may have pre-conceptions about which categories are most fatiguing and limit the duration of these categories to spend more time on perceived lower intensity categories. This, however, results in the same overall training load across each day and week. This lack of periodisation may explain the absence of neuromuscular or cardiorespiratory adaptations to MMA technical/tactical training (Kostikiadis et al., 2018). Knowledge of each MMA training category's external load, and how this relates to the category internal load, may facilitate more appropriate programming to enable a balanced training-recovery-adaptation cycle to be achieved (Impellizzeri et al., 2018). Currently, however, there is no accepted method of measuring external load in this population, and real time internal load data is limited (Petersen and Lindsay, 2020). Proxy external load via time motion analyses (TMA) have been reported extensively from competition (Coswig et al., 2016b; dal Bello et al., 2019; dos Santos et al., 2018), though no such data has been provided from training. Regardless, the time-consuming nature of TMA makes its application impractical in such an environment.

Accelerometry has been suggested as a potential solution to this problem (Worsey et al., 2019), with the Catapult Playerload metric being found to be highly correlated ($r = .70 - .84$) to subjective and objective internal load in other contact and non-contact sports (Casamichana et al., 2013; Scott et al., 2013; Svilar et al., 2018). Summated from the magnitude of changes in accelerations in the three cardinal planes (Bredt et al., 2020), Playerload is proposed as a global score of external load (Boyd et al., 2011) and is related to indications of performance readiness changes in contact sports (Heishman et al., 2018). Previous studies have demonstrated the high reliability and potential utility of Playerload in measuring isolated MMA movements (Hurst et al., 2014; Kirk et al., 2015b) and subsequently provided insight into the external load and pacing of simulated bouts (Kirk et al., 2020a, 2015a). Playerload resulting from MMA training practices, and its relationship to internal load, is yet to be examined in an open MMA training environment. Kirk et al. (2015a) did report a nearly perfect relationship between Playerload and lactate in simulated competition ($r = .99$), but a small sample size of $n = 6$ rendered this result non-significant. Given that Playerload is capable of distinguishing between training modes and intensities in boxing (Finlay et al., 2020, 2018), it may provide similar insight for MMA training categories. If accelerometer derived external load shares a relationship with internal load, the combination of both may provide a practical model for monitoring and planning training loads in MMA.

Therefore, the aim of this study was to quantify the external loads of MMA training practices that are used to prepare participants for competition. A secondary aim was to determine the relationship between MMA internal and external loads to propose a load monitoring model for use in MMA competition preparation. To that end, a cohort of international standard amateur and professional MMA athletes was observed undertaking their regular training for a two-week period. Internal load using a post training questionnaire and external load via torso-mounted accelerometry were collected. Following on from the results of Chapter 5, it was hypothesised that within week changes in external training loads would be absent in MMA. Based on evidence from other contact and combat sports (Casamichana et al., 2013; Scott et al., 2013; Svilar et al., 2018) a secondary hypothesis was that absolute and relative Playerload metrics would share a predictive relationship with markers of internal load.

6.3 Methods

6.3.1 Participants and Procedures

A cohort of twenty experienced male (n = 14) and female (n = 6) MMA competitors (age = 23.2 ± 5.7 years; habitual mass = 72.1 ± 7.2 kg; stature = 171.5 ± 8.4 cm) from four clubs were recruited for this study following institutional ethical approval and using the inclusion criteria established in Chapter 4. Participants were observed taking part in their normal MMA training without intervention. Seven participants were engaged in competition preparation during data collection, however, the data collection period did not overlap with any of the weeks of competition, meaning their training practices did not differ to the rest of the cohort (Chapter 5, Figure 5.3). Data were collected following the procedures established in Chapter 4 for collection of training duration, internal load and external load. For details of the time of day of sessions, please refer to Chapter 4.1.1. To allow a more contextual analysis of external load, the following sub-categories were applied to PLd_{ACC} and $PLd_{ACC}\cdot min^{-1}$ data in addition to the training categories established in Chapters 4 and 5:

Striking drills: boxing; kickboxing; with takedowns/sprawls.

Wrestling drills: open space; against wall; with strikes.

BJJ drills: positional; submission.

Sparring: boxing; kickboxing; BJJ; BJJ with strikes; wrestling; MMA.

6.3.2 Statistical Analyses

Unless stated, comparisons were made using Bayesian ANOVA with a default prior r = 0.5, and a default t test with a Cauchy prior as post hoc analysis. Omega squared (ω^2) was calculated as the effect size. Daily training duration, sRPE, PLd_{ACC} and $PLd_{ACC}\cdot min^{-1}$ were compared between days for Week 1 and Week 2. Daily session and category duration, segRPE, sRPE and external load variables were then averaged between the two weeks to allow between days comparisons to be made. External load differences between training categories, and between sub-categories, were also assessed. For between sub-category comparisons with < 3 sub-categories, Bayesian independent t-tests with a JZS Cauchy prior = .707 at location parameter = 0 were calculated with Cohen's d using the standard deviation of the mean scores as the denominator for the effect size.

Relationships between internal load and external load variables were determined using Bayesian Kendall's Tau-b correlation with a stretched beta prior width = 1, and 95% credible intervals. Predictive relationships between variables with correlation $BF_{10} \geq 3$ were calculated using Bayesian linear regression with a JZS default prior r = 0.354. It should be noted, the predictive equation for Bayesian regression is modified from frequentist regression and is expressed:

$$y = b_o + b_1 * x_1$$

Where:

y = estimated dependent outcome variable score; b_0 = intercept constant; b_1 = regression coefficient; x_1 = score difference for the independent variable predictor (= independent variable – independent variable mean)

6.4 Results

6.4.1 Daily training loads and durations

Session overall displayed mean PLd_{ACC} = 310.6 ± 112 AU whilst mean sRPE = 448.6 ± 191.1 AU. Appendix E displays specific means ± SD of each variable for each category. Appendix F displays category internal load and duration per day, whilst Appendix G contains absolute and relative external load for each category per day. The number of sessions completed per participant in Week 1 = 4.7 ± 1.7, with Week 2 = 4.2 ± 1. As seen in Figure 6.1 the only difference in any variable between days within weeks occurred in Week 2 $PLd_{ACC}\cdot min^{-1}$ due to Friday being greater than Monday (BF_{10} = 6), Tuesday (BF_{10} = 10), Wednesday (BF_{10} = 98) and Saturday (BF_{10} = 8) respectively. Figure 6.2 displays training duration, absolute internal load, absolute external load and relative external load per category by day. Averaged across both weeks, less time was spent on warm-ups on Wednesdays and Fridays (post-hoc BF_{10} = 54 – 882) than any other training day (BF_{10} = 190, ω^2 = .25). Striking drills duration displayed a post-hoc difference between Tuesdays and Fridays, (BF_{10} = 6), despite no difference between days overall (BF_{10} = 0.9, ω^2 = .7). Training time spent on striking sparring was decisively different between days (BF_{10} = 600, ω^2 = .55) with moderate-decisive post-hoc differences caused by Wednesday and Fridays having shorter durations (BF_{10} = 4 – 215). BJJ sparring had strong differences in duration between days with no post-hoc differences (BF_{10} = 22, ω^2 < .01). The longest duration MMA sparring occurred on Fridays, with decisive post-hoc differences to Mondays and Wednesdays (BF_{10} = 35,136). No other differences in durations between days were found.

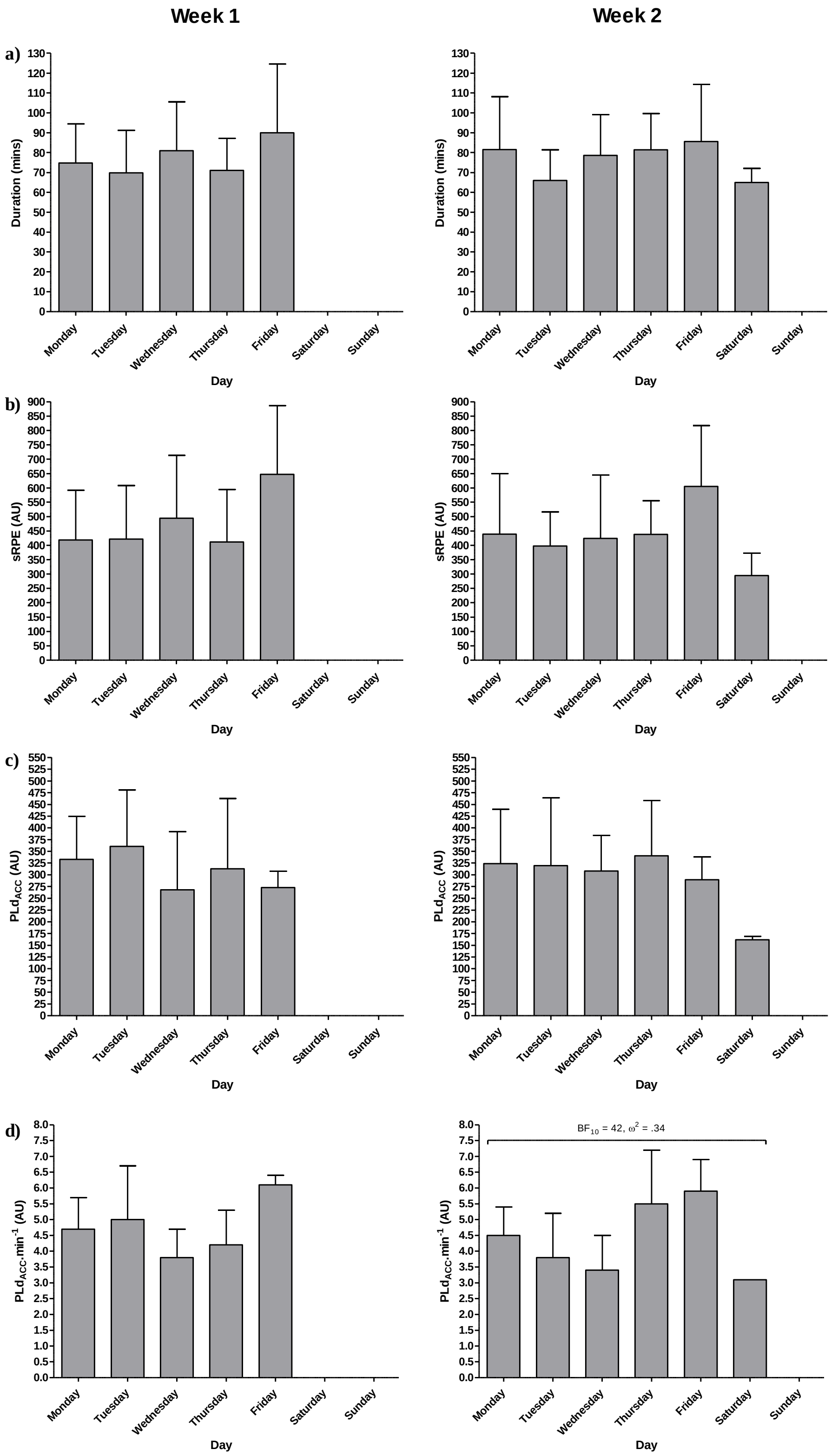

Figure 6.1 – Mean ± SD a) duration (mins), b) internal load, c) absolute external load and d) relative external load (all AU unless stated) between days within weeks. *Nb. PLd$_{ACC}$ = accumulated Playerload; PLd$_{ACC}$·min $^{-1}$ = accumulated Playerload per minute; sRPE = sessional rating of perceived exertion; Error bars = SD.*

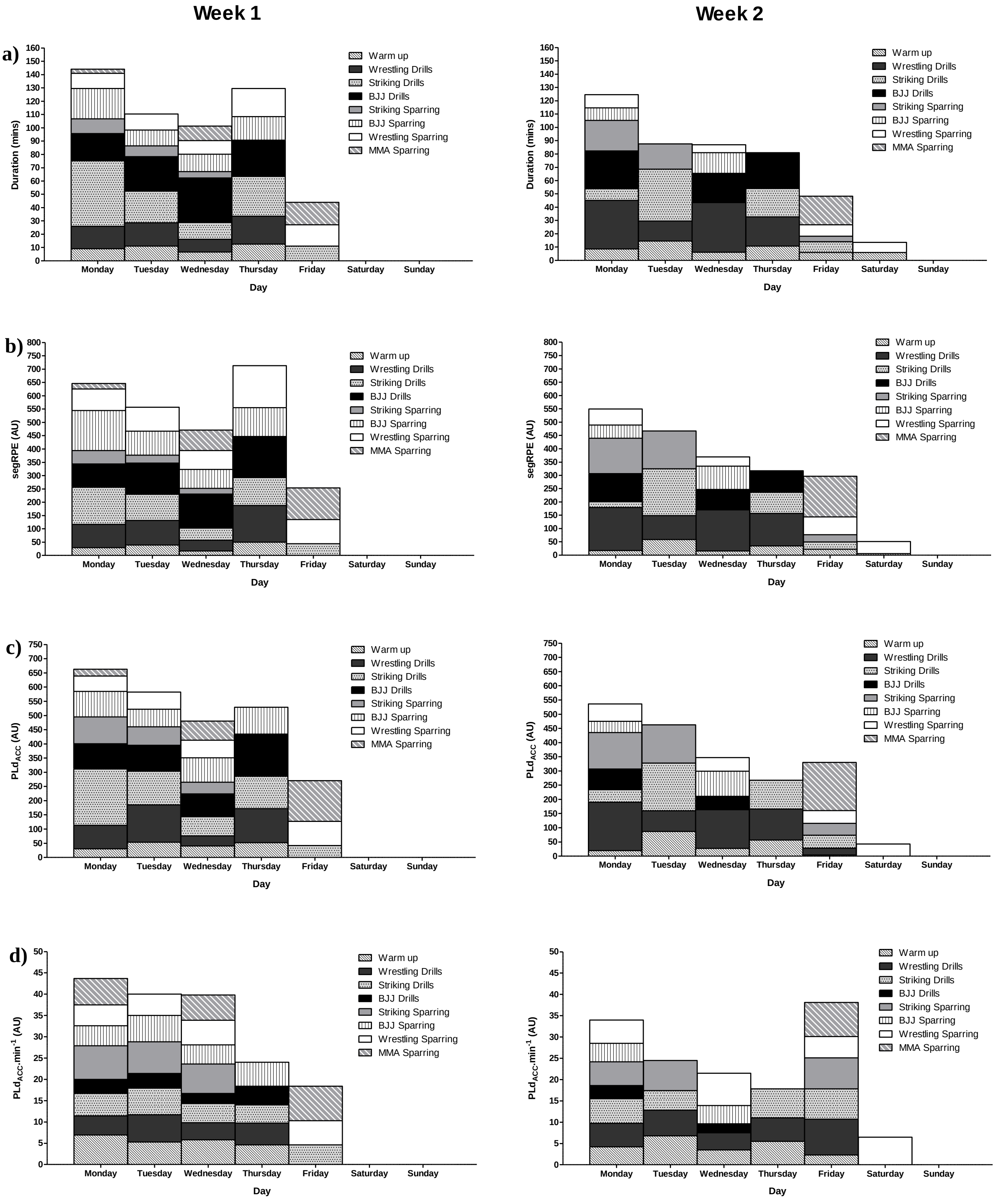

Figure 6.2 – Mean category a) duration (mins), b) internal load, c) absolute external load and d) relative external load (all AU unless stated) by category between days within weeks. *Nb.* PLd_{ACC} = *accumulated Playerload;* $PLd_{ACC}\cdot min^{-1}$ = *accumulated Playerload per minute; sRPE = sessional rating of perceived exertion; segRPE = segmented sessional rating of perceived exertion.*

Warm-ups caused less internal load on Wednesdays than Tuesdays and Thursdays (BF_{10} = 1,034, ω^2 = .32, post-hoc BF_{10} = 376 - 601). Post-hoc differences in warm-up segRPE were also observed between Mondays and Tuesdays, and Thursdays and Saturdays (post-hoc BF_{10} = 3 - 4). Daily differences in striking sparring segRPE were found to be moderate (BF_{10} = 9, ω^2 = .32) due to Wednesdays and Fridays displaying lower loads than Mondays and Thursdays. BJJ sparring had moderate differences between days with no post-hoc differences found (BF_{10} = 6, $\omega^2 < .01$). MMA sparring was found to be distributed differently between days, with the majority of sessions and greatest mean segRPE occurring on Fridays (BF_{10} = 98). Despite no overall differences between days, post-hoc tests found moderate differences between some days for striking drills, wrestling sparring and the session overall.

Warm-ups caused greater PLd_{ACC} on Thursdays and Tuesdays than other days of the week (BF_{10} = 25, ω^2 = .23). BJJ drills PLd_{ACC} was moderately different between days (BF_{10} = 3, ω^2 = .24) due to Thursdays being moderately greater than Wednesdays (post-hoc BF_{10} = 3). Striking sparring PLd_{ACC} was decisively different between days (BF_{10} = 820, ω^2 = .56) due to Wednesdays and Fridays displaying moderate to decisive post-hoc differences to the other days (post-hoc BF_{10} = 4 – 372). The absolute external load of MMA sparring was distributed more towards Thursdays and Fridays (BF_{10} = 40,516, ω^2 = .83), with moderate to decisive post-hoc differences between these days and the others (post-hoc BF_{10} = 3 – 2,961). Despite no other overall PLd_{ACC} differences being found, post-hoc differences were found in striking drills (Tuesday/Friday BF_{10} = 7), wrestling drills (Friday/Saturday BF_{10} = 23) and the session overall (Friday/Saturday BF_{10} = 65).

When using $PLd_{ACC}\cdot min^{-1}$ as a marker of relative external load, decisive differences between days were found for wrestling drills (BF_{10} = 9.531, ω^2 = .49) due to Tuesdays and Fridays displaying greater intensity than other days (post-hoc BF_{10} = 3 – 888). The overall majority of wrestling sparring sessions, however, took place on Mondays and Wednesdays. BJJ drills $PLd_{ACC}\cdot min^{-1}$ was different between days (BF_{10} = 247, ω^2 = .54) due to Wednesdays relative external load being less than other days for this category (post-hoc BF_{10} = 3 – 773). BJJ sparring $PLd_{ACC.}\cdot min^{-1}$ was greater on Tuesdays than Mondays (post-hoc BF_{10} = 6) and Wednesdays (post-hoc BF_{10} = 10) leading to strong differences across the week (BF_{10} = 10, ω^2 = .27). MMA sparring relative external load was found to be different over the week (BF_{10} = 5, ω^2 = .38), with Wednesdays being lower than Fridays (post-hoc BF_{10} = 5). The relative external load of the overall sessions differed across the week (BF_{10} = 156, ω^2 = .2) with Fridays being greater than all other days (post-hoc BF_{10} = 3 – 36,603), and Wednesdays being less intense than Thursdays (post-hoc BF_{10} = 3). Post-hoc differences were found in striking sparring (Tuesday/Thursday BF_{10} = 5) and wrestling sparring (Wednesday/Friday BF_{10} = 3) $PLd_{ACC}·min^{-1}$ despite no overall differences being found for these categories.

6.4.2 External load of training categories

Differences between training categories can be viewed in Figure 6.3. Absolute external load was decisively different between training categories with a large effect (BF_{10} = 4.551^{e+8}, ω^2 = .16). Warm up PLd_{ACC} was lower than all other categories with the exception of wrestling sparring (BF_{10} = 703 – 1.779^{e+6}). Wrestling sparring also caused lower absolute external load than all other categories (BF_{10} = 9 – 8,698) apart from warm up. BJJ sparring displayed lower absolute external load than striking drills (BF_{10} = 3) and MMA sparring respectively (BF_{10} = 7).

Relative external load was also different between categories with a large effect (BF_{10} = 4.621^{e+10}, ω^2 = .20). BJJ drills caused least $PLd_{ACC}·min^{-1}$ of all categories (BF_{10} = 17 – 5.638^{e+10}). Both striking drills (BF_{10} = 176) and wrestling drills (BF_{10} = 498,174) displayed lower relative external load than striking sparring. Striking sparring also produced more relative external load than wrestling sparring and BJJ sparring (BF_{10} = 293 – 3.773^{e+6}), though wrestling sparring was greater than BJJ sparring (BF_{10} = 7). MMA sparring caused greater $PLd_{ACC}·min^{-1}$ than all other categories with the exception of striking sparring (BF_{10} = 6 – 2.213^{e+11}).

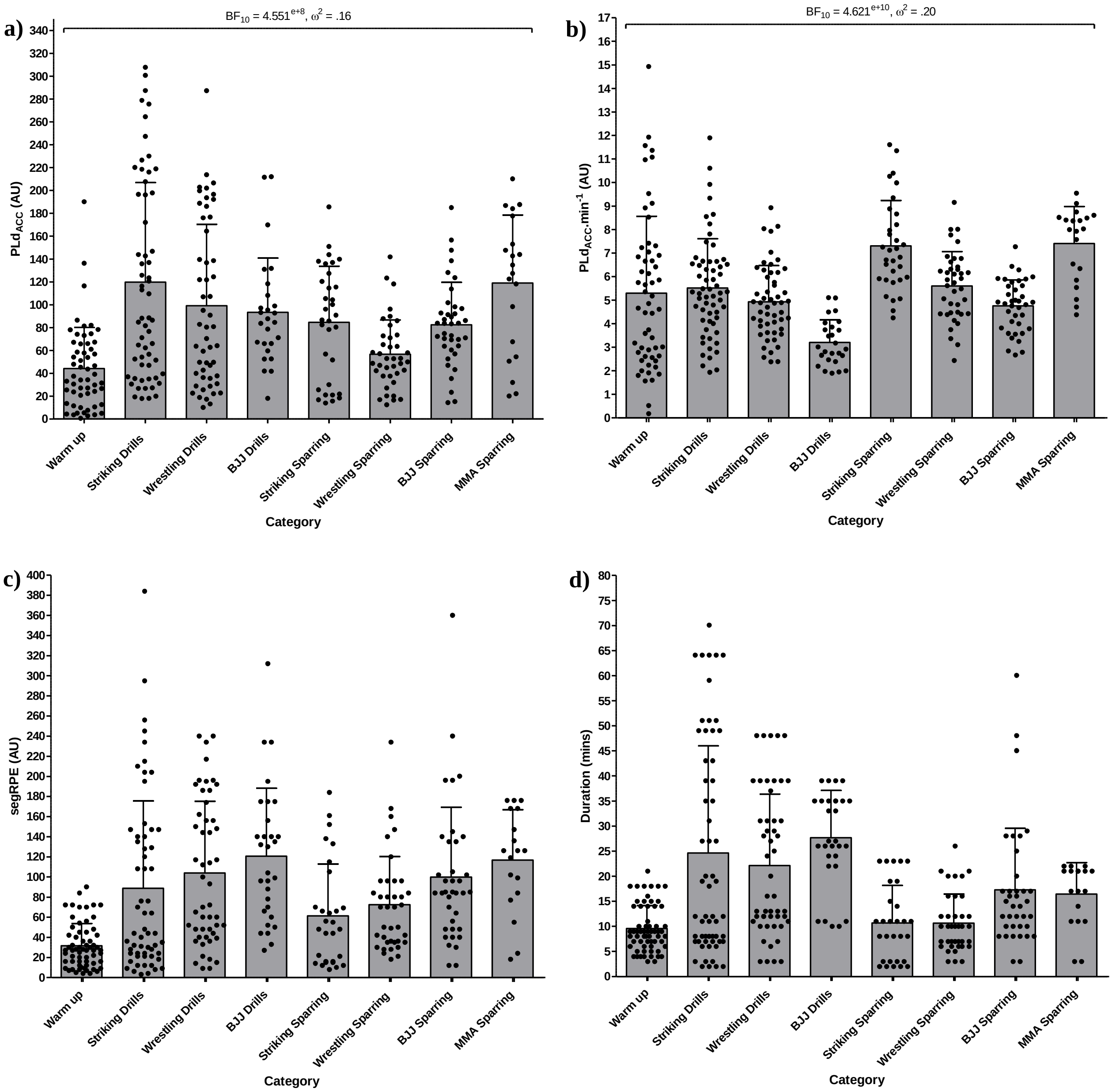

Figure 6.3 – Mean ± SD a) absolute external load, b) relative external load, c) absolute internal load (all AU) and d) duration (mins) of each training category. *Nb.* PLd_{ACC} *= accumulated Playerload;* $PLd_{ACC} \cdot min^{-1}$ *= accumulated Playerload per minute; segRPE = segmented sessional rating of perceived exertion; black dots represent individual training sessions; Error bars = SD.*

6.4.3 Differences between sub-categories

Descriptive data for external load of training sub-categories are provided in Table 6.1. Within striking drills (BF_{10} = 108, ω^2 = .17) the absolute load of kickboxing was greater than boxing (BF_{10} = 23) and striking with takedowns/sprawls (BF_{10} = 5). The relative load of striking with takedowns/sprawls was greater than boxing (BF_{10} = 34) and kickboxing (BF_{10} = 21,447) respectively (BF_{10} = 516, ω^2 = .22). Moderate differences in absolute external load were found between wrestling drills sub-categories (BF_{10} = 10, ω^2 = .12). These differences were found between wrestling against wall and wrestling with strikes (BF_{10} = 62). There were no differences, however, in relative external load for these sub-categories. BJJ sub-categories were found to produce different relative external load (BF_{10} = 7, d = 1.6) only. The absolute external loads of sparring sub-categories were decisively different with a large effect (BF_{10} = 53,290, ω^2 = .23). Boxing was found to produce greater absolute external load than all other sparring sub-categories except MMA sparring (BF_{10} = 30 – 198,061), which in turn was greater than all other categories except boxing sparring (BF_{10} = 11 – 5,536). In terms of relative external load of sparring sub-categories (BF_{10} = 1.112^{e+12}, ω^2 = .41), however, kickboxing sparring was found to produce greater loads than all other sub-categories except boxing and MMA (BF_{10} = 171 – 2.611^{e+7}). BJJ sparring was the least load inducing (BF_{10} = 186 – 5.344^{e+7}). MMA sparring relative external load was greater than wrestling, BJJ and BJJ with strikes respectively (BF_{10} = 216 – 293).

Table 6.1 – Descriptive data for external load of sub-categories (mean±SD)

Categories and Sub-categories		PLd_{ACC} (AU)	$PLd_{ACC}\cdot min^{-1}$ (AU)
Striking drills [a b]	**Boxing**	66.1 ± 41.3	5.4 ± 2.5
	Kickboxing	122.7 ± 89.7	4.9 ± 1.6
	With takedowns/sprawls	34.8 ± 12.1	9 ± 2.8
Wrestling drills [c]	**Open space**	72.6 ± 57.4	4.7 ± 1.2
	Against wall	36.7 ± 25.3	4.7 ± 1.8
	With strikes	93.9 ± 57.3	5.7 ± 1.6
BJJ drills [d]	**Positional**	81.9 ± 52.6	3.2 ± 0.9
	Submission	30 ± 17.4	1.8 ± 0.5
Sparring [a b]	**Boxing**	131.2 ± 14.6	6.1 ± 1
	Kickboxing	69.2 ± 46.7	7.7 ± 2
	BJJ	69.4 ± 45.2	4.1 ± 1.2
	BJJ with strikes	66.3 ± 30.2	5.5 ± 0.9
	Wrestling	57.3 ± 30.5	5.6 ± 1.5
	MMA	125 ± 58.8	7.3 ± 1.6

Nb. PLd_{ACC} = accumulated Playerload; $PLd_{ACC}\cdot min^{-1}$ = accumulated Playerload per minute; a = decisive differences in PLd_{ACC} between sub categories; b = decisive differences in $PLd_{ACC}\cdot min^{-1}$ between sub categories; c = moderate differences in PLd_{ACC} between sub categories; d = moderate differences in $PLd_{ACC}\cdot min^{-1}$ between sub categories.

6.4.4 Relationships between external load and internal load

Correlations between absolute internal and external loads can be viewed in Figure 6.4. All drill and sparring category correlations were moderate to large, with the exception of both BJJ categories which each displayed lower boundaries below the small threshold. Similarly, warm-up and session overall correlations are small-to-moderate only. The data also supported predictive relationships between PLd_{ACC} and segRPE/sRPE in all categories (Table 6.2), though this support was only moderate-to-strong for warm-up and BJJ drills.

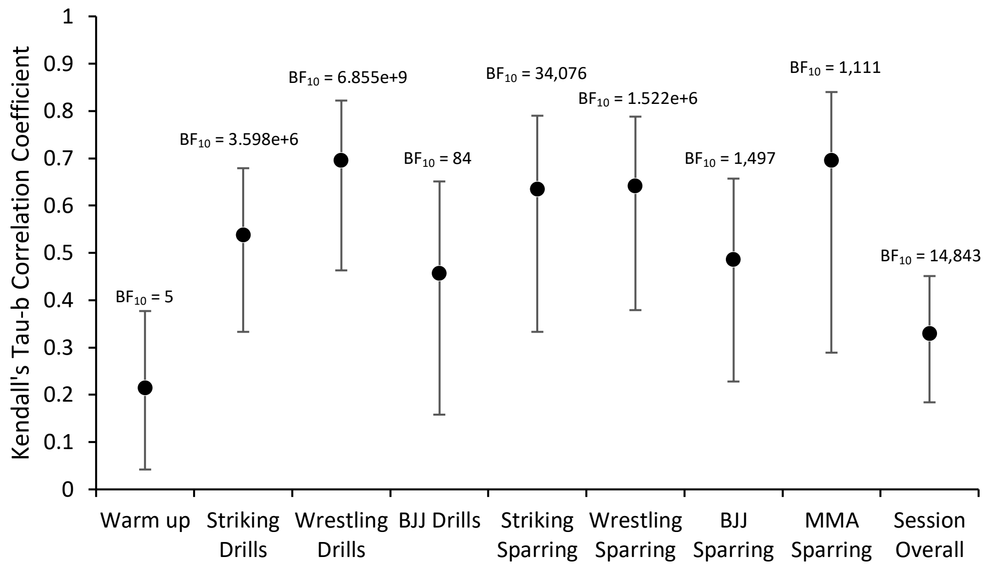

Figure 6.4 – Kendall's Tau-b correlations between MMA absolute internal load (segRPE/sRPE) and absolute external load (PLd_{ACC}). *Nb. Individual training categories display Tau-b between PLd_{ACC} and segRPE; session overall displays Tau-b between PLd_{ACC} and sRPE. Error bars = 95% credible intervals.*

Table 6.2 – Bayesian regression parameters for estimating MMA absolute external load (PLd_{ACC}) from absolute perceived internal load (segRPE/sRPE)

Category	Intercept (b_0)	Regression coefficient (b_1)	BF_{10}	R^2
Warm up	43.983	0.555	18	.167
Striking drills	114.875	0.639	3.063^{e+6}	.497
Wrestling drills	103.554	0.853	7.324^{e+11}	.738
BJJ drills	93.44	0.331	7	.272
Striking sparring	82.734	0.69	4,389	.560
Wrestling Sparring	57.296	0.563	8.656^{e+8}	.746
BJJ sparring	84.855	0.44	4,982	.491
MMA sparring	124.997	0.984	6,901	.772
Session overall	310.631	0.191	67	.129

Nb. Individual categories display predictive relationships between PLd_{ACC} and segRPE; Session overall displays predictive relationship between PLd_{ACC} and sRPE.

Correlations between absolute external training load and training duration (Figure 6.5) were also mostly moderate-to-strong. The exceptions again were BJJ related categories (lower bounds below the small threshold), warm up and session overall (both small-to-moderate). In terms of predictive relationships, BJJ drills was the only category to not have a better than anecdotal relationship between absolute external load and duration (Table 6.3). Analyses of relative external load and absolute internal load found only one statistical relationship, with the evidence for $PLd_{ACC}{\cdot}min^{-1}$ being a predictor of segRPE in MMA sparring being very strong (b_0 = 116.83, b_1 = 18.67, R^2 = .516, BF_{10} = 36).

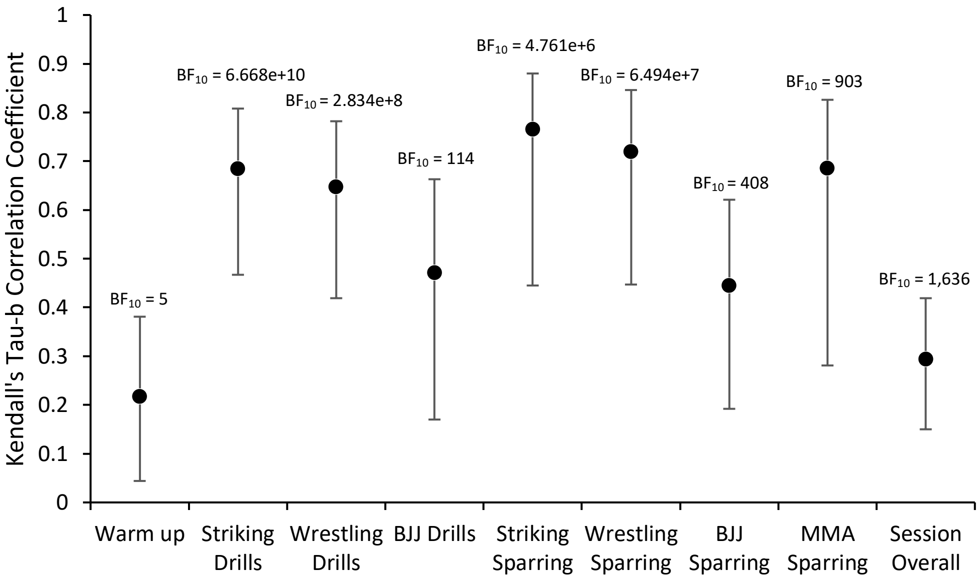

Figure 6.5 – Kendall's Tau-b correlations between MMA absolute external load (PLd_{ACC}) and training duration (mins). *Nb. Error bars = 95% credible intervals.*

Table 6.3 – Bayesian regression parameters for estimating MMA absolute external load (PLd_{ACC}) from duration (mins)

Category	Intercept (b_0)	Regression coefficient (b_1)	BF_{10}	R^2
Warm up	43.983	2.002	6	.126
Striking drills	114.875	3.331	8.834^{e+14}	.769
Wrestling drills	103.554	4.039	1.110^{e+10}	.684
BJJ drills*	93.440	0.622	1	.097
Striking sparring	82.734	5.610	2.403^{e+6}	.734
Wrestling Sparring	57.296	4.923	4.000^{e+12}	.846
BJJ sparring	84.855	1.974	169	.362
MMA sparring	124.997	8.168	38,381	.820
Session overall	310.631	2.090	1,255	.186

*Nb. * = Evidence for BJJ drills regression is anecdotal but shown for reference*

6.5 Discussion

The aim of this study was to quantify the external loads of MMA training practices that are used to prepare participants for competition, with a secondary aim of determining the relationship between external and internal loads of MMA training. The data demonstrate that external loads of MMA training categories are distinguishable via the recording of PLd_{ACC} from torso-mounted accelerometry. Similar to internal load data presented in Chapter 5, MMA training categories are distributed unevenly across the week, with low-moderate intensity, drill-based categories used more often earlier in the week. High intensity, sparring categories were used most on Thursdays and Fridays. Despite this, daily absolute external training load does not change across the week. The PLd_{ACC} of most training categories have moderate–very large predictive relationships to internal load. The exception to this is in BJJ related categories and session overall, both of which display small-to-moderate predictive relationships only. $PLd_{ACC}\cdot min^{-1}$ was only moderately related to segRPE in MMA sparring. These relationships demonstrate the PLd_{ACC}-segRPE model of training load monitoring may be appropriate for use during MMA competition preparation, but potentially only in absolute terms.

Reflecting the analyses of internal load in Chapter 5, MMA training categories are distinguishable by accelerometer derived external load. PLd_{ACC} has been used to quantify external load in a range of sports (Bredt et al., 2020; McLaren et al., 2018; Svilar et al., 2018), including combat sports (Finlay et al., 2018; Kirk et al., 2015a; Worsey et al., 2019). Previous work has demonstrated different MMA actions result in different instantaneous Playerload (Kirk et al., 2015b), likely due to the varying kinematic characteristics of each movement (McGill et al., 2010). It was expected, therefore, that absolute external load would differ between training categories. PLd_{ACC} research in most sports tends to be concerned with the effects of ambulatory movement on changes in accelerations owing to these being the primary types of actions occurring in these events (McLaren et al., 2018; Nedergaard et al., 2017). The complex nature of MMA, however, requires equal consideration of the effects of ambulatory, non-ambulatory, physical impact and opponent mass bearing on external load (Kirk, 2018a). The data presented here demonstrate that non-ambulatory categories such as BJJ drills produce comparable PLd_{ACC} to ambulatory and impact inducing categories including striking drills and wrestling drills. This occurs despite BJJ drills being the least intense in terms of $PLd_{ACC} \cdot min^{-1}$ and results from this category having the greatest duration of training time dedicated to it. The second greatest duration of training time was afforded to striking drills, which conversely produced the most intensive external load amongst drill categories and was equal to the external load intensity of wrestling sparring. This is further evidence that as far as drill categories are concerned, MMA coach preconceptions about the relative intensities of training modes may be inaccurate. Underestimating the relative external load of striking drills and the absolute external load of BJJ drills appears to lead to an overuse of these categories across the week. Similar to the internal load data reported in Chapter 5 and replicated here, this leads to a flat loading pattern and an absence of load undulation, despite attempts to train the most intense categories later in the week.

The data reported here also provides evidence of which sub-categories are more and less intense in terms of external load. BJJ sparring with strikes may be equal external load intensity to wrestling sparring, whilst including takedowns/sprawls in striking drills may increase the external load intensity of these drills almost two-fold. There is little evidence in these data, however, that these differences between sub-categories are accounted for in terms of duration, or their effect on overall session training load. As such, coaches may use the PLd_{ACC}-segRPE model detailed here to plan microcycles based on technical and tactical requirements alongside physiological requirements (Farrow and Robertson, 2017). Use of this model may allow a more appropriate within week loading pattern to be applied. Between weeks training load may also be adapted to allow overreaching and restitution weeks to occur and for tapering to be more effectively applied (Turner, 2011). For example, a high load week may consist of more instances of wrestling or sparring categories with fewer drill-based categories trained. Conversely, a low load week may only include drill-based categories and BJJ sparring without strikes. For this to be achieved, however, coaches will need to record the internal and external loads of their athletes across several weeks to quantify their own loads and responses to the training methods employed (Bourdon et al., 2017). In lieu of being able to collect individual external load data, coaches may use the category intensities reported here to estimate which categories should be prioritised in terms of duration for their athlete's specific technical development, whilst simultaneously planning the distribution of their training intensity more appropriately (Farrow and Robertson, 2017; Jeffries et al., 2021).

Effective use of internal and external load markers in applied settings requires a dose-response relationship between the proposed measures (Impellizzeri et al., 2018; Jeffries et al., 2021). The predictive relationship between internal and external load for session overall was found to be small-to-moderate only, which contrasts to studies in ambulatory sports reporting r > .77 between sRPE and PLd_{ACC} (Scott et al., 2013; Svilar et al., 2018). PLd_{ACC} being directly indicative of the amount of active movement time in MMA (Kirk et al., 2020a) may explain this result. To allow analysis of the full training sessions all rest periods were included, without any differentiation between static time and movement time within or between drills. The intermittent nature of drill-based coaching sessions means less active movement time will occur. This reduces changes in acceleration as measured by PLd_{ACC}, but not necessarily in internal load as measured by sRPE/segRPE. This finding mirrors association football matches, where PLd_{ACC} and sRPE display a large correlation (r = .79) when sRPE is calculated from the number of minutes played, but reduces (r = .55) when total duration of the match is used (Pustina et al., 2017). As each full session contained multiple incidences where participants were being coached or taking on fluids without movement, this likely reduced accelerometry external load but not perceived internal load, causing reductions in correlations for the session overall.

As training loads were found to differ between categories, so too did the strengths of the predictive relationships between internal and external load for each category. BJJ related categories and striking drills all had moderate relationships between segRPE and PLd_{ACC}, with all other categories being large. Similarly, in team sports, skill-based training displays a reduced relationship between internal load and accelerometer derived external load in comparison to open or mixed mode training (McLaren et al., 2018). The difference in correlations between MMA categories may be caused by altered ambulatory requirements between training modes. Repeated foot-ground contacts increase accelerometer readings due to ground reaction forces acting on the torso and the unit individually (Edwards et al., 2018). This may particularly be the case for actions of greater intensity or velocity (Barreira et al., 2017; McLean et al., 2018), potentially explaining the differences between striking drills and striking sparring. Though both categories include foot-ground contacts, striking drills are performed at a lower intensity (Chapter 5) leading to lower PLd_{ACC}. Due to perceived exertion being influenced by multiple factors including mental and psychobiological strain (Robertson and Noble, 1997), reducing ambulatory movement and intensity would not necessarily affect segRPE/sRPE in the same manner as it does PLd_{ACC}. Therefore, despite similar PLd_{ACC}-segRPE correlations observed across striking drills and BJJ related categories, these relationships likely result from different interactions between variables. BJJ drills segRPE were the highest amongst drill categories, but with similar durations between each. BJJ drills PLd_{ACC} was, however, the lowest amongst drill categories. Striking drills show the opposite pattern, with high PLd_{ACC} but low segRPE. Similarly, both BJJ sparring and striking sparring have comparable PLd_{ACC}, but BJJ sparring results in greater segRPE with a weaker predictive relationship to external load than seen in striking sparring. Therefore, internal load of BJJ related categories appear to be more affected by isometric contractions and physical bearing of opponent mass rather than changes in acceleration. Added to this would be the mental strain of skill learning which also cannot be measured by accelerometry but would still contribute to RPE (Farrow and Robertson, 2017). These different contributions to training load seen in these data further reinforces the need for multiple, complimentary measures in practice (Halson, 2014).

Increases in impulse during ambulatory movements result in greater PLd_{ACC} with concomitant increases in perceived intensity (Barreira et al., 2017; McLean et al., 2018). During ground-based grappling exchanges, however, this direct relationship between movement and intensity likely only occurs when the training partner is not providing resistance or pressure, as would be the case during BJJ drills. Opponent resistance during BJJ sparring potentially increases RPE without any changes in movement, hence the absence of a relationship in this category. The ambulatory movements and training partner pressure present in other categories may also mask any influence Pld_{ACC} or $PLd_{ACC}{\cdot}min^{-1}$ has on RPE in these instances. Absolute external load having comparable relationships to both internal load and training duration requires further investigation to determine whether PLd_{ACC} is reflective of the absolute intensity of the task, or simply time on task. These data were collected in live training sessions without intervention. Coach preconceptions of which training modes are more intense may limit the durations of these categories to avoid athlete fatigue. This may cause absolute external load of more intense categories to be masked within the data due to shorter durations. It may also be that relationships between PLd_{ACC} and segRPE/sRPE only present due to mathematical coupling caused by the shared variable of duration (Archie Jr, 1981). This has been highlighted as a potential confound for training load research in general (McLaren et al., 2018). The aforementioned nearly perfect relationship between PLd_{ACC} and total active time but not inactive time in MMA sparring (Kirk et al., 2020a), alongside the differences between categories in the current study, suggests movement intensity is somewhat reflected by PLd_{ACC}. Unfortunately, the relative contributions of intensity and duration to PLd_{ACC} cannot be elucidated from these data. If PLd_{ACC} is more reliant on duration, it may still be an acceptable global indicator of overall work completed, but may not be predictive of the differing internal responses to sessions of greater/lesser intensities (Seiler, 2010). The influence of duration on PLd_{ACC}, therefore, needs to be determined by future duration matched studies before this variable can be fully supported for applied use in MMA training.

In summary, this study quantifies the external loads of MMA training practices for the first time. MMA training categories and sub-categories are distinguishable in terms of overall external load and intensity as measured by PLd_{ACC} and $PLd_{ACC}\cdot min^{-1}$ respectively. Despite this, there is an absence of changes in external load within or between weeks, reflecting the internal load findings reported in Chapter 5. This provides further support for the suggestion that coaches underestimate the intensity and resulting loads of drill categories in relation to sparring categories, leading to a flat loading pattern across the week. The predictive relationships reported provide support for a model of PLd_{ACC} in combination with sRPE/segRPE to monitor and plan the training loads of MMA participants preparing for competition. PLd_{ACC} has a moderate-to-large predictive relationship with segRPE/sRPE for most MMA training categories. BJJ related categories only display a moderate relationship between these variables, likely due to isometric contractions and opponent mass bearing not being measured by accelerometry, but still contributing to RPE and therefore load. It is recommended for MMA coaches to work with researchers to determine their athletes PLd_{ACC}-segRPE relationships and develop predictive equations to plan training content, intensity and duration in advance, enabling weeks of overload and restitution to be planned in keeping with current training recommendations (Jeffries et al., 2021; Kellmann et al., 2018; Turner, 2011).

6.6 Chapter Summary

- The external loads of MMA training categories are distinguishable via the recording of PLd_{ACC} from torso-mounted accelerometry.
- The within week external load of MMA training sessions does not change between days with the exception of relative external load as measured using $PLd_{ACC} \cdot min^{-1}$. This, however, only changed in one of the two weeks observed.
- External load as measured via PLd_{ACC} has moderate-large predictive relationships with internal load as measured by segRPE, with the exception of BJJ related categories which are small-moderate due to non-ambulatory and isometric actions not being measured by accelerometry. Coaches may work with researchers to develop predictive training load equations to assist training planning for their specific athletes.
- The physiological responses to MMA training practices are currently unknown and are explored in Chapter 7.

End of Study 3 Thesis Map

Study Aim	Study Type	Objectives	Outcomes
Study 1 – Chapter 3 **Thesis Objective 1** **Study Aim** Explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition	**ARMSS Stage 1: Defining the problem** Qualitative semi-structured interviews	1. Interview professional MMA coaches to explore their training and coaching backgrounds, and how they developed as MMA coaches 2. Explore the structure, aims and focus of MMA coaches practice in preparing participants for competition 3. Explore how MMA coaches attempt to monitor the load-fatigue-adaptation cycle of the participants preparing for competition within their practice.	1. MMA coaches developed via experience and peer learning. Peer learning reduces when they become club owners 2. Sessions must cater both to competitive athletes and recreational participants simultaneously. 3. Training practices are led by folk pedagogy potentially underpinned by pseudoscience with minimal evidence of objective monitoring of athlete load-fatigue-adaptation.
Study 2 – Chapter 5 **Thesis Objective: 2** **Study Aim** Quantify the internal loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the durations, intensities and internal loads of MMA training categories 2. Record subjective fatigue and soreness response of MMA athletes in relation to these internal loads 3. Determine the intensity and load distribution of MMA training sessions and categories 4. Determine any changes in load, fatigue or soreness when MMA athletes are preparing for competition	1. MMA training does not appear to be periodised between or within weekly microcycles. 2. Pre-competition tapers are stepwise 1 week prior to a bout, leading to no reductions in fatigue markers 3. Each MMA training category may be distinguished by intensity and internal load, with 20% of training time spent at high intensity.
Study 3 – Chapter 6 **Thesis Objective: 2** **Study Aim** Quantify the external loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the external loads of MMA training categories 2. Determine the relationship between external and internal loads in MMA training. 3. Determine the distribution of external loads of MMA training categories	1. External loads of MMA training categories are distinguishable using torso-mounted accelerometry. 2. Within week external load of MMA training sessions does not change between days with the exception of relative external load. This, however, only changed in one of the two weeks observed. 3. External load has moderate-large predictive relationships with internal load, with the exception of BJJ related categories which are small-moderate due to non-ambulatory actions not being measured by accelerometry.
Study 4 – Chapter 7 **Thesis Objective: 3** **Study Aim** Determine the physiological adaptations and changes in body composition that arise from completing a typical 6-8 week MMA training period that is used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative laboratory data collection without intervention	1. Record physiological and body composition data of a group of international standard MMA athletes prior to commencing training for competition 2. Record the same physiological and body composition variables upon completion of the training period but prior to pre-competition RWL. 3. Determine the effects of a pre-competition training period on MMA athlete's physiological capabilities and body composition	
Study 5 – Chapter 8 **Thesis Objective: 4** **Study Aim** Examine the effects of a supplementary high-intensity aerobic training intervention (completed alongside traditional MMA training practices) on aerobic capacity and indices of competition specific performance	**ARMSS Stage 3: Predictors of performance** Quantitative field and laboratory data collection with training intervention	1. Apply a cardiovascular training intervention to MMA athlete's regular technical-tactical training 2. Determine the effects of training intervention on physiological and body composition measures collected in laboratory 3. Determine the effects of training intervention on bout pacing as measured via body worn accelerometry in simulated competition	

Chapter 7 - Study 4: The Effects of an MMA Training Camp on Athlete Physiology and Body Composition

7.1 Chapter Rationale

Chapters 5 and 6 demonstrated that MMA training displays a flat loading pattern that does not follow recognised periodisation theory. This was shown to be the case for those athletes preparing for competition and those who are not. Chapter 3 provided evidence that MMA coaches do not view maximising physiological performance as one of their roles, preferring their athletes to complete S&C training in their own time, with sparring performed within technical/tactical sessions perceived as being sufficient to improve 'sharpness' and sports specific fitness. It is currently unknown, however, whether this approach provides adequate stimuli for positive physiological adaptations. This may also be influenced by the BM manipulation processes completed by MMA participants leading into competition. In order to provide training recommendations for this population, the effects of their current training practices must first be understood. Therefore, the aim of this study was to determine the physiological and body composition adaptations of a cohort of MMA participants in response to their regular pre-competition training practices without intervention.

ARMSS Stage: 2 – Descriptive research

7.2 Introduction

Preparation for competition in combat sports is often centred on the concept of a 'training camp', whereby training will become more focussed on a set of specific outcome goals related to that contest (Jukic et al., 2017; Tomazin et al., 2021). The coaches interviewed in Chapter 3 discussed the preferred length of an MMA training camp to be eight - twelve weeks. This timeframe is in keeping with training camps reported in existing literature (Jukic et al., 2017; D. Lovell et al., 2013) as well as the time suggested for improvement of specific biomotor abilities such as force production and cardiorespiratory endurance (Harvey, 2018; Mikeska, 2014). The coaches also stated, however, that the main aims of the MMA training camp were for the participant to achieve the BM required for their desired competitive division, and attainment of 'sharpness' without reference to specific components of athletic fitness. In relation to the structure of a training camp, Chapter 5 demonstrated that MMA training is characterised by a flat loading pattern and an abrupt step taper prior to competition. This does not differ between those participants who are in training camp, and those who are not.

MMA competition is typified by repeated, high impulse actions for a maximum of 9-25 mins (Chapter 2). Trained athletes are capable of greater impulse and rate of force development (RFD) than untrained participants, with these advantages being due to a combination of increased strength and positive neural adaptations (Aagaard et al., 2002; Rodriguez-Rosell et al., 2018; Tillin et al., 2010). Athletes displaying greater impulse and/or RFD will be capable of producing more forceful actions in the initial 100-250 ms of muscle contraction, enabling more successful dynamic sports performance (Aagaard et al., 2002; DeWeese et al., 2015; Maffiuletti et al., 2016; Suchomel et al., 2015). This effect may discriminate between more and less successful MMA competitors (James et al., 2020, 2017a) due to the transference of high RFD from the ground into the opponent during combat sport specific actions (Lenetsky et al., 2013; Ruddock et al., 2016; Turner, 2009). Given the potential duration and intensity of a bout (Kirk et al., 2015a; Petersen and Lindsay, 2020) competitors would also require sufficient aerobic capacity to ensure adequate resynthesis of energy substrates capable of supporting repeat high-intensity efforts (Campos et al., 2012; Crisafulli et al., 2009; Rodrigues-Krause et al., 2020). It would therefore be important for force, impulse and aerobic adaptations to be maximised during an MMA training camp.

Extreme BM manipulation is nearly ubiquitous during MMA competition preparation (Coswig et al., 2018; Kirk et al., 2020b; Matthews and Nicholas, 2017; Murugappan et al., 2021). The energy and fluid restriction methods employed may result in suboptimal or negative training adaptations and reduced physical performance (Barley et al., 2017; Burke et al., 2021; Soolaman et al., 2017; Zubac et al., 2019). These effects may result from the large reductions in fat free mass (FFM) that occur concurrently to the losses of fat mass (FM) (Kasper et al., 2018), and may also impede positive training adaptations as a whole. The negative effects of BM manipulation on strength and anaerobic capacity may be minimised if a structured strength and conditioning (S&C) program is followed and BM reduction is < 5% (Lovell et al., 2013). MMA athletes, however, regularly reduce BM by 8-12%

(Brechney et al., 2019; Kirk et al., 2020b) and Chapter 5 showed that the use of S&C in the form of resistance training and/or cardiorespiratory training is rare within this population.

To that end, it is currently unknown how a training camp effects the physiological performance of MMA competitors. Despite the training period observed in Chapter 5 not following a 'traditional' load-deload pattern (Turner, 2011), it is currently unknown whether or not this is optimal for MMA performance. It may be the case that the training partner mass bearing activities typical of technical/tactical sessions provide sufficient mechanical overload for muscular adaptations. The regular use of sparring may also provide stimulus for cardiorespiratory adaptations. Given the inadequate energy intake alongside the absence of training periodisation or supplementary S&C, however, it is also possible that the athletes involved would experience no, or possibly negative, physiological adaptations. Therefore, the aim of this study was to determine the body composition and physiological performance changes of a group of MMA athletes in response to a six-eight week competition training camp without intervention.

7.3 Methods

7.3.1 Participants

A cohort of nine competitive male MMA participants were recruited for this study (age = 24 ± 4 years; habitual BM = 76.6 ± 6.4 kg; stature = 177 ± 9 cm) following institutional ethical approval (H15/SPS/32). Of this group, five were full time, international standard (UFC, Bellator and Cage Warriors) competitors preparing for professional bouts. The remaining four were international standard amateurs preparing to compete in the IMMAF World Championships. Participants completed each of these procedures six-eight weeks prior to taking part in a competitive MMA bout. The same test order was then repeated one week prior to competition. Each of the participants were recruited from different clubs and regions of the UK, meaning it was not practically viable to record reliable training content or load data between the testing sessions.

7.3.2 Body Composition

Participant FM, FM% and FFM were estimated using dual x ray absorptiometry (DXA, Hologic Inc, USA). Measures were taken from the whole body minus the head by an IR(ME)R registered DXA operator in keeping with best practice protocol. Participants were instructed to refrain from food and fluid intake for 10 hours prior to commencement of testing, and to avoid strenuous training or activities for 12 hours prior (Nana et al., 2015). Laboratory derived CV for DXA measures are FM = 1.9%, FM% = 1.9% and FFM = 1% respectively (Langan-Evans et al., 2020). Participants were then permitted to drink water ad libitum before completing the treadmill based GXT to record $\dot{V}O_2$max as described in Chapter 4.

7.3.3 Physiological Components

Following completion of the GXT participants were given two hours to recover and consume food and water ad libitum before completing the following tests of impulse and maximal force. Participant impulse was estimated by proxy via a series of jump tests using Optojump (Microgate, ITALY). For each test jump height was automatically calculated from participant flight time via Optojump Next 1.12.15 (Microgate, ITALY) using (9.81*flight time^2)/8 (Bosco et al., 1983; Byrne et al., 2017). Participants first completed 3 squat jumps (SJ) with hands on hips, dipping to a knee flexion of ~110º, holding this position for ~2-3 s before jumping as high as possible. Participants then completed 3 countermovement jumps (CMJ) with their hands on hips, dipping to a knee flexion of ~110º and jumping as high as possible without pausing. Only jump height (cm) was recorded for CMJ and SJ. All jumps were interspersed with a 2 mins recovery period and the best score was recorded from each of the jump types. Each participant's eccentric utilisation ratio (EUR) was calculated in $cm \cdot cm^{-1}$ using best CMJ / best SJ. Finally, participants completed three drop jumps (DJ) with their hands on hips from a box height of 30 cm. Participants were instructed to step off the box and jump as high as possible upon contact with the ground, minimising knee flexion and ground contact time (GCT). DJ height (m) and GCT (s) were recorded and used to calculate reactive strength index (RSI) in m per second of GCT ($m \cdot s_{GCT}^{-1}$) using DJ height / GCT. All jumps were interspersed with a 2 mins recovery period and each participant's best jump was chosen by identifying their greatest RSI result of the 3 DJs. Optojump has previously been reported to be reliable (ICC > .97) for calculation of jump height and GCT (Byrne et al., 2017). Laboratory derived measures of reliability for each variable were calculated for pre and post measures as follows: SJ $ICC_{(3,1)}$ = .945 - 986, CV = 1 - 2%; CMJ $ICC_{(3,1)}$ = .751 - .989, CV = 2 - 3%; DJ $ICC_{(3,1)}$ = .802 - .962, CV = 3 - 7%; GCT $ICC_{(3,1)}$ = .853 - 899, CV = 4 - 9%.

Maximal dynamic force was measured via 1 repetition maximum (1RM) testing for back squat, bench press and prone bench row. For each exercise, participants performed a readiness set of 10 repetitions with a 20 kg Olympic standard barbell followed by 10 repetitions at 50%, 5 repetitions at 75% and 1-2 repetitions at 90% of their predicted 1RM. All subsequent 1RM attempts were interspersed with 2 mins recovery. The load on the bar was exponentially increased on each attempt until failure occurred. Maximal isometric force was measured using a isometric midthigh pull via a digital dynamometer strain gauge (Takei, JAPAN) which has been found to have test-retest reliability of r = .8 - .91 (Coldwells et al., 1994) and CV = 5.5% (Sawczuk et al., 2018). Participants performed three repetitions with 2 mins recovery between each. The highest force recorded in kg was taken as their result. Laboratory derived reliability for this test was calculated pre and post as $ICC_{(3,1)}$ = .920 - .991, CV = 2 - 4%.

7.3.4 Statistical Analyses

Statistical inference was determined following the procedures established in Chapter 4. Parametric variables were compared between pre and post measures using Bayesian paired samples t-tests with a JZS Cauchy prior = .707 at location parameter = 0 and Cohen's d using the standard deviation of the mean scores as the denominator for the effect size. Non-parametric variables were compared between pre and post measures using Bayesian Wilcoxon signed-rank tests with rank-biserial correlation (R_x) as the effect size (Cureton, 1956). Inference thresholds may be viewed in Chapter 4.

7.4 Results

7.4.1 Body Composition

Figure 7.1 displays the observed changes in BM, FFM, FM and FM% pre and post training camp. Analyses strongly supported BM reducing with a large effect during the training camp (BF_{10} =

29, d = 1.3). FM (BF_{10} = 10, d = 1.1) and FM% (BF_{10} = 10, d = 1.1) both strongly displayed moderate reductions. Moderate reductions in FFM also occurred, but this result was only moderately supported by the data (BF_{10} = 9, d = 1).

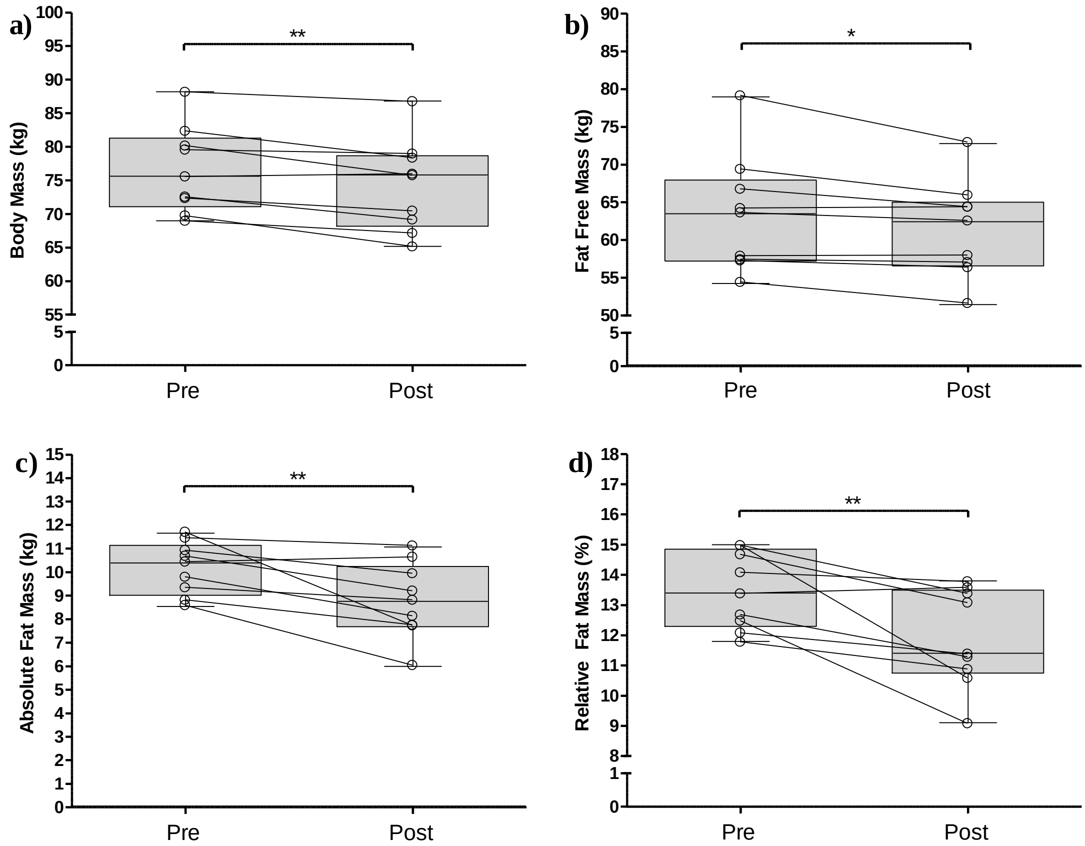

Figure 7.1 – Median [IQR] body composition changes in response to MMA training camp. a) Body mass (kg); b) Fat free mass (kg); c) Fat mass (kg); d) Fat mass (%). *Nb. * = data moderately support reductions post training camp; ** = data strongly support reductions post training camp; joined circles represent individual participant change*

7.4.2 Physiological Components

Pre and post training camp physiological performance data can be viewed in Figure 7.2 for force production variables, Figure 7.3 for jump variables and Figure 7.4 for $\dot{V}O_2max$. The isometric midthigh pull was the only force variable to display improvements, though this was a moderate effect that was only moderately supported by the data (BF_{10} = 4, d = .83). The data moderately supported the null hypothesis that SJ (BF_{01} = 4, d = .17), CMJ (BF_{01} = 6, R_x = .467), RSI (BF_{01} = 4, d = .06) and EUR (BF_{01} = 5, d = .3) did not improve in response to an MMA training camp. No other force related variables displayed any statistically relevant responses. Similarly, there were no statistically relevant change in either relative or absolute $\dot{V}O_2max$ following an MMA training camp.

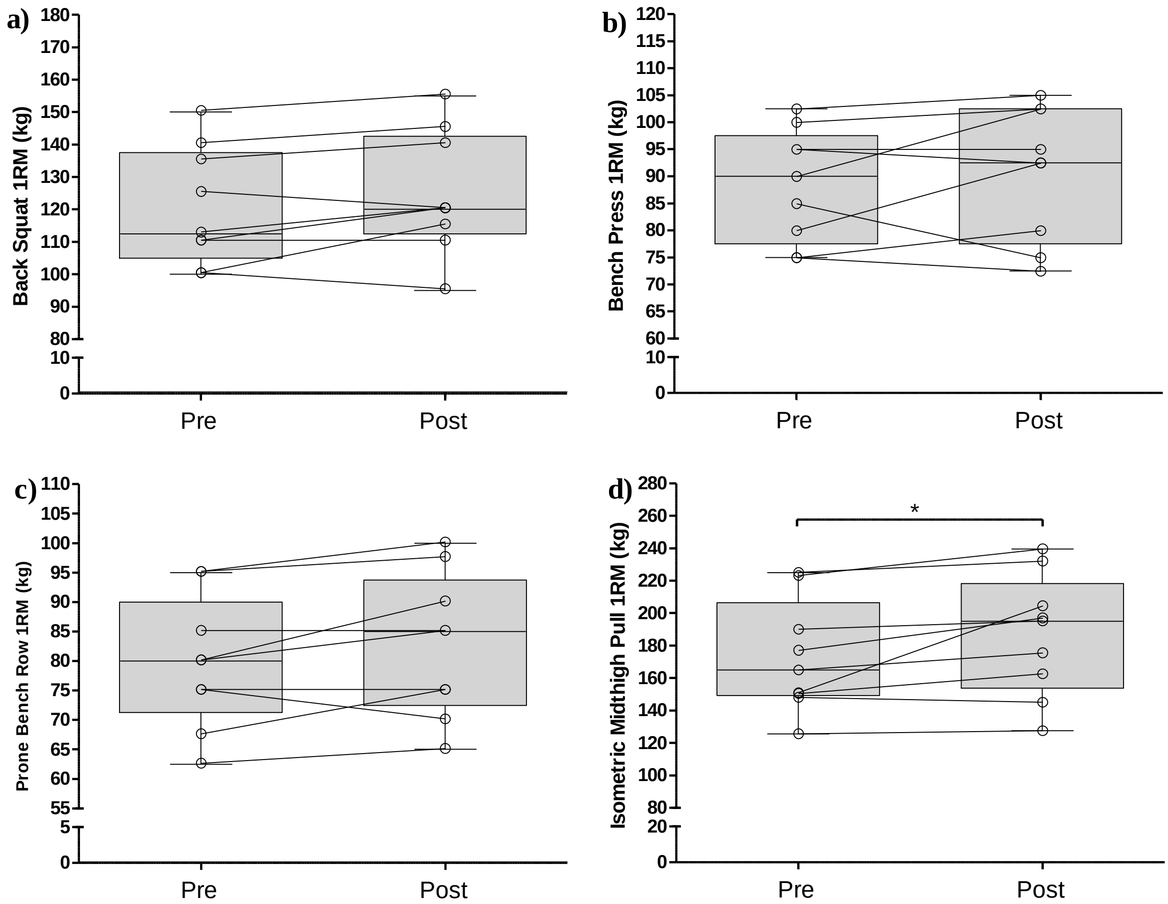

Figure 7.2 – Median [IQR] maximal force production changes in response to MMA training camp. a) Back squat 1RM (kg); b) Bench press 1RM (kg); c) Prone bench row 1RM (kg); d) Isometric midthigh pull 1RM (kg). *Nb. * = data moderately support increases post training camp; joined circles represent individual participant change;1RM = one repetition maximum*

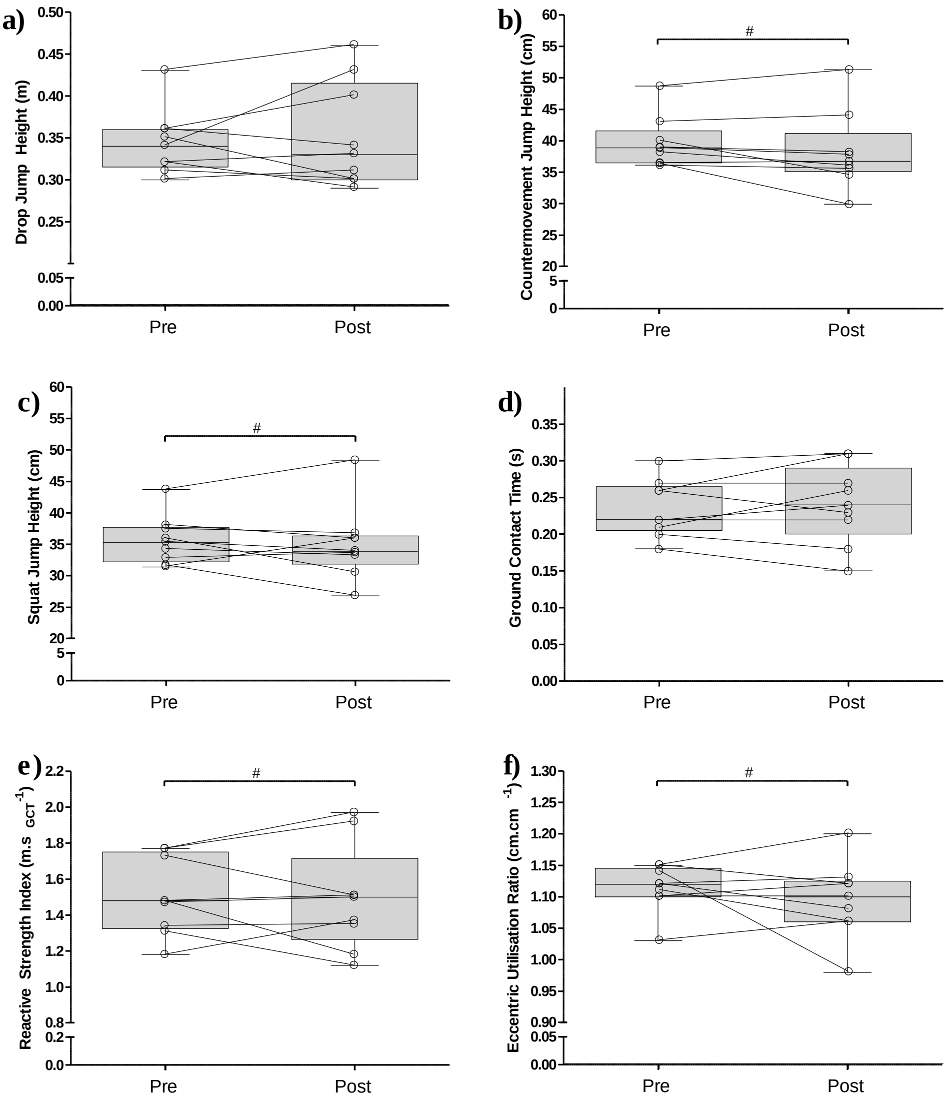

Figure 7.3 – Median [IQR] jump variable changes in response to an MMA training camp. a) Drop jump height (m); b) Countermovement jump height (cm); c) Squat jump height (cm); d) Ground contact time (s); e) Eccentric utilisation ratio (cm·cm^{-1}); f) Reactive strength index (m·s$_{GCT}^{-1}$). *Nb. # = data moderately support null hypothesis of no changes post training camp; joined circles represent individual participant change; m·s$_{GCT}^{-1}$ = metres per second of ground contact time*

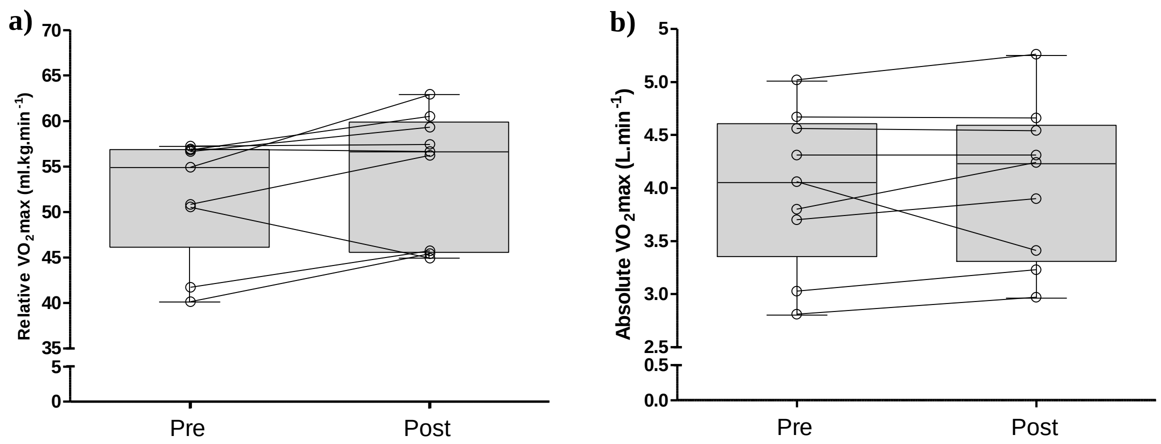

Figure 7.4 – Median [IQR] $\dot{V}O_2$max responses to an MMA training camp, a) Relative $\dot{V}O_2$max, b) Absolute $\dot{V}O_2$max

Nb. $\dot{V}O_2$max = maximal aerobic capacity; joined circles represent individual participant change; ml·kg·min^{-1} = millilitres per kilogram of body mass per minute; L·min^{-1} = litres per minute

7.5 Discussion

The aim of this study was to determine the effects of an MMA training camp on measures of body composition and physiological performance. To achieve this, a cohort of professional and international amateur MMA athletes took part in a laboratory test battery six-eight weeks before, and again one week prior to competition. The results demonstrate that MMA competitor's body composition changes during this period, predominantly due to reductions in FM with smaller reductions in FFM. Conversely, there were no changes in any marker of physiological performance with the exception of moderate increases in isometric midthigh pull force.

Body composition manipulation was revealed to be a key aim of training camp by each of the coaches interviewed in Chapter 3. This is achieved via 'weight cutting' (Murugappan et al., 2021) to attempt to achieve a morphological size advantage over the opponent (Brechney et al., 2019; Kirk et al., 2020b). As such, it is not surprising that BM and FM reduced during the observation period. Indeed, the observed ~3% (~2.4 kg) BM reduction is in keeping with the pattern of chronic 'weight' loss (CWL) (Reale et al., 2017) generally experienced up to the week before competition (Kasper et al., 2018; Park et al., 2019). It is also less than the ~8-16 kg of total BM reduction documented amongst MMA competitors (Brechney et al., 2019; Kirk et al., 2020b; Murugappan et al., 2021), suggesting that this cohort was yet to begin acute 'weight' loss (AWL) and/or rapid 'weight' loss (RWL) (Kasper et al., 2018; Reale et al., 2018, 2017). Pre training camp FM, whilst lower than reported in other MMA studies (Alm and Yu, 2013; Marinho et al., 2016), was within the FM range of competitive athletes from team, individual, contact and non-contact competitive sports (Malina, 2007; Santos et al., 2014). Attempting BM manipulation by mostly reducing FM may therefore be appropriate and safe (Langan-Evans et al., 2020). This cohort, however, also displayed FFM losses of 2% (1 ± 1 kg). Surveys demonstrate that MMA participants predominantly attempt FM loss via reduced energy intake and increased energy expenditure during training camp (Barley et al., 2018; Park et al., 2019). Whilst the energy intake of this group was not recorded, MMA athletes have been reported to reduce their energy and macronutrient intake far below the levels required to avoid maladaptive responses (Burke et al., 2021; Coswig et al., 2018; Kasper et al., 2018). Such FFM reductions may therefore indicate this cohort engaged in dietary and training practices that did not support optimal body composition adaptations while maintaining and/or improving physical performance capacity. Given the high impulse requirements of competition (James et al., 2017a), it would be desirable for athletes to maintain as much functional mass as possible. Instead, these results demonstrate MMA competitors are losing a statistically relevant amount of FFM even prior to engaging in the most extreme stage of BM reduction. The body composition changes observed are therefore indicative of practices that may not be suitable for athlete preparation.

This potentially suboptimal provision is also evidenced by the physiological performance measures. Only one of the recorded variables demonstrated improvements during the training camp, with the data supporting the null hypothesis of no change in three others. Regarding specific S&C training, the coaches in Chapter 3 preferred their athletes to organise and undertake this in their own time, focussing MMA training time on improving 'sharpness'. Chapter 5, however, demonstrated that MMA participants do not tend to take part in any form of supplementary training outside of their technical/tactical sessions. As such, it would not be expected for any improvement in force related biomotor abilities to occur (DeWeese et al., 2015; Stone et al., 2000). Consequently, this cohort had poor upper and lower body strength compared to most other sports (McGuigan, 2016). This group was also found to be weaker than competitors from related combat sports such as wrestling (Schmidt et al., 2005), judo (Franchini et al., 2011, 2007) and BJJ (Marinho et al., 2016) both before and after the training camp. The only variable in which the MMA cohort was stronger than other combat sport athletes was the back squat, and only in comparison to BJJ (Marinho et al., 2016; Ovretveit and Tøien, 2018) and taekwondo (Bridge et al., 2014). These differences may be due to taekwondo success being more dependent on movement velocity rather than maximal force, and BJJ being predominantly a non-ambulatory sport, rather than appropriate training on the part of MMA participants. Whilst MMA athletes occasionally take part in brief periods of circuit training during their technical/tactical sessions (Chapter 5), this type of training does not provide sufficient mechanical muscle strain to stimulate strength adaptations (Aagaard, 2011; DeWeese et al., 2015; Kostikiadis et al., 2018). Equally, given the regularity with which these types of training are applied to MMA participants (Chapter 5), any potential neuromuscular adaptations in response to such stimuli may have already occurred in the current cohort. This absence of any further muscular overload during MMA training camps would therefore explain the lack of improvements seen here (Aagaard, 2011; Stone and Stone, 2011). Isometric midthigh pull force being the only strength related variable to improve may be related to the lower torso isometric muscle actions common to grappling training (Gracie and Danaher, 2003). Given the potential for isometric muscle actions to improve strength at specific and irregular joint angles (Lum and Barbosa, 2019), this result may support the use of grappling drills within technical/tactical training to achieve some strength improvements. Without details of the specific training actions undertaken in terms of volume, intensity and duration in relation to this measure, this outcome requires further study under controlled conditions.

It is possible for training to improve impulse and RFD without concomitant strength increases owing to improved neural drive, motor unit activation and synchronisation (Tillin et al., 2010). MMA athletes with greater impulse may be more successful in competition (James et al., 2017a) likely due to high impulse actions being decisive in MMA bouts (Del Vecchio et al., 2011; Kirk, 2018a). Additionally, improved CMJ and SJ performance has been related to increased punch force (Loturco et al., 2016) and increased activity in boxing (Rimkus et al., 2019) due to jump performance being dependent on RFD (McLellan et al., 2011). The cohort observed here, however, did not show improved jump variables, meaning their impulse or RFD did not improve during the six-eight weeks. In comparison to other combat sports, the participants here produced jumps heights similar to boxers (Rimkus et al., 2019), and elite wrestlers (Bayraktar and Koc, 2017), but inferior to those produced by judo, karate and taekwondo athletes (Tabben et al., 2014). Such comparisons to other combat sport athletes across a spectrum of performance standards demonstrate that MMA technical/tactical training is unlikely to be providing sufficient stimulus to cause enhanced neural adaptations in the absence of increased maximal force (Maffiuletti et al., 2016). Whilst there is no evidence that maximal strength is a determining factor in MMA performance, increased force production is related to increased impulse and RFD (Blazevich et al., 2020; Suchomel et al., 2016). Training to improve strength and RFD may be achieved concurrently via heavy resistance training conducted at higher movement velocities or with the intent to move at higher velocities (Aagaard et al., 2002; Blazevich et al., 2020; Rodriguez-Rosell et al., 2018). Incorporating heavy resistance training via core, structural and power exercises alongside plyometric movements in a periodised format would therefore be a key recommendation for MMA athletes during and in preparation for training camp (Aagaard, 2011; Stone and Stone, 2011; Suchomel et al., 2016, 2015).

Similar to the absence of changes in force production, there were no improvements in $\dot{V}O_2max$ during the training camp. Both pre and post camp the participants displayed aerobic capacities towards the middle of the range reported previously in this population (Alm and Yu, 2013; de Oliveira et al., 2015; Kostikiadis et al., 2018; Schick et al., 2010). This would place these participants on the suggested threshold between 'recreationally trained' and 'trained' (De Pauw et al., 2013). Aerobic contributions to energy production during other combat sports has been estimated to be 60 - 70% (Campos et al., 2012; Doria et al., 2009; Rodrigues-Krause et al., 2020), with contributions during 5 mins of high intensity exercise as high as ~85% (Gastin, 2001). Despite this, MMA performance has previously been suggested to be predominantly anaerobic due to individual decisive actions lasting ~3 – 9 s (Del Vecchio et al., 2011; Tack, 2013) and post bout lactate being > 9 $mmol \cdot L^{-1}$ (Amtmann et al., 2008; Coswig et al., 2016a; Kirk et al., 2015a). These decisive actions rarely occur in isolation, however, with MMA performance consisting of such movements repeated multiple times in succession throughout a contest (Del Vecchio et al., 2011; dos Santos et al., 2018; Kirk et al., 2015a; Miarka et al., 2018). Under these conditions, each subsequent set of high impulse actions in the absence of adequate recovery would increase athlete reliance on aerobic metabolism (Ruddock et al., 2021; Spencer et al., 2005). Equally, whilst anaerobic capacity is trainable, this is finite and is ultimately limited by the athlete's aerobic capacity (Gastin, 2001). As such, whilst $\dot{V}O_2max$ cannot be directly linked to combat sport performance in a causative manner, it likely has an indirect influence on success in supporting the metabolic demands of repeated high intensity force production and inter-round recovery (Bridge et al., 2014; Ovretveit, 2018). Accordingly, it would be logical to include the improvement of aerobic capacity as one of the key aims of preparing an MMA athlete for competition (Ruddock et al., 2021). The data reported here, however, demonstrate that this does not occur in a standard MMA training camp. An explanation for this is provided in Chapter 5, where the cohort observed did not perform any supplementary cardiorespiratory training. The technical/tactical training conducted was also performed in an intermittent fashion with prolonged periods of rest owing to the coaching taking place. These factors together reduce the aerobic stimulus of training and therefore any potential $\dot{V}O_2max$ improvements.

In summary, a six-eight week training camp without intervention does not improve the maximal aerobic or force capacity of MMA athletes. The only force production change to occur was a moderate increase in isometric midthigh pull force, potentially caused by the isometric lower torso actions of grappling training. Conversely, BM, FM and FFM all reduced during the training period, demonstrating the effects of increased exercise and dietary restrictions in the absence of a supporting training strategy. Based on the repeated high impulse requirements of MMA performance and the absence of positive physiological changes observed here, it is strongly recommended that MMA athletes supplement their technical/tactical training with periodised S&C. This should aim to increase maximal force production, impulse and aerobic capacity. Such provision should also aim to maintain FFM during athlete BM manipulation to minimise the potentially deleterious effects of CWL/AWL on performance. MMA coaches should work alongside qualified S&C coaches and/or sport and exercise physiologists to design long term training programmes both within and between training camps. Future studies should test these training programmes in controlled conditions to determine the most appropriate strategies to achieve optimal athletic performance for this population.

7.6 Chapter Summary

- A six-eight week MMA training camp does not cause improvements in maximal force, impulse or aerobic capacity in professional and international amateur MMA athletes
- Athlete body composition does change in this period, with BM and FM both reducing with smaller reductions in FFM also being apparent
- These results indicate that MMA training camps without supplementary physiological support are unlikely to result in optimal athletic performance
- Future studies should design and test training interventions to be completed alongside technical/tactical training to maximise athlete performance whilst minimising the effects of CWL and AWL.

End of Study 4 Thesis Map

Study Aim	Study Type	Objectives	Outcomes
Study 1 – Chapter 3 **Thesis Objective 1** **Study Aim** Explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition	**ARMSS Stage 1: Defining the problem** Qualitative semi-structured interviews	1. Interview professional MMA coaches to explore their training and coaching backgrounds, and how they developed as MMA coaches 2. Explore the structure, aims and focus of MMA coaches practice in preparing participants for competition 3. Explore how MMA coaches attempt to monitor the load-fatigue-adaptation cycle of the participants preparing for competition within their practice.	1. MMA coaches developed via experience and peer learning. Peer learning reduces when they become club owners 2. Sessions must cater both to competitive athletes and recreational participants simultaneously. 3. Training practices are led by folk pedagogy potentially underpinned by pseudoscience with minimal evidence of objective monitoring of athlete load-fatigue-adaptation.
Study 2 – Chapter 5 **Thesis Objective: 2** **Study Aim** Quantify the internal loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the durations, intensities and internal loads of MMA training categories 2. Record subjective fatigue and soreness response of MMA athletes in relation to these internal loads 3. Determine the intensity and load distribution of MMA training sessions and categories 4. Determine any changes in load, fatigue or soreness when MMA athletes are preparing for competition	1. MMA training does not appear to be periodised between or within weekly microcycles. 2. Pre-competition tapers are stepwise 1 week prior to a bout, leading to no reductions in fatigue markers 3. Each MMA training category may be distinguished by intensity and internal load, with 20% of training time spent at high intensity.
Study 3 – Chapter 6 **Thesis Objective: 2** **Study Aim** Quantify the external loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the external loads of MMA training categories 2. Determine the relationship between external and internal loads in MMA training. 3. Determine the distribution of external loads of MMA training categories	1. External loads of MMA training categories are distinguishable using torso-mounted accelerometry. 2. External load has moderate-large predictive relationships with internal load, with the exception of BJJ related categories which are small-moderate due to non-ambulatory actions not being measured by accelerometry. 3. Within week external load of MMA training sessions does not change between days with the exception of relative external load. This, however, only changed in one of the two weeks observed.
Study 4 – Chapter 7 **Thesis Objective: 3** **Study Aim** Determine the physiological adaptations and changes in body composition that arise from completing a typical 6-8 week MMA training period that is used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative laboratory data collection without intervention	1. Record physiological and body composition data of a group of international standard MMA athletes prior to commencing training for competition 2. Record the same physiological and body composition variables upon completion of the training period but prior to pre-competition RWL. 3. Determine the effects of a pre-competition training period on MMA athlete's physiological capabilities and body composition	1. A 6-8 week training camp does not cause improvements in maximal force, impulse or aerobic capacity in MMA athletes. 2. BM, FM and FFM all reduce during this period. 3. The absence of training load undulations seen in MMA technical/tactical training and the lack of supplementary S&C means MMA training camps are unlikely to be providing optimal pre-competition preparation.
Study 5 – Chapter 8 **Thesis Objective: 4** **Study Aim** Examine the effects of a supplementary high-intensity aerobic training intervention (completed alongside traditional MMA training practices) on aerobic capacity and indices of competition specific performance	**ARMSS Stage 3: Predictors of performance** Quantitative field and laboratory data collection with training intervention	1. Apply a cardiovascular training intervention to MMA athlete's regular technical-tactical training 2. Determine the effects of training intervention on physiological and body composition measures collected in laboratory 3. Determine the effects of training intervention on bout pacing as measured via body worn accelerometry in simulated competition	

Chapter 8 - Study 5: The Effects of a Treadmill based High-intensity Interval Training Intervention on Cardiorespiratory and MMA Performance Measures

8.1 Chapter Rationale

Chapter 5 demonstrated that MMA athletes do not tend to engage in structured strength and conditioning (S&C) as part of their training. Indeed, the coaches interviewed in Chapter 3 generally considered this aspect of athlete preparation to be external to their role and down to the athlete themselves to organise and manage. This is likely to lead to suboptimal preparation, however, as Chapter 7 demonstrated that MMA training alone does not cause improvements in physiological markers of performance. These data support previous research showing that an athlete specific S&C program is required to improve physiological performance in this population (Kostikiadis et al., 2018). In Chapter 3, the coaches interviewed stated they preferred their athletes completing S&C related activities outside of their technical/tactical training time to allow these sessions to focus on sports specific training. S&C provision would therefore need to be structured to allow optimal physiological adaptations to be achieved in a time efficient manner with minimal disruption to the athlete's technical/tactical training capacity. It should also be targeted at improving the athlete's aerobic capacity and force production. Therefore, the aim of this study was to examine the effects of a supplementary high-intensity aerobic training intervention (completed alongside traditional MMA training practices) on aerobic capacity and indices of competition specific performance.

ARMSS Stage: 3 – Predictors of performance

8.2 Introduction

As established in Chapter 2 MMA is a sport of high impulse, intermittent actions likely requiring a broad range of physiological and metabolic capabilities. Due to the combative nature of the sport, the relative energy system contributions to MMA performance have not been directly quantified. Capillary lactate responses to official and simulated competition indicate a relatively high anaerobic demand (Amtmann et al., 2008; Coswig et al., 2016a; Kirk et al., 2015a). Recent data from simulated bouts (HR > 90% HRmax between rounds) further demonstrates the nature of MMA as a high intensity event (Petersen and Lindsay, 2020). The maximal length of a bout, however, suggests that performance also has significant aerobic energy demands to complete repeated, high impulse actions for potentially 9 - 25 mins (Miarka et al., 2019a, 2016c). Simulations from the related combat sports of karate, taekwondo and BJJ report aerobic energy contributions of 60 - 70% over durations of 90 s – 6 mins (Campos et al., 2012; Doria et al., 2009; Rodrigues-Krause et al., 2020). Despite this apparent demand, MMA athletes may be classified as 'untrained' – 'trained' (De Pauw et al., 2013) with $\dot{V}O_2max$ ranging between 41.5 ± 11.1 – 62.8 ± 4.9 $ml{\cdot}kg{\cdot}min^{-1}$ (Alm and Yu, 2013; de Oliveira et al., 2015; Kostikiadis et al., 2018; Schick et al., 2010) which does not improve in response to a training camp (Chapter 7). Such moderate aerobic capacity may manifest as a reduction in pacing and activity for both winners and losers as bouts progress (Antoniettô et al., 2019; Kirk et al., 2020a).

Owing to the training patterns and nature of MMA (Chapters 2 and 5) multiple authors have recommended the use of high-intensity interval training (HIIT) as a primary method of improving cardiorespiratory function in this population (Amtmann, 2010b; French, 2019; Harvey, 2018; Ruddock et al., 2021). A meta-analysis of HIIT in combat sports found improvements in relative $\dot{V}O_2max$ in both striking (pooled mean difference = +2.83 $ml{\cdot}kg{\cdot}min^{-1}$; +5 ± 3%) and grappling based sports (pooled mean difference = +2.36 $ml{\cdot}kg{\cdot}min^{-1}$; 4 ± 5%) but with concomitant improvements of anaerobic capacity (W and $W{\cdot}kg^{-1}$) in grappling sports only (Vasconcelos et al., 2020). Conversely, a review of HIIT responses in Olympic combat sport athletes found greater increases in relative $\dot{V}O_2max$/peak (+4.2 ± 1.9 $ml{\cdot}kg{\cdot}min^{-1}$; 8 ± 5%) but no changes in absolute $\dot{V}O_2max$/peak (0.1 ± 0.1 $L{\cdot}min^{-1}$; 0 ± 3%). This study also found HIIT to be related to increased lower body peak power (W and $W{\cdot}kg^{-1}$) and maximal accumulated oxygen deficit (MAOD, $ml{\cdot}kg^{-1}$) in comparison to controls (Franchini et al., 2019). The results of these two studies indicate that effects of HIIT on $\dot{V}O_2max$ in combat sports may be dependent on which type of combat sport is being assessed and, crucially, whether reported measures are in relation to BM or not. A positive effect of such training on anaerobic capacity may, however, have more support. A common element also discussed by both reviews was the highly varied exercise modes, HIIT types, durations, frequencies and intensities used in combat sport investigations. Given the differing effects of each of these variables on physiological responses (Laursen and Buchheit, 2019; Rosenblat et al., 2022) there remains a need to investigate the effects of established HIIT practices in MMA.

Suggested MMA HIIT modalities range from a focus on 'game based'/sport specific HIIT (Amtmann, 2010b; French, 2019; Harvey, 2018) through to a combination of running HIIT, 'game based' HIIT and steady state endurance at different points of the training period (Mikeska, 2014). There is, however, an absence of studies testing these suggestions. Currently, the only controlled study that applied HIIT to MMA athletes prescribed short interval HIIT (6 x 60 s rowing ergometer) twice a week and sprint interval training (SIT) (3 x 6 x 60 m sprinting) once a week for four weeks. Participants following this protocol experienced a 13.3 ± 14.5% improvement in estimated $\dot{V}O_2max$ (pre = 41.5 ± 11.1; post = 46.2 ± 10.3 $ml{\cdot}kg{\cdot}min^{-1}$) (Kostikiadis et al., 2018). Given the short work periods and duration of this intervention, improvements in $\dot{V}O_2max$ were most likely due to improved O_2 extraction by the working muscles (a-$\dot{V}O_2$diff) rather than enhanced O_2 delivery (Jacobs et al., 2013; Vincent et al., 2015). Improvements in a-$\dot{V}O_2$diff appear to plateau after three-four weeks of HIIT (Granata et al., 2018; MacInnis et al., 2017) with enhancements in O_2 delivery via improved stroke volume (SV) and therefore cardiac output ($\dot{Q}$) requiring longer interventions with longer HIIT intervals (Bostad et al., 2021; Cox et al., 1986; Rosenblat et al., 2022; Wisløff et al., 2009). Given the aforementioned moderate aerobic capacity of MMA athletes and their low aerobic training exposure (Batra, 2019), optimal performance improvements in this population may be achieved by using long HIIT intervals alongside short HIIT intervals.

To that end, the aim of this study was to examine the effects of a supplementary high-intensity aerobic training intervention on aerobic capacity and indices of MMA performance. It was expected that completing one short HIIT session and one long HIIT session a week at intensities based on participant's running velocity at $\dot{V}O_2max$ (v$\dot{V}O_2max$) would lead to improvements in cardiorespiratory endurance alongside improved pacing in training-based sparring bouts.

8.3 Methods

8.3.1 Participants

An initial cohort of seven international amateur and professional MMA athletes was recruited for this study following institutional ethical approval (H15/SPS/32) using the inclusion criteria established in Chapter 4. During the training period, one participant dropped out of the study by choice, one participant suffered an MMA training-based injury and two other participants contracted unrelated illnesses. Further, two participants were booked for short notice competitive bouts during the data collection period so were unable to complete the training intervention for the minimum required time. As a result, each of these participants had to be withdrawn from the study. Therefore, the one remaining participant (male, age = 30 years, habitual body mass = 77.1 kg, stature = 174.5 cm, professional) completed the training intervention and data collection as an individual case study. This participant was not preparing for competition during data collection, and stated they were involved in 'training maintenance between camps'. A schematic of the following case study protocol can be viewed in Figure 8.1.

8.3.2 Laboratory Measures

The participant was instructed to refrain from food and fluid intake for 10 hours prior to commencement of testing, and to avoid strenuous training or activities for 12 hours prior. Participant BM (kg) was measured whilst FM (kg), FM%, FFM (kg) and FFM % were estimated via bioelectrical impedance (Seca mBCA 515, GERMANY) with the participant in a standing, anatomically neutral position. Resting metabolic rate (RMR, $kcal \cdot day^{-1}$) was measured using indirect calorimetry (GEMNutrition Ltd., UK) calibrated via known concentrations of O_2/CO_2, a zero span gas and an ethanol burn to confirm an established respiratory exchange ratio of 0.67. Error of measurement was measured as 42 $kcal \cdot day^{-1}$, with CV < 2%. Following this, the participant was then permitted to drink water ad libitum before completing the GXT as described in Chapter 4 to measure $\dot{V}O_2max$ ($L \cdot min^{-1}$ and $ml \cdot kg \cdot min^{-1}$), ventilatory thresholds (VT_1 and VT_2, both $L \cdot min^{-1}$ and % of $\dot{V}O_2max$), O_2pulse ($ml \cdot beat^{-1}$) and velocity at $\dot{V}O_2max$ ($v\dot{V}O_2max$, $km \cdot h^{-1}$). Treadmill speed during the GXT stage at which $\dot{V}O_2max$ was attained was designated as the participant's $v\dot{V}O_2max$. These procedures were conducted one week before starting their training intervention and again the week immediately after completing the training intervention. Participant pre and post running economy at 9, 10 and 11 $km \cdot h^{-1}$ was calculated using the following equation (Jones, 2006):

$$O_2 \text{ cost of running (ml·kg·km}^{-1}) = \dot{V}O_2 \text{ (ml·kg·min}^{-1}) / (\text{speed [km·h}^{-1}] / 60)$$

Energy expenditure (kcal·min^{-1}) at 9, 10 and 11 km·h^{-1} was also estimated post hoc using updated nonprotein respiratory equations (Peronnet and Massicotte, 1991). These speeds were chosen as they fell between the participant's VT_1 and VT_2, and coincided with RER < 1, thus reducing potential anaerobic contribution to energy resynthesis and ensuring the participant was at or close to steady state conditions (Barnes and Kilding, 2015; Jones, 2006).

8.3.3 Performance Measures

The participant took part in a 3 x 5 mins simulated bout with 60 s rest between rounds using MMA rules modified for participant safety (no elbows or knees to the head). This was conducted at the participant's club training venue. The participant was equipped with 198 g MMA sparring gloves and standard shin and instep guards. They were also fitted with a Catapult Optimeye S5 torso mounted accelerometer (Catapult Innovations, AUSTRALIA) fitted on T3-4 vertebrae in keeping with recommended practice (McLean et al., 2018). Accelerometery was used to measure participant external load by recording the PLd_{ACC} of the entire bout, and bout pacing via PLd_{ACC}·min^{-1} as applied previously (Kirk et al., 2020a). Participant RPE was collected immediately after each round and 10 mins after the end of the simulated bout using the Foster 0-10 scale (Foster, 1998) in keeping with the procedures established in Chapter 4. PLd_{ACC} and RPE were both recorded in arbitrary units (AU). Internal training load of each bout was calculated using the equations established in Chapter 4. The participant took part in three simulated bouts during the collection period: during week 0 (pre-intervention), during week 4 (mid intervention) and during week 8 (post-intervention). Due to scheduling conflicts beyond the control of the author, it was not possible to conduct each simulated bout against the same opponent, so each bout was conducted against a different opponent in each bout matched for BM and performance standard.

8.3.4 Training Monitoring

During the intervention, the participant was asked to record duration and RPE of all training sessions completed each day, including HIIT sessions and all technical/tactical sessions related to

MMA. Weekly internal training load was calculated using the equations established in Chapter 4. They were also asked to complete SQF to record total fatigue score (AU) and body region soreness (AU) questionnaires at the end of each training day in the same manner as described in Chapter 4.

8.3.5 Training Intervention

The participant took part in the following treadmill-based training intervention: one long HIIT session a week = 4 x 3 mins at 90% v$\dot{V}O_2$max with 2 mins of passive recovery between each work period; one short HIIT session a week = 8 – 10 x 60 s at 110% v$\dot{V}$O2max with 60 s active recovery at 50% v$\dot{V}O_2$max between each work period, with instructions to complete a minimum of eight and a maximum of ten work periods. Both long and short HIIT sessions throughout the intervention included a 2 mins warm up at 50% v$\dot{V}O_2$max immediately prior to the first work period to reduce time to attain $\dot{V}O_2$max in the first work interval (Midgley and McNaughton, 2006). From week 5 onwards the intensity of long HIIT sessions was increased to 95% v$\dot{V}O_2$max with 2 mins of passive recovery between each work period. The intensity of the short HIIT sessions were also increased to 115% v$\dot{V}$O2max with 60 s active recovery at 50% v$\dot{V}O_2$max between each work period, with the participant instructed to complete exactly ten work periods in these weeks. A combination of long and short HIIT was chosen in keeping with recommendations for the use of these HIIT types outside of specific combat sport competition preparation (French, 2019) to provide stimuli for both central (Rosenblat et al., 2022) and peripheral (Granata et al., 2018) cardiorespiratory training adaptations. HIIT sessions were conducted in addition to their normal training at least 48 hours apart from each other and at least 24 hours from their more intense technical/tactical sessions. No changes were made to the participant's daily energy intake or technical/tactical training sessions.

	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Performance measures	 **RPE**				 **RPE**				 **RPE**
Laboratory measures	  								  
		Each week: Long HIIT session: work = 4 x 3 mins @ 90% v$\dot{V}O_2$max interspersed by 2 mins passive recovery Short HIIT session: work = 8-10 x 60 s @ 110% v$\dot{V}O_2$max interspersed by 60 s @ 50% v$\dot{V}O_2$max			No HIIT sessions completed this week due to reported fatigue	Each week: Long HIIT session: work = 4 x 3 mins @ 95% v$\dot{V}O_2$max interspersed by 2 mins passive recovery Short HIIT session: work = 10 x 60 s @ 115% v$\dot{V}O_2$max interspersed by 60 s @ 50% v$\dot{V}O_2$max			

Figure 8.1 – Schematic showing testing completed by and HIIT session programmed for the participant

Nb. HIIT = high-intensity interval training; v$\dot{V}O_2$max = velocity at $\dot{V}O_2$max; RPE = rating of perceived exertion

 *= simulated MMA bout;*  *= Playerload;*  *= bioelectrical impedance;*

 *= resting metabolic rate;*  *= graded exercise test*

8.4 Results

The participant completed twelve sessions of HIIT in total, six long HIIT and six short HIIT. They completed each HIIT session in weeks 1 - 3 and weeks 5 - 7 but did not complete any HIIT sessions in week 4 by their own choice due to reporting increased fatigue. The participant only completed seven repetitions of the short HIIT session in weeks 5 and 7. Total HIIT training time equated to 235 mins. The participant's weekly training load, strain and monotony can be viewed in Figure 8.2a, whilst their weekly mean fatigue score and mean body region soreness ratings are available in Figure 8.2b. The internal training load and intensity for each of the HIIT sessions completed is shown in Figure

8.2c. Mean weekly training load for the full intervention = 2,312 ± 658 AU whilst mean daily load = 330 ± 94 AU. Mean within weeks monotony = 1.15 ± 0.15 AU, leading to mean strain = 2,708 ± 937 AU. Between weeks monotony = 3.5 AU. Mean fatigue score for the full intervention = 8.9 ± 0.9 AU.

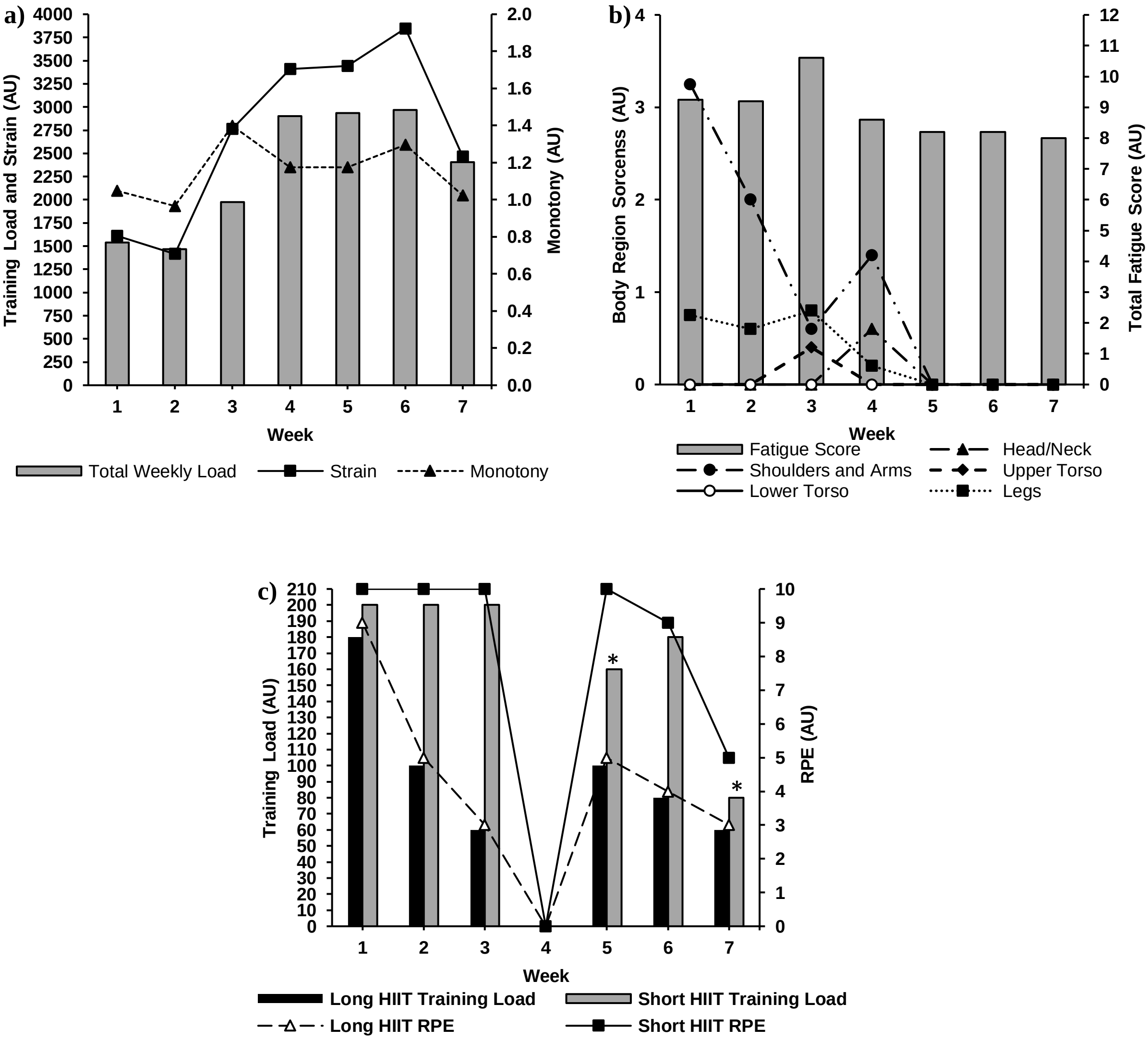

Figure 8.2 – a) Training load data for MMA and HIIT sessions combined; b) Weekly mean fatigue score and body region soreness; c) Sessional training load and rating of perceived exertion for each long and short HIIT session per week. *Nb. * = participant only completed seven repetitions of short HIIT in these weeks*

The participant's laboratory results pre and post intervention are reported in Table 8.1 Following a 4% reduction in BM, relative $\dot{V}O_2$max increased by 3%, but this equated to a 1% reduction in absolute $\dot{V}O_2max$. $\dot{V}O_2$ at VT_1 and VT_2 both improved by 1% respectively. Despite reduced absolute aerobic capacity, $v\dot{V}O_2max$ increased by 4%. Their $\dot{V}O_2$ and HR reduced at each submaximal GXT intensity, resulting in enhanced running economy and reduced energy expenditure at 9, 10 and 11 $km \cdot h^{-1}$ (Figure 8.3).

Table 8.1 – Pre and Post Intervention Laboratory Measurements

	Pre	Post
BM (kg)	77.10	73.95
FM (kg)	12.50	10.83
FM (%)	16.22	14.64
FFM (kg)	64.55	63.12
FFM (%)	83.70	85.30
$\dot{V}O_2max$		
$L \cdot min^{-1}$	4.13	4.08
$ml \cdot kg \cdot min^{-1}$	53.6	55.24
$v\dot{V}O_2max$ ($km \cdot h^{-1}$)	16.70	17.40
VT_1		
$L \cdot min^{-1}$	2.45	2.45
% of $\dot{V}O_2max$	59	60
VT_2		
$L \cdot min^{-1}$	2.90	2.89
% of $\dot{V}O_2max$	70	71
RMR ($kcal \cdot day^{-1}$)	1,731	1,762
O_2 pulse ($ml \cdot beat^{-1}$)		
At rest	11.5	17
At $\dot{V}O_2max$	23.10	22.20

Nb. BM = body mass; FM = fat mass; FFM = fat free mass; $v\dot{V}O_2max$ = velocity at $\dot{V}O_2max$; VT = ventilatory threshold; RMR = resting metabolic rate.

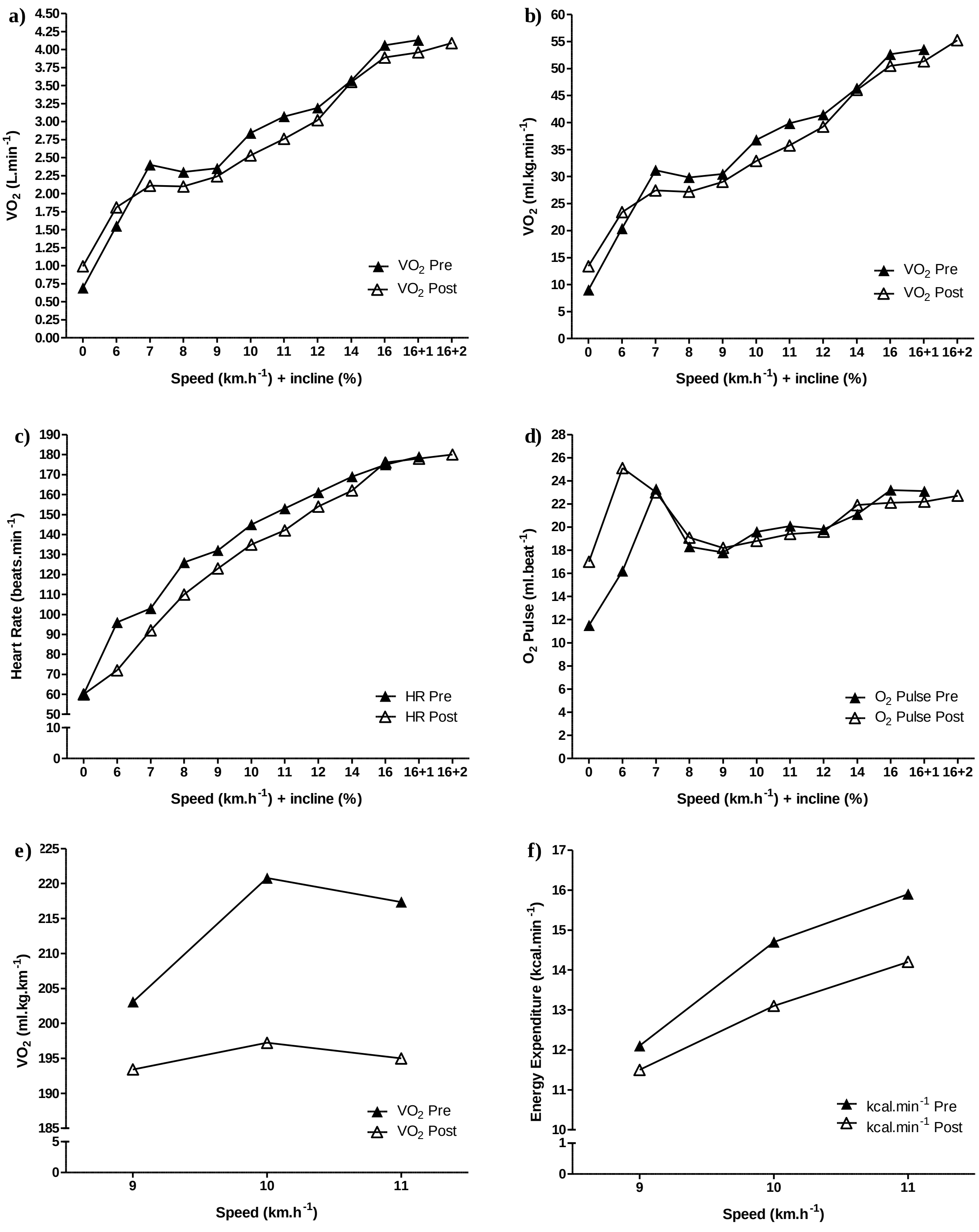

Figure 8.3 – Pre and post intervention cardiorespiratory graded exercise test results for a) absolute $\dot{V}O_2$max (L·min^{-1}); b) relative $\dot{V}O_2$max (ml·kg·min^{-1}); c) heart rate (beats·min^{-1}); d) O_2pulse (ml·beat^{-1}); e) submaximal running economy (ml·kg·km^{-1}); f) submaximal energy expenditure (kcal·min^{-1})

The participant's internal and external load data from each of the sparring bouts can be viewed in Table 8.2. These data displayed by round are provided in Figure 8.4.

Table 8.2 – External and internal load of each sparring bout completed

	Pre	Mid	Post
PLd$_{ACC}$ (AU)	168.4	185.3	182.1
PLd$_{ACC}$·min^{-1} (AU)	11.2	12.4	12.1
RPE (AU)	5	9	8
sRPE (AU)	85	153	136

Nb. AU = arbitrary units; PLd$_{ACC}$ = accumulated Playerload; PLd$_{ACC}$·min^{-1} = accumulated Playerload per minute; RPE = rating of perceived exertion; sRPE = sessional rating of perceived exertion

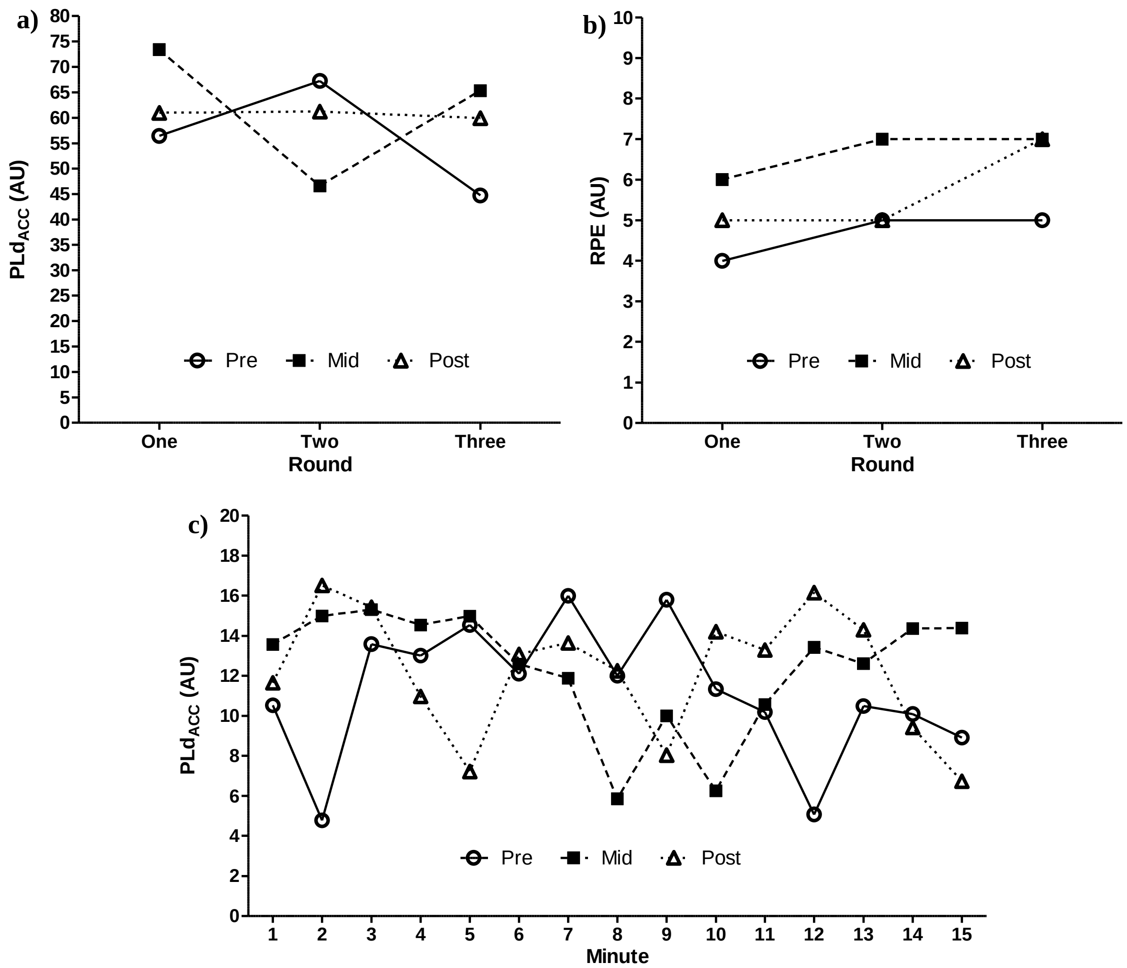

Figure 8.4 – a) Accumulated Playerload (PLd$_{ACC}$) of each sparring bout by round; b) rating of perceived exertion of each sparring bout by round; c) PLd$_{ACC}$ of each sparring bout by minute excluding between round rest periods.
Nb. AU = arbitrary units

8.5 Discussion

The aim of this study was to examine the effects of a supplementary high-intensity aerobic training intervention on aerobic capacity and indices of MMA competition performance. Due to circumstances beyond control of the researcher, only one participant completed all twelve HIIT sessions and the final laboratory data collection session. Despite evidence of HIIT improving $\dot{V}O_2$max/peak, SV and $\dot{Q}$ in athletic, non-athletic (Bacon et al., 2013; Wen et al., 2019) and MMA populations (Kostikiadis et al., 2018), no such changes occurred in the current case study, with participant absolute $\dot{V}O_2$max reducing slightly. The participant's exercise economy did appear to improve, however, with reduced cardiorespiratory responses and energy expenditure during submaximal GXT intensities. This may have allowed them to perform with greater economy in their sparring bouts, as evidenced by PLd_{ACC} becoming more consistent across the 3 rounds and increasing from the pre intervention to mid intervention. In the post intervention bout they were able to maintain movement with PLd_{ACC} equalling that of the mid intervention bout. This was done with reduced RPE and therefore reduced internal training load.

Long HIIT and short HIIT have been suggested to increase $\dot{V}O_2$max by improving O_2 delivery via enhanced SV and $\dot{Q}$ (Bostad et al., 2021; Cox et al., 1986; Wisløff et al., 2009), but this did not occur in the participant studied here. Following the finding of minimal cardiorespiratory training in this population (Chapter 5) and the recreationally trained (De Pauw et al., 2013) $\dot{V}O_2$max (49.3 ± 3.7 ml·kg·min^{-1}) of the cohort originally recruited for this study, a conservative cardiovascular load was chosen. The participant's maximum pre intervention O_2pulse (Bhambhani et al., 1994; Sietsma et al., 2021) was already within the range of elite endurance athletes without left ventricular hypertrophy (Sharma et al., 2000) and above the mean and range of recreational athletes (Padilla et al., 2000; Sharma et al., 2000). As a result of this above average SV, their pre training $\dot{V}O_2$max was towards the upper limit of the range for competitive MMA athletes (de Oliveira et al., 2015; Kostikiadis et al., 2018; Schick et al., 2010) and within the normal range of active 30-39 years olds (Loe et al., 2013). Active participants with $\dot{V}O_2$max > 50 ml·kg·min^{-1} may respond to HIIT with lower or even negative adaptations in comparison to untrained people (Milanovic et al., 2015; Rosenblat et al., 2022; Wen et al., 2019). This may result from trained participants displaying improved O_2 kinetics at exercise onset, greater reliance on lipids in place of glycogen, and enhanced muscle buffering (βm). Each of these effects would reduce the acute cardiorespiratory and metabolic signals required to cause adaptations during relatively low volume exercise (Cipryan et al., 2017; Jones and Carter, 2000; Lundby et al., 2017). Having greater than average baseline $\dot{V}O_2max$ may therefore result in reduced HIIT response (Astorino et al., 2012), meaning training of greater intensity or volume would be required. Even allowing for the 5% increase in intensity in weeks 5 - 7, the overall cardiorespiratory load was seemingly still too low for the given fitness of this participant, and thus did not provide sufficient stimulus for adaptation (Lundby et al., 2017).

RPE recorded during the long HIIT sessions was > 7 AU in week 1 only, falling below the suggested RPE demarcation for high intensity during weeks 2-7 (Seiler and Kjerland, 2006). Exercising at RPE corresponding to moderate or low intensity may indicate the participant spent less than the target of ~6 - 9 mins at $\dot{V}O_2max$ during long HIIT sessions (Buchheit et al., 2012). RPE for short HIIT sessions = 10 AU for four of the seven weeks. This intensity may have provided ~9 mins at $\dot{V}O_2max$ per short HIIT session, but it is still improbable that the combined long and short HIIT time at $\dot{V}O_2max$ during each week provided sufficient stimulus (Billat, 2001; Buchheit and Laursen, 2019; Midgley and McNaughton, 2006). Time at $\dot{V}O_2max$ and thus potential adaptation was further reduced by the participant not completing more than seven repetitions of short HIIT in weeks 5 and 7. Long HIIT using 4 x 3 mins intervals at 100% $v\dot{V}O_2max$ has previously resulted in $\dot{V}O_2$, HR and RPE being above VT_2 during each interval, maximising potential time at $\dot{V}O_2max$ (Cipryan et al., 2017). This suggests that sufficient time at $\dot{V}O_2max$ may be achieved in future MMA interventions by increasing the number and length of intervals at 95 - 100% $v\dot{V}O_2max$. This would be in keeping with previous research supporting high volume long HIIT (16 mins) being superior to low-moderate volume long HIIT (5 - 15 mins) for athletes, with little effect of short HIIT on $\dot{V}O_2max$ in this population (Wen et al., 2019). This suggests that greater volume provided by long HIIT may be required to bring about improved SV and therefore $\dot{V}O_2max$ in recreationally trained-trained people (Jones and Carter, 2000; Lundby et al., 2017).

$\dot{V}O_2$ and HR was reduced at each given intensity during the GXT post intervention. Energy expenditure and therefore O_2 cost also reduced at moderate intensity speeds. This was matched with an increase in PLd_{ACC} and $PLd_{ACC}{\cdot}min^{-1}$ from pre to mid intervention sparring bouts with a concomitant decrease in RPE from mid intervention to post intervention. The 2nd rounds of the pre and mid intervention sparring bouts displayed marked changes in PLd_{ACC} alongside increased RPE. This contrasts to post intervention where PLd_{ACC} was consistent across all three rounds despite an increase in RPE in the 3rd round. These results taken together demonstrate an improved exercise economy in this participant despite an absence of improvements to $\dot{V}O_2max$ or O_2 pulse. HIIT at intensities > 90 - 100% may result in enhanced βm via increased abundance of monocarboxylate (MCT) 1 and 4 proteins (Akmali and Saghebjoo, 2019; Pilegaard et al., 1999; Weston et al., 1997). Such adaptations may provide modest improvements to repeat intermittent work capacity in the absence of $\dot{V}O_2max$ alterations, similar to those observed here (McGinley and Bishop, 2016). Efficiency of muscle metabolism may also be improved via increased mitochondrial content from high training volume (Granata et al., 2018) and enhanced mitochondrial respiration from high training intensity (Bishop et al., 2018). Each of these peripheral adaptations, however, tend to be more apparent following SIT or 'all out' training rather than long or short intervals (Burgomaster et al., 2006; Gibala et al., 2006; Granata et al., 2016; Kelly et al., 2021; MacInnis and Gibala, 2017; Rosenblat et al., 2022). Increased blood volume (Schmidt and Prommer, 2008), capillary density (Laughlin and Roseguini, 2008) and SV (Skattebo et al., 2020) may also contribute to improved exercise economy by enabling greater O_2 absorption and extraction (Barnes and Kilding, 2015; Saunders et al., 2004). However, the lack of changes in O_2pulse, as a non-invasive measure of O_2 delivery (Sheykhlouvand et al., 2016; Sietsma et al., 2021), demonstrates that these adaptations likely did not occur in this participant.

It is more conceivable, therefore, that the increased economy seen here was caused by improved neural drive and muscular co-contraction making the athlete's movement more efficient overall (Kinnunen et al., 2019; Vera-Ibañez et al., 2017), thus reducing post intervention energy requirement for intensity matched exercise. Such responses have been noted in athletes following maximal - supramaximal HIIT protocols for the first time (Garcia-Pinillos et al., 2017), with such changes related to high threshold motor units only (Martinez-Valdes et al., 2017). This improved economy may also be achieved through increased ankle stiffness and more optimal gait reducing energy requirements at submaximal intensities (Folland et al., 2017), leading to reduced $\dot{V}O_2$ and HR at each running speed (Saunders et al., 2004). Improved exercise economy due to these adaptations may be particularly apparent in participants completing running based training for the first time (Moore et al., 2012). This effect has even been observed following a six week plyometric intervention without additional aerobic training (Turner et al., 2003). As such, whilst this participant was able to attain a greater $v\dot{V}O_2max$ and perform with lower cardiorespiratory strain at each sub maximal GXT intensity, these improvements were most likely due to more efficient neuromuscular and/or biomechanical performance reducing the energy and O_2 cost of exercise (Barnes and Kilding, 2015; Saunders et al., 2004). Direct measurements of joint stiffness and running mechanics would, however, be required to confirm this explanation. Given the nature of MMA as an event of intermittently repeated high impulse actions (Miarka et al., 2019a, 2016c) this ability to perform at a particular intensity with lower cardiorespiratory strain, energy requirements and therefore fatigue may explain the more consistent PLd_{ACC} with reduced RPE in the mid and post sparring bouts. Between bout differences due to altered tactical approaches or fluctuations in participant/opponent activity and/or fatigue, however, cannot be ruled out. The application of PLd_{ACC} as an MMA performance outcome measure (Jeffries et al., 2021) should be examined in future cohort controlled studies to explore the effects of training interventions on this variable.

Body composition was the only other change observed in this participant, with reduced BM, FM and FFM. Chapter 7 also revealed reductions in these variables in MMA athletes following a training camp without intervention. The participants in that study were, however, likely engaged in pre-competition BM manipulation, which the current participant was not. Despite this, the participant in this case study reduced FFM by ~2%, a similar magnitude as the cohort in Chapter 7. Kostikiadis et al. (2018) reported their MMA cohort reducing FM by 4.3 ± 2.3% and FM% by 4.5 ± 2.04% alongside a trivial increase in BM (0.3 ± 1.8%). Vasconcelos et al. (2020) found no pooled effect of HIIT on BM in athletes from a range of grappling and striking combat sports. Notably, striking athletes increased FM% whilst grappling athletes displayed reduced FM%. This suggests there may be an interaction of combat sports training modality on HIIT related body composition changes that should be considered in future studies and applications. Despite the well evidenced effect of HIIT on FM, this influence appears to be greater and more consistent in overweight or obese individuals (Maillard et al., 2018). The participant's initial FM% was in the upper range for a competitive athlete (Garrido-Chamorro et al., 2012; Santos et al., 2014), but below that of an average male adult (Bradbury et al., 2017). Any influence of HIIT alone on body composition is therefore unlikely. MMA athletes have been observed to have inadequate energy intake during periods of training (Coswig et al., 2018; Kasper et al., 2018). The participant was instructed to not change their habitual dietary practices, but daily energy intake was not monitored during the current intervention. Therefore, it is unknown whether the participant changed their diet or not. The addition of 140 - 380 AU to their weekly training load (9 - 26% of total weekly load) in the absence of concomitant dietary and/or strength interventions to support increased energy expenditure may explain the reduced BM (Hottenrott et al., 2012; Hoyt and Friedl, 2006; Langan-Evans et al., 2020; Slentz et al., 2004). Without daily energy intake data, however, the causative effect of this intervention alone on the participant's body composition can only be speculated.

In conclusion, twelve sessions of HIIT over a seven-week period was insufficient to bring about cardiorespiratory adaptations in a single MMA competitor. It is likely that long intervals were too few and conducted at too low an intensity for this participant, with too few short intervals in weeks 5 and 7 to elicit sufficient weekly time at $\dot{V}O_2max$ for a trained individual. Despite this, $v\dot{V}O_2max$ and GXT submaximal economy improved post intervention. This may have been caused by improved muscular co-contraction and more efficient force production from enhanced gait and musculotendon stiffness reducing the energy and O_2 cost of submaximal exercise. This may also have positively influenced their total movement in MMA sparring bouts where pacing became more consistent between rounds with reduced exertion, though this requires further research in cohort-controlled studies. Future interventions for MMA participants with a 'trained' $\dot{V}O_2max$ should provide more weekly time at $\dot{V}O_2max$ by increasing the number and intensity of long intervals performed. Following the participant's FM loss, future studies may also consider the effects of HIIT on body composition changes in MMA populations and dietary interventions to support desired adaptations.

8.6 Chapter Summary

- Six sessions of long HIIT and six sessions of short HIIT over seven weeks does not provide a great enough stimulus for $\dot{V}O_2max$, $VT_{1/2}$ or O_2pulse adaptations in an MMA participant with baseline $\dot{V}O_2max$ = 53.6 ml·kg·min^{-1}.
- This intervention did cause a reduction in BM and FM, with this potentially being a combined effect of the increased training load and inadequate dietary intake.
- Performing treadmill based HIIT also appears to improve exercise economy, potentially due to improved neuromuscular performance reducing the energy requirement of submaximal exercise, which may transfer to MMA performance in the form of more consistent activity across rounds with reduced exertion.
- Future studies should apply long HIIT intensity of 95 - 100% v$\dot{V}O_2max$ over > 5 intervals of 3 – 4 mins per session to increase time at $\dot{V}O_2max$ and overall training stimulus. This should be completed alongside monitoring of participant dietary intake.

End of Study 5 Thesis Map

Study Aim	Study Type	Objectives	Outcomes
Study 1 – Chapter 3 **Thesis Objective 1** **Study Aim** Explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition	**ARMSS Stage 1: Defining the problem** Qualitative semi-structured interviews	1. Interview professional MMA coaches to explore their training and coaching backgrounds, and how they developed as MMA coaches 2. Explore the structure, aims and focus of MMA coaches practice in preparing participants for competition 3. Explore how MMA coaches attempt to monitor the load-fatigue-adaptation cycle of the participants preparing for competition within their practice.	1. MMA coaches developed via experience and peer learning. Peer learning reduces when they become club owners 2. Sessions must cater both to competitive athletes and recreational participants simultaneously. 3. Training practices are led by folk pedagogy potentially underpinned by pseudoscience with minimal evidence of objective monitoring of athlete load-fatigue-adaptation.
Study 2 – Chapter 5 **Thesis Objective: 2** **Study Aim** Quantify the internal loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the durations, intensities and internal loads of MMA training categories 2. Record subjective fatigue and soreness response of MMA athletes in relation to these internal loads 3. Determine the intensity and load distribution of MMA training sessions and categories 4. Determine any changes in load, fatigue or soreness when MMA athletes are preparing for competition	1. MMA training does not appear to be periodised between or within weekly microcycles. 2. Pre-competition tapers are stepwise 1 week prior to a bout, leading to no reductions in fatigue markers 3. Each MMA training category may be distinguished by intensity and internal load, with 20% of training time spent at high intensity.
Study 3 – Chapter 6 **Thesis Objective: 2** **Study Aim** Quantify the external loads of MMA training practices that are used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative field observation	1. Record the external loads of MMA training categories 2. Determine the relationship between external and internal loads in MMA training. 3. Determine the distribution of external loads of MMA training categories	1. External loads of MMA training categories are distinguishable using torso-mounted accelerometry. 2. External load has moderate-large predictive relationships with internal load, with the exception of BJJ related categories which are small-moderate due to non-ambulatory actions not being measured by accelerometry. 3. Within week external load of MMA training sessions does not change between days with the exception of relative external load. This, however, only changed in one of the two weeks observed.
Study 4 – Chapter 7 **Thesis Objective: 3** **Study Aim** Determine the physiological adaptations and changes in body composition that arise from completing a typical 6-8 week MMA training period that is used to prepare participants for competition	**ARMSS Stage 2: Descriptive research** Quantitative laboratory data collection without intervention	1. Record physiological and body composition data of a group of international standard MMA athletes prior to commencing training for competition 2. Record the same physiological and body composition variables upon completion of the training period but prior to pre-competition RWL. 3. Determine the effects of a pre-competition training period on MMA athlete's physiological capabilities and body composition	1. A 6-8 week training camp does not cause improvements in maximal force, impulse or aerobic capacity in MMA athletes. 2. BM, FM and FFM all reduce during this period. 3. The absence of training load undulations seen in MMA technical/tactical training and the lack of supplementary S&C means MMA training camps are unlikely to be providing optimal pre-competition preparation.
Study 5 – Chapter 8 **Thesis Objective: 4** **Study Aim** Examine the effects of a supplementary high-intensity aerobic training intervention (completed alongside traditional MMA training practices) on aerobic capacity and indices of competition specific performance	**ARMSS Stage 3: Predictors of performance** Quantitative field and laboratory data collection with training intervention	1. Apply a cardiovascular training intervention to MMA athlete's regular technical-tactical training 2. Determine the effects of training intervention on physiological and body composition measures collected in laboratory 3. Determine the effects of training intervention on bout pacing as measured via body worn accelerometry in simulated competition	1. 12 sessions of treadmill based HIIT @90-115% $v\dot{V}O_2max$ is insufficient to cause cardiorespiratory adaptations in a single MMA participant with $\dot{V}O_2max$ = 53.6 $ml \cdot kg \cdot min^{-1}$. 2. This stimulus does improve exercise economy which may lead to increased activity with reduced exertion in simulated competition 3. Future studies should apply training interventions at a greater intensity or frequency to determine the required physiological stimulus for improvement in this population.

Chapter 9 - Synthesis

9.1 Chapter Rationale

The purpose of this chapter is to provide a summary of the findings of the thesis in relation to the aims and objectives outlined in Chapter 1 and detailed in the thesis map at the end of each subsequent chapter. A general discussion is then presented, focussing on how these analyses further our understanding of the current coaching and training practices that are used to prepare MMA athletes for competition. Following this, limitations of this work and recommendations for future research will be discussed.

9.2 Achievement of Thesis Aims and Objectives

Combat sports permitting the use of both striking and grappling actions existed in antiquity (Buse, 2006; Seidenberg, 2011) and started to re-emerge in the early 20th Century (Gracie and Danaher, 2003). The sport now known as MMA, however, was not codified until 2002 (NJSAC, 2002), with formal academic research not appearing widely until a decade later (Chapter 2). As such, our collective understanding of the nature of training in this population is minimal, with practitioners being under-served by, and showing little engagement with, sport and exercise science (Batra, 2019; Bujak et al., 2013). Assessment of extant MMA research within the ARMSS model revealed that most studies are descriptive in content, with none providing a detailed evaluation of current training practices (Chapter 2). The few offering training recommendations are therefore based on unevidenced assumptions regarding the loads and effects of technical/tactical training. Discussions of the practices, aims and backgrounds of the coaches responsible for training MMA competitors was found to be completely absent. This deviation from the ARMSS model highlighted a need for Stage 1 and Stage 2 research to be conducted to evaluate the nature of training in this sport, its practices, and the coaches responsible for these practices. This would then enable the designing and testing of training interventions to support the work of these practitioners.

The overall aim of this thesis, therefore, was to evaluate the current coaching and training practices that are used to prepare MMA athletes for competition. This was to be followed by an examination of a specific training intervention to provide recommendations for future protocols and research. This aim was designed to realign MMA research within the ARMSS model to ensure data is recorded, analysed and interpreted following a systematic structure whilst being informed by the target population (Bishop, 2008). This was achieved through a series of qualitative interviews, field observations and laboratory studies conducted in Chapters 3, 5, 6, 7 and 8. An overview of how each thesis objective was achieved follows below.

Objective 1: **To explore the coaching and training practices of professional MMA coaches who actively prepare participants for competition. This was achieved through the completion of Study 1 (Chapter 3) and sits within ARMSS Stage 1 – Defining the problem.**

This objective was achieved using reflexive, thematic analyses following a series of semi-structured interviews with four professional MMA coaches. It was found that MMA coaches have mostly developed through experiential learning and peer feedback in lieu of a formal coach education and development structure. Session content and format is largely influenced by the economic requirements of the majority of club members being recreational customers, which restricts the provision of athlete specific competition preparation. Training practices tend to be led by folk pedagogies and potentially sports 'pseudoscience' with little objective monitoring of training load or athlete improvements.

Objective 2: **To quantify the external and internal training loads of MMA training practices that are used to prepare athletes for competition. This objective was achieved via the completion of Study 2 (Chapter 5) and Study 3 (Chapter 6), both of which sit within ARMSS Stage 2 – Descriptive research.**

This objective was achieved over two studies using observational field data collected without intervention, consisting of objective and subjective measures. Internal load and markers of fatigue were monitored over an eight-week period in Chapter 5. The main outcome was that MMA training displays a flat loading pattern resulting in no observable changes in athlete fatigue. This does not differ between participants who are preparing for competition and those who are not. This occurs despite each training category being distinguishable by intensity and internal load. The external load of MMA training was measured over a two-week period of field observation in Chapter 6. Torso-mounted accelerometry revealed that each MMA training category is characterised by different absolute and relative external loads which have moderate-very large predictive relationships with the corresponding category internal load. For both internal and external loads, however, periodisation is absent in MMA training with no changes in overall session training load within or between weeks.

Objective 3: **To determine the physiological adaptations and body composition changes that arise from completing a typical six - eight week MMA training period that is used to prepare participants for competition. This objective was achieved through completion of Study 4 (Chapter 7) and sits within ARMSS Stage 2 – Descriptive research.**

This objective was achieved using a pre/post training camp laboratory-based testing battery conducted with a cohort of MMA athletes preparing for official bouts. No intervention was placed on their training, dietary or BM manipulation practices. The resultant data demonstrate that an MMA training camp without specific S&C supplementation or dietary support does not improve physiological markers of force, impulse or aerobic capacity. During this period, however, MMA athletes do experience large reductions in BM as a consequence of moderate reductions in FM and FFM. In light of the extreme energy restriction typical amongst MMA athletes and the absence of supplementary S&C provision, an MMA training camp does not generate sufficient stimulus for positive physiological performance adaptations or maintenance of FFM.

Objective 4: **To examine the effects of a supplementary high-intensity aerobic training intervention (completed alongside traditional MMA training practices) on aerobic capacity and indices of competition specific performance. This was achieved through the completion of Study 5 (Chapter 8) and sits within ARMSS stage 3 – Predictors of performance.**

This objective was achieved using a pre/post laboratory testing battery designed to observe physiological, body composition and simulated MMA performance responses to a supplementary HIIT intervention. This was completed as an n = 1 case study. Following twelve sessions of HIIT conducted at 90 - 115% $v\dot{V}O_2max$ over seven weeks, participant submaximal exercise economy, energy expenditure, HR, and $v\dot{V}O_2max$ displayed positive adaptations. These may have led to improved activity with reduced exertion in simulated bouts. Despite these enhancements, the intensity of the intervention may have been too conservative for their baseline fitness ($\dot{V}O_2max$ = 53.6 ml·kg·min^{-1}), meaning no improvements to $\dot{V}O_2max$ or O_2pulse occurred, though they did experience 1% increases in VT_1 and VT_2. This participant also experienced reduced BM during this study, though it is unknown whether this resulted from the intervention or their personal dietary practices. HIIT performed at this intensity and volume may not be sufficient to improve aerobic capacity in a participant with a 'trained' $\dot{V}O_2max$. It may, however, improve exercise economy in athletes performing running based training interventions for the first time, likely due to neuromuscular adaptations.

9.3 General Discussion of Findings

9.3.1 Coaching and Training Practices in MMA

Success in a competitive sport is dependent on the athlete's training practices which are centred on the coach as provider of said practices (Gordon, 2009). The effectiveness of the coaching process is determined by the coach having knowledge of the demands of the sport and being able to apply this knowledge to the improvement of the athlete (Cushion, 2010; Lyle and Cushion, 2017). With the coach therefore being an integral part of the training environment, understanding the 'who' of the coach enables a deeper appreciation of the 'what' of MMA training (Cassidy et al., 2009). Analyses of this kind cannot be undertaken through quantitative measures alone (Braun et al., 2017; Sparkes and Smith, 2014). As such, Study 1 (Chapter 3) used reflexive, semi-structured interviews to examine MMA coach's development, aims and beliefs regarding their practices. These interviews revealed that MMA training has been heavily influenced by the unique and rapid development of the sport since the mid-1990s (Chapter 1). The absence of any formal club or competition structure in MMA's embryonic phase led to 'early explorers' learning from each other via trial-and-error. The exponential growth in the popularity of MMA in the mid-2000s provided financial opportunities for the 'early explorers' to open their own clubs catering to a growing number of recreational participants and their families. As a competitive sport there is still a desire, and potentially a reputational need, on the part of the coaches to train and produce successful athletes. The combative nature of the sport, however, means individuals wishing to compete are in the absolute minority. As such, the coach's ability to design training sessions and programs aimed at maximising athlete performance is restricted by the majority of their club members being unlikely to enjoy athlete specific repetition of key skills and contest simulations.

The effects of this restriction are seen in Studies 2 and 3 (Chapters 5 and 6), where measurements of internal and external training loads revealed an absence of within or between microcycle periodisation (Figures 5.1 and 6.1). Session content, duration and intensity followed a set weekly pattern leading to the same overall load being applied to the athlete each day (Table 5.3, Appendices F and G). This may be a consequence of sessions catering to the aforementioned paying customers, who may be unlikely to enjoy repetition of key skills or training aimed at improvement of athlete biomotor abilities. Additionally, it may be caused by coach preconceptions of which training categories are less/more intense and their beliefs of how to balance these. Each MMA training category is distinguishable by intensity (Figure 5.8) and the subsequent internal and external loads (Figures 6.3, 6.4 and 6.5). Led by their preconceptions of how much each category differs, coaches limit the duration and frequency of the more intense categories, with more training time being devoted to those perceived to be of lower intensity (Table 5.3 and Figure 5.7). Categories within each session, however, are combined in a manner that results in the flat loading pattern observed. Such static training load deviates from periodisation and training theory, meaning positive physiological adaptations are unlikely (Kellmann, 2010; Turner, 2011; Turner et al., 2015).

Determining whether changes in load and fatigue are occurring requires active monitoring using objective and/or subjective measures (Halson, 2014; Meeusen et al., 2013; Thorpe et al., 2017). Use of such methods is, however, almost entirely absent in this population (Chapter 3). MMA coaches are therefore unaware of the static training load and fatigue of their athletes. This becomes particularly apparent during competition preparation where an abrupt step taper the week of the bout provides no opportunity for athlete fatigue to dissipate (Figures 5.3 and 5.4). This is likely exacerbated by the 11.6 ± 2.4% BM reduction undertaken by the participants in this period (Table 4.1). Each of these factors in concert make it improbable that MMA athletes are experiencing positive, individualised physiological adaptations as a result of their training, and as such are unlikely to be optimally prepared for competition.

The internal training load (Chapter 5) and external training load (Chapter 6) data provided here may be used as a starting point to improve training load manipulation in this population. The relative internal loads (Figure 5.8a) and relative external loads (Figure 6.3b and Appendix E) reported in this thesis are the first data to estimate the intensities of the different MMA training categories. In addition, the moderate-very large predictive relationships between the absolute forms of these metrics demonstrate the potential utility of the PLd_{ACC}-segRPE model for monitoring the training loads of MMA competition preparation. Coaches may work with researchers to determine their specific athlete's training category intensities alongside their personal PLd_{ACC}-segRPE relationships. The resultant data may be used to plan training sessions and periods in a manner that may enable more appropriate training load distribution via the calculation of required duration and intensity of each training category. This in turn may be used to plan and achieve athlete's required daily and weekly training load. This would give coaches the tools to plan sessions in such a way that days/weeks of overreaching and restitution may be applied where required, in addition to being able to plan an appropriate pre-competition taper (Bosquet et al., 2007b; Le Meur et al., 2012; Uddin et al., 2020). This may also give coaches the flexibility to design sessions around the technical/tactical needs of their athletes and the enjoyment of their recreational members simultaneously.

9.3.2 The Physiological Effects of MMA Training and Potential Training Interventions

Discussion with MMA coaches provided insight to the factors affecting the planning and provision of MMA training sessions (Chapter 3), whilst field observations of the sessions detailed the content and structure of the sport's training environment (Chapters 5 and 6). These data were not able to demonstrate the physiological effects of these processes on the athletes involved. To address this gap in the literature, Study 4 (Chapter 7) was conducted to elucidate the effects of an MMA training camp on markers of athlete physiological performance for the first time. Due to the nature of MMA as an activity of repeated high impulse movements over a maximum of 9 - 25 mins, it may be potentially classified as a high intensity endurance sport (Draper and Marshall, 2013). Accordingly, training would be expected to contribute to enhanced force production, aerobic and anaerobic capacity. Despite this, six - eight weeks of pre-competition training does not result in statistically relevant changes to these performance factors (Figures 7.3, 7.4 and 7.5). The flat loading pattern and absence of S&C (Chapter 5) results in a lack of training overload, explaining the dearth of physiological improvement (Kellmann, 2010; Kellmann et al., 2018). As a result, MMA athletes were found to be weaker than athletes from a range of sports (McGuigan, 2016) including other combat sports (Franchini et al., 2011, 2007; Schmidt et al., 2005). Additionally, the $\dot{V}O_2max$ of the cohort would classify them as 'recreationally trained-trained' (De Pauw et al., 2013). In light of such moderate strength and fitness combined with the participant's low S&C exposure, adaptations may potentially be achieved with relatively low training stimuli (Peterson et al., 2005). Such stimuli are, however, not provided by MMA training.

In an attempt to provide an evidence based solution to this, Study 5 (Chapter 8) tested a HIIT intervention designed to provide cardiorespiratory stimulus at an intensity that would also elicit neuromuscular adaptation (Buchheit and Laursen, 2019, 2013a, 2013b). This was programmed to be completed in a time efficient manner with minimal residual fatigue to avoid negatively affecting technical/tactical sessions. The resulting improvements to exercise economy may result from neuromuscular adaptations reducing the energy cost and therefore the cardiorespiratory strain of submaximal exercise. This economy may potentially have manifested as increased activity and reduced exertion in simulated MMA bouts. This secondary finding, however, is conjecture at this stage as the PLd_{ACC} and RPE of simulated bouts may be affected by multiple confounders both internal and external to the participant. Future studies should examine the relationship between PLd_{ACC} and markers of fitness amongst MMA athletes in cohort-controlled studies. If support is found for a positive influence of participant exercise economy on sports specific performance, this may provide a performance outcome measure for what MMA coaches refer to as improved 'sharpness' (Chapter 3). Whilst the coaches did not provide an explanation for this term, it may possibly be interpreted to mean more efficient and effective techniques applied more consistently throughout a bout. An athlete's 'sharpness' could therefore be underpinned by neuromuscular force production, aerobic capacity and anaerobic capacity

(Davison et al., 2009; DeWeese et al., 2015; Stone et al., 2000; Suchomel et al., 2016). Though this particular HIIT intervention was insufficient to improve each of these variables, given that exercise economy did increase, it does provide support for the use of supplementary high-intensity aerobic training to achieve ‘sharpness’.

It may be recommended, therefore, for supplementary S&C to be completed alongside MMA technical/tactical training to provide the mechanical muscle strain and cardio-metabolic disturbances required for physiological adaption (Viru and Viru, 2000). The relatively low levels of strength and fitness (Chapter 7) and low S&C exposure (Chapter 5) of MMA athletes means a linear periodisation model may be appropriate between training camps enabling maximal force and aerobic capacity to be achieved under a loading pattern suitable for recreationally trained participants, such as a ‘traditional’ 3:1 load:deload paradigm (Bompa and Buzzichelli, 2019; Haff, 2016). Strength training may focus on core, structural and power exercises (Stone et al., 2000; Suchomel et al., 2016, 2015) with cardiorespiratory training based on low intensity, steady-state efforts (Esteve-Lanao et al., 2007; Seiler and Kjerland, 2006; Seiler, 2010) to minimise training interference and residual fatigue (Berryman et al., 2019; Vechin et al., 2021). When in training camp, a conjugated model to optimise the application of maximal force to maximal RFD may be appropriate (Bompa and Buzzichelli, 2019; Haff, 2016). This may be supported by a mesocycle of long HIIT (5 - 7 x 3 - 4 mins > 95% v$\dot{V}O_2$max:2 mins passive recovery) during the first half of training camp, leading to a mesocycle of SIT (3 x 6 x 60m sprinting) (Kostikiadis et al., 2018; Ruddock et al., 2021) prior to competition. Thus, the athletes may improve aerobic capacity and develop training tolerance prior to training camp (Esteve-Lanao et al., 2007; Seiler, 2010; Stone et al., 2000; Viru and Viru, 2000). HIIT methods and training at VT_2 could then be used during training camp to improve βm (Akmali and Saghebjoo, 2019; Pilegaard et al., 1999; Weston et al., 1997), exercise economy and FM reduction (Chapter 8; Kostikiadis et al., 2018). Compound resistance training to maximise force production and RFD could be used throughout the training process regardless of whether the athlete is specifically in training camp or not, with adjustments made to the loading pattern used in relation to the needs of the athlete and the time from competition (Bompa and Buzzichelli, 2019; Haff, 2016). A fourteen day fast exponential taper may be recommended prior to competition to enable dissipation of fatigue, restitution of performance and to allow BM manipulation to occur with minimal effect on training or adaptation (Bosquet et al., 2007b; Le Meur et al., 2012). This may improve the current pre competition preparations which feature a seven day step taper only (Chapter 5; Uddin et al., 2020).

Such training should be programmed by S&C coaches/sports and exercise physiologists working in tandem with MMA coaches. This may be completed alongside technical/tactical session planning using the specific athlete's external/internal load relationships (Chapter 6) determined via application of the PLd_{ACC}-segRPE model demonstrated in this thesis. This approach may provide sufficient training stress to cause physiological adaptation whilst being balanced against the loads of the athlete's sports specific training. Potential concurrent training interference may therefore be avoided (Berryman et al., 2019; Vechin et al., 2021) whilst achieving the coaches goal of athlete 'sharpness' alongside satisfying their paying customers (Chapter 3).

9.4 Summary and Conclusion

MMA training is characterised by a flat loading pattern both within and between weeks (Chapters 5 and 6). This may be due to the combined influence of MMA coaches primarily designing sessions for recreational club members (Chapter 3) and potential pre-conceptions of the effects of different training categories on athlete load. S&C is mostly absent in this population, both during and outside of training camp (Chapter 5). This leads to a lack of physiological adaptation prior to competition and possibly suboptimal body composition changes (Chapter 7). This potentially may be rectified by use of the PLd_{ACC}-segRPE model (Chapter 6) to monitor the training category intensities and loads (Chapters 5 and 6) of individual athletes. The resultant data may be used to program technical/tactical sessions and micro/mesocycles that provide sufficient load undulation for athlete preparation alongside session content that is desirable for recreational participants. It would also be recommended for MMA athletes to conduct supplementary S&C in preparation for and during a training camp. Such training should target the enhancement of maximal force production, RFD, aerobic capacity and anaerobic capacity. This should be co-ordinated between MMA coaches and S&C/sport and exercise physiologists to ensure load and recovery is balanced between technical/tactical and S&C

sessions to minimise concurrent interference. Of note, whilst twelve sessions of HIIT at 90 - 115% $v\dot{V}O_2max$ appears to be sufficient to improve the exercise economy of MMA athletes who may be classified as 'trained', a greater volume and/or intensity of training should be targeted if improvements in $\dot{V}O_2max$ or ventilatory thresholds are sought (Chapter 8).

9.5 Limitations

Each of the studies in this thesis provide data on the practices, loads and effects of MMA training for the first time within the literature. As such, this work furthers our collective understanding of the MMA training process as well as producing data that may be used in future coaching applications and research to improve the provision for the athletes and coaches involved. Nevertheless, these studies are not without limitations, some of which apply to each study. Firstly, these data and analyses have been completed using athletes and participants based in the UK only. Other countries and regions may display different practices and outcomes to those reported here. Secondly, each of the participants were recruited from across the competitive spectrum of MMA, from amateurs preparing for their first international competition through to established professionals competing at the elite level. Due to the competition and club structures of the sport, however, each of these participants are trained by the same groups of coaches in the same sessions and same facilities. Accordingly, it is not thought that this inherent 'quirk' of the sport had significant impact on the results reported. The use of the ARMSS model in structuring the thesis and may have some limitations. Previous authors have critiqued the amount of time and resources required for a research question to progress from stage 1 to stage 8 if each step is followed sequentially, with these commitments unlikely to be appropriate in an applied setting (Drust and Green, 2013). Similarly, it has been highlighted that the ARMSS model appears to have minimal appreciation of the knowledge transfer process that largely determines whether produced data has any real world impact or not (Eisenmann, 2017). It may also be that the ARMSS model is too restrictive in terms of stage descriptors for use in applied field work such as conducted in this thesis. For example, Study 5 (Chapter 8) may potentially be classed as 'descriptive research' rather than a 'predictor of performance', given that it describes the responses to a training intervention with only a proposed link to a sports performance outcome measure. There being no stage specifically for intervention based descriptive studies may be a weakness of the model for non-clinical laboratory-based research programs. Despite these limitations, however, the ARMSS model still provides a robust framework to guide foundational research to understand sports or events where little data currently exist. There were also a number of limitations specific to each study that are discussed in turn.

Study 1 (Chapter 3)

The coaches interviewed were all recruited from one region in the UK. Therefore, the responses may only reflect the experiences and development of MMA within this specific region. In addition, whilst these clubs are established competitive training centres that produce international standard athletes, they would not necessarily be classified as 'elite' clubs. There is, however, evidence that the structure of these clubs is very similar to such 'elite' clubs in terms of their reliance on recreational members, coaches transitioning into this role primarily to financially support their own competition career and an absence of coaching qualifications and/or scientific support (Batra, 2019; Bujak et al., 2013; Spencer, 2012). There is also the possibility that each of the coaches interviewed have interest in the application and use of sport science in MMA, hence their agreement to take part in this study. This may reduce how generalisable the data are to other MMA coaches who may not be concerned with sport science or its use in their practice. Similarly, these data may not be entirely applicable to coaches from other sports. This, however, was not the aim of this particular study. Rather, the interview questions and interviews themselves were structured to provide a detailed enough account of each coach's practice to enable robust themes to be developed across the cohort. Specific details of each participating coach were also provided to allow the reader to draw comparisons between their own practice and background, and those of the coaches interviewed. As such, the reader should be able to recognise which elements or sections of the data are applicable to their context within and without the sport of MMA to better understand their own practice. Transferability and generalisability of the presented data should therefore be possible despite the relatively small sample (Braun and Clarke, 2013a; Smith and McGannon, 2018; Smith, 2018).

Studies 2 and 3 (Chapters 5 and 6)

Owing to the absence of an accepted performance outcome measure for MMA, responses to training load were measured using subjective (SQF) and proxy measures (PSQI, CRT and perceived soreness). As such, it is currently unknown how these training patterns influence the specific performance of the athletes involved. The Pittsburgh Sleep Quality Index (PSQI) is accepted to be a relatively blunt tool for the assessment of sleep (Gupta et al., 2017), with direct measurements via polysomnography or actigraphy being considered ‘gold standard’ for this purpose (Lastella et al., 2018; Roberts et al., 2019). Logistical limitations of using these techniques to attain regular measurements from multiple athletes across multiple separate clubs for eight consecutive weeks, however, made these options unfeasible for this particular project. Choice reaction time (CRT) and perceived soreness may also not be sensitive enough to reflect responses to training load or fatigue, with further research being required on both of these markers in studies with deliberate increases and decreases in load.

The cohort studied were mostly international standard amateurs and national standard professionals. Whilst the training practices of international standard professionals may be different, restrictions on duration and content caused by MMA training sessions including recreational paying customers is a common feature across the sport for professionals and amateurs alike, outside of a very small number of large training centres (Spencer, 2012). It is also common in MMA for even professional competitors to work in paid employment alongside their training, restricting the amount and frequency of training in a similar manner to amateur athletes. Therefore, training frequencies and patterns reported here may well be reflective of the majority of MMA athletes. There was a smaller number of recorded sessions for external load data in Chapter 6. This was due to the availability of Catapult Optimeye units for continuous collection for eight weeks across each club, meaning a compromise of two weeks at each club was reached. Finally, there was reliance on some self-reporting of training content and load for sessions completed by a small number of participants away from their main club. In this instance it was determined that having a more complete estimate of the athlete’s true training pattern and load was preferable to recording ‘no session’ where one actually occurred.

Study 4 (Chapter 7)

This study includes a relatively small sample size for the purposes of measuring statistically relevant changes in a paired samples design. The use of Bayesian analyses, however, reduces the need for large sample sizes to detect potential changes. Bayesian analyses compare the strength of the hypothesis against the null hypothesis using the observed data regardless of sample size or hypothetical repeat trials as is the case in frequentist analyses (Morey et al., 2016). The strength of Bayesian analyses are instead based on the prior, which in this case was an informed JZS prior r = .707, recommended for such analyses where there is little existing evidence to support a predicted effect size, as is the case here (Kruschke and Liddell, 2018b; Wagenmakers et al., 2015). In keeping with recommendations regarding use of default informed priors, and as discussed in Chapter 4, robustness checks were performed on each test with each reported where required in the corresponding results sections (van de Schoot and Depaoli, 2014; van Doorn et al., 2019; Wagenmakers et al., 2018).

Each of the participants were recruited from different clubs and regions of the UK, meaning it was not practically viable to record training content or load between the testing sessions, which means these results cannot be directly linked to specific training practices. Owing to the aforementioned absence of an MMA specific performance outcome measure, it is currently unknown how these results affect or relate to MMA performance, with this being a key area for future research. Each of the participants may have been at different stages of their 'weight making' practices during the post training camp testing, which may have influenced the body composition data reported. Despite this, and as discussed in the chapter itself, the data suggest that none had entered the RWL stage of this process so this may be considered to have minimal effect on the results. Though the participants reported to the laboratory on both testing sessions under standardised conditions (≥ 10 hours overnight fast) and all DXA scans were completed by an IR(ME)R registered operator to recommended practice protocols (Nana et al., 2015), exercise and dietary intake in the preceeding 24 hours was not standardised. Due to the potential for gastrointestinal, bladder and muscle glycogen content to influence body composition as measured by DXA (Nana et al., 2015), this may have affected the results reported. This study did not include a control group, meaning the observed results may have also occurred even with the addition of supplementary S&C training. Previous research (Kostikiadis et al., 2018), however, used a control cohort to demonstrate that MMA athletes completing a specific S&C programme have greater positive physiological adaptations than MMA athletes completing their normal training routine supplemented by generic circuit training common in MMA technical/tactical sessions (Chapter 5). As such, the results provided in this chapter have support in lieu of a control group.

Due to the post testing session occurring at the end of a pre-competition training camp, the lack of statistically relevant changes may also result from the participant's weight making practices and residual fatigue caused by 6-7 weeks of technical/tactical training. Neither of these potential influences can be entirely controlled in this study. Previous research, however, came to a similar conclusion regarding the null effect of MMA training periods on markers of force and endurance capacities in lieu of a training camp (Kostikiadis et al., 2018). Following this, there is support for the results reported in Chapter 7 even accounting for the potential for athlete fatigue. The tests chosen for this battery were not specific to MMA, as no such tests currently exist. Each, however, was chosen to provide a simple and direct measurement of a physiological capacity that is likely to be related to MMA performance whilst enabling comparisons between sports to occur (McGuigan, 2016).

Study 5 (Chapter 8)

Only one of the seven recruited participants was able to complete the study protocol due to a series of events beyond the control of the author. The timing of this study coincided with the reopening of MMA gyms and competitions following the COVID19 related 'lockdowns' of 2020 and 2021. As such, participants were more susceptible to injuries and illness in this time and many were accepting short notice (one - two weeks) competitive bouts, meaning they were unable to complete the full data collection process. Ongoing COVID19 restrictions also prevented direct coaching of resistance training interventions from taking place. Given the low S&C training exposure of this population, it was not deemed appropriate for remote coaching of resistance training programs to be used in this instance. Equally, it was not possible to intervene in the planning of technical/tactical loading patterns in this period. As such, a remote HIIT intervention was deemed the only approach available at this time. Whilst the participant was asked to refrain from making any changes to their dietary intake, this was not monitored. This, therefore, may have had an influence on the body composition changes reported in this chapter. The use of open, simulated bouts with different opponents as a performance measure has positive and negative aspects for measuring intervention effects. The ecological validity of an open simulated bout against a resisting opponent at competition pace and with physical impact is a positive aspect. This may provide indication of how a participant's pacing and external load in a live, competitive environment may change over time. This may come at the expense, however, of being able to control the activity profile and/or physiological demands of each simulated bout due to different movements and potentially different pacing being used in each bout. This reduces the experimental control of this part of the study, potentially increasing noise in the data (Maxwell et al., 2018). As such, results regarding the participant's performance changes in response to the intervention should be viewed with caution. The absence of changes in cardiorespiratory variables reported in this chapter may have also been an effect of residual fatigue from the participant's training in the days prior to the laboratory post intervention testing session. Whilst this cannot be entirely ruled out, the demonstrated improvement to economy and $v\dot{V}O_2max$ suggest that the participant was not fatigued during this session and was still able to reach maximal capacity.

9.6 Future Studies

This thesis has evaluated the training practices, loads and physiological effects of training in MMA for the first time in the literature. As such, these data provide the basis for several future studies to further our collective understanding of and support for this growing group of athletes.

1. Design and test longitudinal technical/tactical training plans in conjunction with MMA coaches using the training category intensity data reported here to determine more optimal loading patterns for athlete preparation.
2. Replicate Study 5 with intensity starting at 95% and increasing to 100% over three sessions per week to provide greater time at $\dot{V}O_2max$. This type of intervention should also be compared to other cardiorespiratory interventions such as low intensity steady-state interventions, 'game based' HIIT

interventions, and VT_2 'threshold' training interventions as suggested by previous authors (Harvey, 2018) to determine the most appropriate approach for the required sports performance outcome.

3. Investigate the effects of linear, step and concentrated S&C periodised models outside of training camp and conjugated periodised models within camp on markers of athlete fitness and sport performance outcome measures to determine the positive and negative effects of each and develop sport specific loading recommendations.
4. Investigate the relationship between torso-mounted accelerometry variables and MMA performance to determine the viability of such variables as training based sport performance outcome measures (Jeffries et al., 2021). This would support further studies investigating effects of different training practices and protocols on pre-competition training and MMA athlete development.
5. Investigate the effects of tapering and deloading strategies of different durations, methods and modes on sports performance outcome measures. This would inform further studies to determine any confounding effects of different AWL/RWL strategies used by athletes and coaches, and the effects of the proposed training plans developed in future studies 2 and 3 listed above.

9.7 Overall Conclusion

To summarise, the presented thesis has used the structure of the Applied Research Model for the Sports Sciences (ARMSS) (Bishop, 2008) to evaluate the coaching and training practices of MMA. Following qualitative interviews with professional MMA coaches, it was concluded that MMA training practices are restricted by the economic and competition structures of the sport. Sitting within ARMSS Stage 1, this study defined a number of potential problems in provision of athlete preparation. Field based observations then supported this finding by recording the training loads and intensities of MMA training practices for the first time. This revealed that within and between weekly changes in load and athlete fatigue are absent in this population. Evidence has also been provided that a pre-competition MMA training period does not result in positive physiological adaptations, potentially due to the flat loading pattern and low S&C exposures reported. These results provide descriptive data of MMA training practices within ARMSS Stage 2 and may contribute to hypothesis development for future research alongside informing future coaching practice. Finally, it was demonstrated how a supplementary high-intensity aerobic training program may provide enhanced exercise economy for a trained MMA athlete, which may potentially be linked to performance outcomes. As such, this study sits in ARMSS stage 3. Therefore, following a pragmatic mixed methodology this thesis provides novel data that highlight several areas for improvement in current MMA training practices, but also provides potential solutions and tools to assist coaches in their work. This thesis may be used to improve MMA training planning and monitoring methods, whilst stimulating future research to assist coaches and practitioners in this ongoing improvement.

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Appendices

Appendix A - 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 activity-to-recovery (A: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.
	(Plush et al., 2021a)	N/A#	Review of existing studies related to testing in combat sports and MMA	Authors suggest a physical and physiological testing battery for MMA.
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, 2010a)	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 activity-to-recovery ratio (A: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 A:R research to investigate the intermittent nature of MMA. Suggests basing training on A:R and individual athlete's responses until more research is conducted. *Nb. A:R = activity-to-recovery ratio*
Injuries & Concussion	(Seidenberg, 2011)	Non-systematic narrative review	Review of MMA injury studies available at the time.	In bout injuries are similar to other combat and contact sports. More research required to determine whether the introduction of the unified rules has reduced injuries or not, particularly brain injuries.
	(Lockwood et al., 2018)	Systematic review of traumatic brain injuries in MMA, n = 18 peer reviewed articles	Occurrence of KO/TKO = 28.3 – 46.2% of bouts; Average No. of KO/TKO during competitive career = 6.2	Studies included in review displayed inconsistent diagnosis and reporting methods of KO/TKO and none included longitudinal or follow-up data. MMA appears to be associated with repeated head trauma and potentially long term negative neurological effects. *Nb. KO = knockouts, TKO = technical knockouts*
Mass Regulation	(Coswig and Del Vecchio, 2016)	N/A#	Response to Crighton et al. (Crighton et al., 2016) suggesting alternatives to issues of RWL and RWG	Argues that statement of 2% of BM loss can increase brain trauma risk is based on research with confounding variables and the occurrence of relative energy deficient syndrome (RED-S) in MMA is speculative. Agreement made that weight cutting practices should be re-evaluated in light of research.
	(Langan-Evans et al., 2017)	N/A#	Brief review of rapid weight loss (RWL) in sports such as MMA	Discussion of the issues surrounding RWL and RWG in MMA, highlighting reported kidney damage, altered hormone balance and hyperphagia.
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., 2015b)	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	Weekly sRPE (au):	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.

		for a one night international tournament	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·min^{-1}; V̇O^{2}max = 55.2 ml·kg·min^{-1}	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·L^{-1}, post 483.9 nmol·L^{-1}; B pre = 458.8 nmol·L^{-1}, post = 641.3 nmol·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·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	A: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); 3rd round: Longest = 289.6 ± 42.3 (WW) Shortest = 246.3 ± 89.1 (HW)	A:R profile of MMA bouts is significantly different between divisions and between rounds, demonstrating intermittent activity and potential differences in pacing strategies between divisions. *Nb. A:R = activity-to-recovery ratio*
	(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;	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.

			Females = 15 ± 6.28.	
	(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., 2015a)	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; A: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 et al., 2016a)	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 et al., 2016b)	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 ($nmol{\cdot}L^{-1}$): 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	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.
	(Ghoul et al., 2017)	n = 12 male MMA competitors paired in sparring bouts, age = 26 ± 5	C ($ng{\cdot}dL^{-1}$): Pre = 88.3 ± 19.6, Post = 131.2 ± 56.4, 30min post = 117.1 ± 46.3, 24H post = 79.3 ± 23.2;	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

			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.	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.
	(Wiechmann et al., 2016)	n = 10 male MMA competitors, (age = 28 ± 5.7, mass = 78 ± 13.5 kg, stature = 181.5 ± 7.1) taking part in national standard competition	CK (U·L^{-1}): pre = 236 ± 190; 2 hrs post = 367 ± 254; 24 hrs post = 829 ± 753; 96 hrs post = 222 ± 135. Mb (µg·L^{-1}): pre = 29 ± 5; 2 hrs post = 210 ± 122; 24 hrs post = 92 ± 27; 96 hrs post = 35 ± 11.	Muscle damage from MMA bouts presents for up to 24 hrs post bout, but dissipates within 96 hrs. Mb may be linked to dehydration during weight cut. *Nb. CK = creatine kinase, Mb = myoglobin*
	(Stellpflug et al., 2021)	n = 904 bouts ending in chokes from a sample of 5,834 bouts	Chokes account for 15.5% of total bout outcomes and 76.2% of submission outcomes. Rear naked chokes = 49.1% of chokes. Rear naked choke, guillotine, arm-in guillotine and triangle = 89.4% of chokes. Loss of consciousness occurs in 11% (count = 97-107) of chokes.	Submission due to chokes account for ~1/6 of MMA bout outcomes, with a small number of techniques being most commonly used. Loss of consciousness is relatively uncommon.
	(Follmer et al., 2021)	n = 1,903 professional MMA bouts, 1,728 = male bouts, 175 female bouts	17.3% of male bouts ended in submission, 21.1% of female bouts ended in submission.	Most common submission type in each division were chokes.
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	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.

			maximus and rectus femoris) during strikes on heavy bag.	
	(Schick et al., 2010)	n = 11 male regional MMA competitors, age = 25.5 ± 5.7	Body fat = 11.7 ± 4%; $\dot{V}O_2max$ = 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	$\dot{V}O_2max$ (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; Relative hang clean (kg·kg^{-1}) Pre = 1.09 ± 0.07, Post = 1.06 ± 0.11;	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.
	(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) ($g{\cdot}cm^3$) = 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*
	(Mekhdieva et al., 2021)	n = 13 international standard MMA participants (INT) (age = 25±4.6; mass = 78.5±210kg; stature = 178.6±4.5cm) and n = 16 national standard MMA participants (NAT) (age = 24.5±3; mass = 78.8±8.2kg; stature = 178.8±5.9cm)	Wingate 30s anaerobic power: Power at Lac threshold: INT = 12.22±0.89 $W{\cdot}kg^{-1}$ NAT = 11.36±1.39 $W{\cdot}kg^{-1}$ Average power: INT = 8.29±0.32 W NAT = 8.14±0.61 W	MMA participants display relatively low anaerobic power in comparison to other sports, with NAT participants displaying lower anaerobic power than INT participants.
	(Plush et al., 2021b)	n = 6 MMA participants. No descriptive data provided.	IMTP peak force = 2,684±597 N; 3.32±0.6 $N{\cdot}kg^{-1}$ CMJ height = 26±6.5 cm $\dot{V}O_2max$ = 54±13.8 $ml{\cdot}kg{\cdot}min^{-1}$ $\dot{V}O_2$ at VT_1 = 37.9±11.1 $ml{\cdot}kg{\cdot}min^{-1}$ $\dot{V}O_2$ at VT_2 = 48.8±12.5 $ml{\cdot}kg{\cdot}min^{-1}$ FM assessed by DXA = 17±11% BMD assessed by DXA = 1.27±0.02 $g{\cdot}cm^2$	Descriptives of MMA participants performance in a testing battery to propose it's use for assessment of MMA athlete capability *Nb. IMTP = isometric midthigh pull; CMJ = countermovement jump; VT = ventilatory threshold; FM = fat mass; BMD = bone mineral density; DXA = dual energy x-ray absorptiometry*
Mass Regulation	(Mendes et al., 2013)	n = 18 combat sport athletes (5 MMA), split into n = 10 who have engaged in cyclic RWL prior to competition (WC) and n = 8 who have not engaged in cyclic RWL prior to competition (NWC). (WC age = 28.7 ± 7; NWC age = 21 ± 3)	Participants RWL kept to ≤5% of BM. WC: Pre = 77.8 ± 12.3 kg, Post = 73.8 ± 11.4 kg. NWC: Pre = 73.5 ± 9.5 kg, Post = 69.5 ± 9 kg. Plasma Lac significantly elevated in both groups ($p<0.001$) post 8x15s arm crank bouts with 20s rest, but no differences between groups.	RWL displayed no effect on arm crank power or plasma lactate pre to post. Results suggest that regular undertaking of RWL does not affect (improve/decrease) the physiological performance response. *Nb. RWL = rapid weight loss*
	(Jetton et al., 2013)	n = 40 MMA competitors (38 male, 2 female)	Participants gain 3.4 ± 2.2 kg (4.4% of BM) in the 22H post weight in and prior to competition. 39% present with urine specific gravity (U_{sg}) ≥1.021 immediately prior to competition, whilst 11% presented a U_{sg} ≥1.030.	Results suggest that MMA competitors enter bouts in a state of significant to severe dehydration, despite undertaking rapid weight gain (RWG) immediately prior to competition.
	(Andreato et al., 2014)	n = 8 MMA competitors, age = 22 ± 5	Mean BM lost during RWL = 5.1 ± 5.4 kg (6.6 ± 6.8%); number of days of RWL = 12 ± 13; Most common RWL methods always used: increased exercise = 50%, fluid restriction = 37.5%, dieting = 25%, fasting = 25%;	MMA participants tend to lose a large amount of BM via restricting fluids and calories and by training in saunas or heated rooms. No significant differences in salivary osmolality or mood states reported.

			Most common RWL methods sometimes used: skipping meals = 50%, heated training rooms = 50%, dieting = 37.5%, diuretics = 37.5%, sauna = 37.5%. 100% reported never using vomiting.	
	(Coswig et al., 2015)	n = 17 MMA competitors, age = 27.4 ± 5.3. n = 12 not engaged in pre bout RWL, n = 5 engaged in pre bout RWL.	Sig. differences between groups: Creatinine (µmol.L^{-1}): Non RWL pre = 101.6 ± 15, post = 142 ± 23; RWL pre = 69 ± 10, post = 79 ± 16 LDH (U.L): Non RWL pre = 211.5 [183.3 – 236], post = 231.1 [203 – 258.7]; RWL pre = 390.1 [370.5 – 443.5, post = 463.5 – 540.5] AST (U.L): Non RWL pre = 30.6 [221. – 37.9], post = 32.2 [22.2 – 41.8]; RWL pre = 39.9 [32.5 – 76.5], post = 72.1 [38.5 – 112.5].	RWL group displayed increased muscle damage markers and catabolic expressions post bout, with significantly greater amount of creatinine, LDH and AST suggesting increased muscle and liver trauma. *Nb. Groups had different weigh in times (RWL 24H pre, non RWL 30mins pre)* *LDH = lactate dehydrogenase* *AST = aspartate aminotransferase* *Results of LDH and AST reported as Median [interquartile range]*
	(Crighton et al., 2016)	n = 30 competitors from WW to FlW, questionnaire survey.	Body mass (BM) reduction = 9 ± 2% in the week before weigh-in; 5 ± 2% in the 24H before weigh-in	Correspondence detailing the known effects of rapid weight loss (RWL) and rapid weight gain (RWG) in MMA. Suggests changes to weigh in structures including addition of more weight divisions, an upper limit placed on RWG and a reduction of the RWG window.
	(Barley et al., 2018)	n = 637 combat sports athletes, of which n= 70 were MMA competitors. Online survey completion.	BM lost for competition: 9.8 ± 7.9 kg; BM lost in 14 days prior to competition: 5.6 ± 3.1 kg; BM lost 24H prior to competition = 3.4 ± 1.9 kg; BM regained 7 days post competition = 7.8 ± 3.7 kg	MMA competitors regularly lose more total body mass during weight reduction, more body mass in the 24H prior to weigh in and regain more body mass post weigh in than other combat sports (including wrestling, boxing Brazilian jiu jitsu and taekwondo). Most common methods: gradual dieting (93%), increased exercise (78%), fluid restriction (76%) and sauna (76%).
	(Matthews and Nicholas, 2017)	n = 7 male MMA competitors, age = 24.6 ± 3.5	Rapid weight loss (RWL) = 5.6 ± 1.4 kg (8 ± 1.8% BM); Rapid weight gain (RWG) = 7.4 ± 2.8 kg (11.7 ± 4.7% BM); Classed as dehydrated during weigh in = 57% (1,033 ± 19 mOsmol.kg^{-1}), severely dehydrated during weigh in = 43% (1,267 ± 47 mOsmol.kg^{-1}), dehydrated immediately prior to competition = 14% (930 mOsmol.kg^{-1}).	MMA participants tend to cut weight via restricting fluids (86%) and calories (86%), increasing exercise (71%), 'water loading' (57%) and by training in saunas (43%). Weight cuts are severe, with some participants competing with a BM 2 - 3 divisional thresholds above what they officially weighed in at. Authors link the magnitude of RWL and methods used to recent fatalities in weight regulated combat sports.
	(Ribas et al., 2017)	n = 25 MMA competitors, age = 24.4 ± 4.1, paper-based survey.	BM lost for competition: 9.3 ± 3.2 kg; Number of days spent reducing BM = 24.5 ± 11.5; BM regained post competition = 9.5 ± 4.4 kg;	MMA participants tend to cut weight via restricting fluids (72%) and calories (56%), using saunas (60%) or heated training rooms (32%) whilst wearing plastic clothing (44%). Practices are mostly prescribed and supervised by coaches (72%) and training partners (64%), rarely by medical or physiology trained personnel (16%).

	(Soolaman et al., 2017)	Male and female MMA competitors engaged in RWL and RWG, n = 50 at first sample point (S1, 10-14 day prior), n = 40 at second sample point (S2, 24H prior), n = 26 at third sample point (S3, 1-3H prior).	BM: S1 = 74.44 ± 13.11 kg, S2 = 70.77 ± 12.26 kg, S3 = 74.07 ± 13.33 kg; Grip strength: S1 = 112 ± 25 kg, S2 = 100 ± 23 kg, S3 = 110 ± 24 kg; Urine specific gravity (U_{SG}, mmol.L^{-1}): S1 = 1.008 ± 0.003, S2 = 1.032 ± 0.004, S3 = 1.007 ± 1.003; Cognitive function (s): S1 = 41.39 ± 4.78, S2 = 42.44 ± 5.92, S3 = 38.48 ± 4.58.	Significant amount of weight lost during cut due to dehydration, having a significant impairment of upper body strength and cognitive function, none of which returned to baseline 24H after weigh-in in participants with greatest magnitude of BM loss.
	(Brandt et al., 2018)	Male MMA competitors age = 25.6 ± 4.5, n = 9 engaged in RWL, n = 3 who did not engage in RWL	RWL group displayed BM loss = 11.6 ± 3.5 kg over 30 days; non-RWL group displayed no BM reduction; sig. between group differences in BM 7 days prior to competition and at weigh in.	Rapid weight loss increases confusion and total mood disturbance throughout weight loss process and increases anger during the official weigh in according to BRUMS scale.
	(Kasper et al., 2018)	Case study of n = 1, Age = 22, BM = 80.2 kg, stature = 180 cm	7 weeks of week reduction prior to competition; BM reduced = 18.1%, 9.3% in final 24H due to severe dehydration; RMR = -331kcal; T at weigh in = 1.8 nmol.L^{-1}; Serum creatinine = 177 µmol.L^{-1}; Urea = 12 mmol.L^{-1}; Osmolality = 322 mOsmol.kg^{-1}	Use of RWL via extreme dehydration in the final 20H prior to weigh in led to evidence of relative energy deficiency (RED-S) and acute kidney injury. Participant also displayed signs of rapid changes to body fat mass (hyperphagia) post bout due to extreme energy restriction. Such practices put MMA competitors at risk of harm. *RMR = resting metabolic rate*
	(Hillier et al., 2019)	n = 287 male professional (Pro) and amateur (Ama) MMA competitors (age = 27.2 ± 5.2, mass = 81.8 ± 12.1 kg), 27 female professional and amateur MMA competitors (age = 28.8 ± 5.2, mass = 63.2 ± 8.1 kg), online survey	BM lost for competition: Pro male = 8.3 ± 3.5 kg, Ama male = 6.4 ± 3.1 kg, Pro female = 5.5 ± 2.7 kg, Ama female = 4.8 ± 2.7 kg. BM lost in week before competition: Pro male = 5 ± 2.6 kg, Ama male = 3.4 ± 2.1 kg, Pro female = 3.2 ± 1.7 kg, Ama female = 2.1 ± 1.2 kg. BM lost 24H before weigh in: Pro male = 3.1 ± 1.9 kg, Ama male = 2 ± 1.6 kg, Pro female = 2.1 ± 1.4 kg, Ama female = 1.2 ± 1.6 kg.	RWL is achieved mostly via gradual dieting (81.2% reporting always using this method, 12.1% reporting sometimes using this method), water loading (50.6% reporting always using this method, 22.3% reporting sometimes using this method) and restricting fluid intake (46.8% reporting always using this method, 24.5% reporting sometimes using this method). Coach is greatest influence on use RWL methods (male = 29.3%, female = 48.1%, Pro = 22.3 %, Ama = 38.6%), followed by training partner (male = 16.7%, female = 3.7%, Pro = 17.6%, Ama = 13.9%). Only females (29.6%) made significant use of dieticians (male = 10.1%, Pro = 14.2%, Ama = 9.6%), with little use of medical advice (male = 0.7%, female = 0%, Pro = 0.7%, Ama = 0.6%).
	(Santos-Junior et al., 2020)	n = 179 professional, male and female MMA competitors, age = 25 (19-37), mass = 77 (57-115) kg, stature = 176 (153-196) cm.	Greatest mass lost during RWL = 12 (4-33) kg; Usual mass lost during RWL = 10 (3-21) kg, 13 (3-23) %; Days spent engaged in weight loss = 20 (2-90);	MMA participants tend to cut weight via increasing energy expenditure (63.1%), restricting fluids (62.6%) and calories (28.5%), using saunas (30.7%) or heated training rooms (26.8%) whilst wearing plastic clothing (55.9%). Practices are mostly prescribed and supervised by coaches (76%) and training partners (55%), rarely by medical or physiology trained personnel (41%) or dieticians (30%).

			Mass regained in week after competition = 9 (2-22) kg.	*Nb. Median (range)*
	(Connor and Egan, 2019)	n = 30 amateur (15) and professional (15) MMA competitors (age = 25.5 ± 4.4, mass = 78.3 ± 9.7 kg, stature = 179 ± 0.07 cm)	Usual BM reduction = 7.9 ± 3.1 %. Usual BM regain post bout = 100 [85, 133]%	MMA participants tend to cut weight via gradual dieting (62.1%), restricting fluids (62.1%) and calories (31%), using saunas (27.6%) or heated training rooms (13.8%) whilst wearing plastic clothing (31%) with water loading also being prevalent (62.1%). Practices are mostly prescribed and supervised by coaches (37.9%) and training partners (41.4%), rarely by medical or physiology trained personnel (3.7%) or dieticians (14.3%). *Nb. BM = body mass, Median[interquartile range]*
	(Alves et al., 2018)	n = 12 male MMA athletes (age = 20.1 ± 1.2 years; stature = 174.2 ± 1.2 cm habitual body mass (BM) = 73.8 ± 10.9 kg; post weigh in BM = 66.5 ± 9.8 kg; in competition BM = 71.1 ± 10 kg)	Handgrip strength (kg): pre RWL = 51.7 ± 5.6; pre RWG = 47.8 ± 6; post RWG = 49.3 ± 5.4. Urine density (g·ml): pre RWL = 978.6 ± 55.6; pre RWG = 1,018.8 ± 9.3; post RWG = 1,019.2 ± 9.3.	Rapid weight loss (RWL) causes significant reductions in handgrip strength and urine hydration, despite post weigh-in rapid weight gain (RWG). BM is not returned to pre-RWL levels by RWG.
	(Park et al., 2019)	n = 90 professional male MMA competitors	Weight cutting advice from social media = 4.9 ± 1.3 different weight cutting methods used; Weight cutting advice from registered dietician = 3.8 ± 1.7 different weight cutting methods used; Weight cutting advice from team mates = 4.5 ± 1.4 different weight cutting methods used.	MMA competitors use a variety of different weight cutting methods, tend to use more methods when taking advice from team mates and social media, fewer methods when taking advice from a registered dietician.
	(Murugappan et al., 2021)	n = 512 professional MMA athletes (455 male, 57 female); data from CSAC official weigh ins (24 hours pre bout) and day of bout weigh ins.	503 (98%) of sample regained 5.5 ± 2.5 kg (8.1 ± 3.6%) BM between weigh ins. International standard participant RWG = 5.8 ± 2.5 kg; Regional standard participants RWG = 5.3 ± 2.5 kg. Sig difference between groups.	RWG is ubiquitous in MMA and appears to be greater amongst high level competitors. Over 25% of males and 33% of females regained >10% BM. *Nb. BM = body mass; RWG = rapid weight gain, CSAC = California State Athletic Commission.*
Injuries & Concussion	(Kochhar et al., 2005)	n = 1 participant performing takedowns (age = 33, mass = 80 kg), 1 participant being taken down (age = 27, mass = 93 kg); 10 trials of four different takedown techniques	Force on impact; driving force on head (N): O goshi = 2,566.2; 178.3; Suplex = 2,848.2; 197.9; Souplesse = 2,801.2; 194.6 Guillotine drop = 1,231.4; 85.5	Motion analysis used to suggest MMA takedowns elicit same forces on the neck as whiplash from car crashes. Takedown techniques studied are not commonly seen/used in MMA competition.
	(Bledsoe et al., 2006)	n = 171 professional bouts, 220 MMA participants.	Injury rate = 28.6 per 100 bout participations; Facial lacerations = 47.9%; Hand injuries = 13.5%; Eye injuries = 8.3%; TKO = 39.8%; KO = 6.4%	Injury types and incidence in competition similar to other combat sports, with lower rates of knockout. *TKO = technical knockout; KO = knockout*

	(Buse, 2006)	n = 642 professional bouts; 1,284 male MMA participants	Bout stopped due to: Head impact = 28.3 ± 3.4%; Musculoskeletal stress (submission) = 16.5 ± 2.9%; Misc. trauma = 27 ± 3.4% (± = 95% CI)	Blunt force trauma to head responsible for majority of competitive bouts being stopped. *Nb. Majority of sampled bouts occurred before the adoption of the unified rules.*
	(Ngai et al., 2008)	n = 635 professional bouts; 1,270 MMA participants	Injury rate = 23.6 per 100 bout participations; Loss of consciousness = 16.5 per 1,000 athlete exposures; Lacerations = 17.3% of bouts; Facial injuries = 10.6% of bouts; Upper limb injuries = 10.1% of bouts	Reported injury rates are similar to other combat sports, with no statistical relationships to participant age, weight or bout experience.
	(Rainey, 2009)	n = 55 MMA male and female participants, amateur and professional, age range = 18 – 39, questionnaire survey of MMA activity related injuries	Most common injuries: Contusion = 29.4%; Strain = 16.2%; Sprain = 14.9% Most commonly injured body regions: Head/face/neck = 38.2%; Lower extremities = 30.4% Upper extremities = 22.7%	Estimated 3 times the number of injuries occurring in training than in competition, mostly to the head and face, 61.3% of participants not wearing head guards in training.
	(Scoggin III et al., 2010)	n = 116 professional MMA bouts, 179 male MMA participants (age range = 18 – 40), post bout medical physician diagnoses	Total injuries = 55; Lacerations = 28; Concussions = 11 (7 = brief loss of consciousness); Orthopaedic injuries = 11; Facial injuries = 5; Injuries per 100 bout participations = 23.7	Injury rates and types in competition similar to other combat sports. *Nb. Some of sampled bouts occurred before the adoption of the unified rules.*
	(Galetta et al., 2011)	n = 39 boxing and MMA competitors (MMA n = 12), age = 24[16-53] *Nb. Median (range)*	King-Devick test scores: No head trauma group (n=31): pre bout = 42.7[32-58.2], post bout = 41.5[30.9-58.8]; Head trauma group (n=8): pre bout = 45.9[40.1-51.7], post bout = 59.9[50.9-69.4]; Loss of consciousness group (n=4): pre bout = 47[41.9-51.7], post bout = 64.9[62.9-69.4].	Observed head trauma during boxing and MMA competition is related to an increase in King-Devick scores (a proxy measure of concussions and brain trauma), which is exasperated by loss of consciousness. The King-Devick test may be a useful tool for early stage assessment of concussion in the field.
	(Heath and Callahan, 2013)	n = 112 male, 7 female MMA trained participants (competitive experience not stated), age = 26.5 ± 7.4	Day per week sparring = 2.5 ± 1.4; Mins sparring per day = 63.3 ± 40.3; No. of KO's suffered in training = 3.2 ± 4.9; No. of TKO's suffered in training = 3.2 ± 4.9;	Nearly 15% of self-reporting participants reported being knocked out in training and nearly 33% reported a technical knockout in training with high subjective ratings of concussion. The high amount of sparring conducted and short RTT times places MMA participants at risk of long-term neurocognitive function impairment, regardless of whether they compete or not. *Nb. KO = knockout, TKO = technical knockout*

			Post-Concussion Scale score (PCS) = 17.5 ± 18.5; Days return to train (RTT) = 5.6 ± 11.7	
	(Shin et al., 2013)	n = 81 male professional MMA competitors, age = 28.2 ± 4.8; n = 74 professional male boxers, age = 28 ± 6.3	MMA No. of bouts = 12.1 ± 14.1, No. of KO's = 1 ± 2.1; boxing No. of bouts = 13.2 ± 15.7, No. of KO's = 1.1 ± 2	Both MMA competitors and boxers display microstructural brain damage. Number of KO's can predict microstructural brain damage in MMA participants with no differences to boxers. Number of total bouts not related to brain microstructural damage. *Nb. KO = knockout, TKO = technical knockout*
	(Bernick et al., 2013)	n = 70 MMA competitors; age = 29.2 ± 5; mass = 75.7 ± 12.1 kg	Age when started competing = 19.9 ± 6.3; Total years competing = 9.4 ± 7.2; Total No. of bouts = 24.1 ± 17.6; No. of bouts per year = 4.4 ± 8.3; No. of KOs = 0.9 ± 1.4	Ongoing use of competitive bout experience and MRI based brain volume measurements. Authors suggest fight exposure score (FES - a composite scoring criteria based on the number of total bouts and the number of bouts per year, scoring range = 0 – 4) may be used as a proxy measure of brain volume reductions due to MMA related head trauma. *Nb. KO = knockouts*
	(Hutchison et al., 2014)	n = 844 international standard, professional MMA bouts	KO rate = 6.4 per 100 athlete exposures (AE); TKO rate secondary to repetitive strikes = 9.5 per 100 AE; Ave time between KO-strike and bout stoppage = 3.5 s (range = 0 – 20 s); Ave No. strikes to head after KO-strike = 2.6 (range = 0 – 20); Ave strikes in 30 s before TKO stoppage = 18.5 (range = 5 -46), 92.3% to the head	Rates of KO's and TKO's higher than other combat and contact sports, high incidence of repetitive strikes after the KO causing strike. Odds ratio (OR) of suffering a KO or a TKO significantly increases from age of 24 to 30 and from 30 to 35. *Nb. KO = knockout, TKO = technical knockout*
	(Lystad et al., 2014)	Meta-analysis n = 6 eligible MMA injury related studies	Most common injured areas: Head = 66.8 – 78% Most common injury type: Lacerations = 36.7 – 59.4% Concussions = 3.8 – 20.4% prevalence; Bout losers 3 times more likely to be injured than bout winners.	Injury incidence seems to be greater in most other combat sports, but similar to boxing. More injury research needed regarding the severity of injuries and potential risk factors in training and competition.
	(McClain et al., 2014)	N = 711 amateur and professional male and female bouts, post bout medical physician diagnoses	Incidence of KO: Males = 29.1%; Females = 32.5%; Injuries classed as 'altered mental state' = 21.5% Injury rate per round of exposure = 5.6%; Most common injury type: lacerations and abrasions = 38%	Injury rates are similar to other contact sports. Results demonstrate that post bout follow-up medical procedures could be implemented/further researched to minimise the effects of head impacts and concussions. *KO = knockout*
	(Bernick et al., 2015)	n = 131 professional MMA participants (age = 27.7, range = 18 – 44), 93 professional boxers (age = 28.2, range = 19 - 40)	Estimated reduction in volume per bout (MMA only): Thalmus: L = 0.2%, R = 0.3%; Hippocampus = 0.1%; Caudate (MMA and boxing) = 0.3%.	Repetitive head trauma led to a reduction in cognitive function and processing speed alongside reduced brain volume in MMA competitors. Reductions have a relationship to the number of bouts and increase in fight exposure score (FES). *Nb. FES - a composite scoring criteria based on the number of total bouts and the number of bouts per year, scoring range = 0 – 4*

			Cognitive processing speed reduction per bout = 0.19%; Cognitive processing speed reduction per increase in FES = 2.1%	
	(Mayer et al., 2015)	N = 9 professional MMA competitors, age = 28.23 ± 4.94; n = 10 non-MMA control participants, age = 28.14 ± 5.08.	Changes in MMA group over a 1-year period in comparison to control (Cohen's d ES): Reduced memory d = -1.06; Reduced cognitive processing speeds d = -0.93; Reduced brain white matter volume d = -1.4; No correlation to self-reported metrics of injury or concussion.	Repeated concussive and sub-concussive blows appear to cause structural and neurochemistry changes in the brain, leading to negative effects on the cognitive functions of the participants over a relatively short time span. This is without injuries being apparent to the participant themselves.
	(Jensen et al., 2016)	Non-systematic review of MMA and combat sports literature from 1980-2015	Injury incidence = 22.9 – 28.6 per 100 bout exposures.	Estimated that 3 times the number of injuries occur in training than in competition, mostly to the head and face, followed by the extremities. Much more research needed.
	(Ji, 2016)	n = 455 MMA participants who had visited a medical institution three times, questionnaire survey	Most frequently reported injuries: Laceration = 37.3%; Concussion = 20.8%; Contusion = 16.5%; Most frequently reported body area: Arm = 30.4%; Neck = 17.6%; Head = 14.2%.	Injuries may be reduced by the development of an alert system in training venues and standardising safety measures. Coach education about causes and types of injuries should be performed periodically.
	(Karpmman et al., 2016)	Post bout medical examinations 2000-2013, n = 1,181 MMA participants and n = 550 boxing participants.	Incidence of injury: MMA = 59.5%, boxing = 49.8%; Most common injury: MMA = contusions (56%), boxing = contusions (44%); Concussions: MMA = 8.3%, boxing = 10.4%; Loss of consciousness: MMA = 4.2%, boxing = 7.1%	The injury rate of MMA is greater than in boxing, but with more injuries being of low seriousness (contusions), with fewer concussions and losses of consciousness in MMA compared to boxing.
	(Venter et al., 2017)	n = 300 professional bouts, n = 173 male MMA participants, age range = 18 – 44.	Injury rate = 37%; Most common injuries (RTP time in weeks): Head/face/neck = 22%(2.2); Traumatic brain injuries = 6%(4); Upper limb = 4%(3.7); Odds ratio (OR) of losing participants suffering an injury = 2.16	Incidences of injury in African MMA are higher than those reported in the USA (24%), as are incidences of traumatic brain injury higher in comparison to the USA (1.8%). Potentially linked to the less stringent safety procedures in African MMA (less pre-bout screening, later referee stoppages) and/or the less structured coaching and training practices. *RTP = return to play*
	(Mayer et al., 2017)	n = 13 MMA participants, age = 28.2 ± 4.9	MMA in comparison to control group (Cohen's d): Memory = -1.06; Processing Speed = -0.93;	Key aim of study was to test validity of a clinical assessment of CTE prior to irreversible symptoms being displayed. Secondary outcome shows neurological effects of MMA participation.

			WTAR = -0.90; mTBIs = 2.11; RPSQ-3 = 1.79.	*Nb. WTAR = Wechsler Adult Reading Test; mTBIs = mild traumatic brain injuries (knockouts/concussions); RPSQ-3 = Rivermead Post-concussion Symptoms Questionnaire; CTE = chronic traumatic encephalopathy.*
	(Fares et al., 2019)	n = 285 international professional bouts from January 2016 to July 2018	Overall injury rate per 100 athlete exposures (AE) = 51; Male injury rate per 100 AE = 54; Female injury rate per 100 AE = 30; Head injuries per 100 AE = 34; KOs in male bouts = 36%; KOs in female bouts = 14%; Submissions in male bouts = 16%; Submissions in female bouts = 36%	Trend line analyses found that as the divisional mass limit increases, so too does the overall injury rate, head injury rate and KO rate. Upper limb injuries, submission frequency and decision frequency decrease as divisional mass limit increases. MMA has a high injury rate which is dependent on gender, mass and bout outcome. *Nb. KO = knockouts*
	(Curran-Sills, 2018)	n= 21 amateur and professional MMA bouts cancelled due to findings of pre-bout medical screening	Cancellation reasons: Failure to obtain neuroimaging results = 28%; Neuroimaging abnormalities = 24%; Incomplete pre-bout screening = 16%; Exceeding of maximum weight differential = 16%	Report suggests implementation of guidelines for pre and post-bout neuroimaging for all MMA competitors, sport-wide medical screening standards, longitudinal approach and management of weight monitoring informed by medical physicians and governing bodies having oversight of the match-making process.
	(Curran-Sills and Abedin, 2018)	n = 686 amateur and professional MMA participants, medical physician diagnoses post bout.	Number of injures = 162; Number of injured bout winners = 19; Number of injured bout losers = 130; Injuries per 100 minutes of bout exposure = 4.1[3.48, 4.7]; Concussions per 100 minutes of bout exposure = 14.7[11.8, 17.2]. *Nb. [95%CI]*	Concussions per contest (0.294) is similar to other contact sports (American football, rugby union). Suggestions made that amateur competitors should not be exposed to the same risks as professional competitors, longitudinal approach and management of weight monitoring informed by medical physicians, governing bodies having oversight of the match-making process, use of a modified standing 8 count in amateur competition and coach education programmes around return to play guidelines and procedures. *Nb. Concussion assumed due to participant being knocked out or technically knocked out.*
	(Stephenson and Rossheim, 2018)	n = 409 cases of MMA participants reporting to medical emergency rooms with injuries. Data used to estimate injury rates across entire MMA population	Estimated total number of injuries across MMA = 16,541[9,487, 23,595]; Most commonly occurring estimated injuries: Contusions = 3,362[2,022, 4,703]; Fractures = 2,947[1,663, 4,230]. *Nb. [95%CI]*	Estimated injury occurrence in MMA greater than Brazilian jiu jitsu (12,538 [6,584, 18,492]) and judo (10,102[6,447, 13,757]). Findings can be used to improve safety standards in training and competition across different levels of performance, especially with regards to use and quality of safety equipment in training. Monitoring of participants should also be improved. *Nb. KO/TKO = knockout/technical knock out*
	(Follmer et al., 2019)	n = 1,903 professional MMA bouts	KO/TKO per 100 athlete exposures: FlW = 5.95; BW = 12.29; FW = 13.07; LW = 13.14; WW = 15.27; MW = 19.53; LHW = 20.8; HW = 26.09; WSW = 3.96; WBW = 10.81	The greater the mass limit of the division, the greater the risk of bouts ending in concussive events (KO/TKO), regardless of gender. *Nb. KO/TKO = knockout/technical knock out* *WSW = women's straw weight* *WBW = women's bantamweight*
	(Lim et al., 2019)	n = 1 case study of MMA practitioner from age ~30 – no indication of competitive or not, age = 40, reports cognitive changes from 2010 - 2013	Weschler Memory Scale sequencing scaled score: 2010 = 14, 2013 = 8; Weschler Memory Scale delayed recall scaled score: 2010 = 16, 2013 = 9;	Authors link cognitive degeneration to head trauma and transient asphyxiation related to MMA training, but do not discuss the occurrence of lack thereof of head trauma during the participant's time in the armed forces, which is mentioned but not discussed. Participant's worsening condition assumed by authors to be entirely due to MMA training, leading to calls for improved education and safeguards for MMA participants.

			Weschler Memory Scale immediate recall scaled score: 2010 = 14, 2013 = 6.	
	(Miarka et al., 2019b)	n = 440 professional MMA bouts (n = 220 ending in a doctor stoppage, n = 220 no doctor stoppage) over a 12-year period.	Most frequent bout ending injuries = lacerations and/or cuts (176, 80%, 17.8 per 1,000AE); Most frequent cause of bout ending injuries = strike actions (192, 87.3%, 19.4 per 1,000AE); Most common round for bout ending injuries = 2nd (117, 53.2%, 11.8 per 1,000AE).	Bouts ending in doctor stoppage feature more total standing strikes landed (ES = 0.11), total standing strikes attempted (ES = 0.22), standing head strikes landed (ES = 0.18) and standing head strikes attempted (ES = 0.28) than bouts without a doctor stoppage. Bouts without a doctor stoppage featured more grounded head strikes landed (ES = 0.015) than bouts with a doctor stoppage. *Nb. AE = athletes exposures* *ES = effect size*
	(LaRocca et al., 2019)	n = 40 amateur MMA participants; age = 26.5 ± 5.8, BMI = 24.6 ± 3.3 kg.m^{-2}	Change in serum UCHL1 correlated to number of hits to head experienced in a 3 x 3 minute bout (R^2 = 0.7339). 13 serum and/or saliva miRNA subsets can accurately classify TBI likelihood.	A subset of salivary and serum miRNAs can be used to predict incidence of TBI associated with head impacts during a bout, cognitive function and balance assessments. Timing of responses is varied between serum and saliva measures. *Nb. miRNA = microRNAs/micro ribonucleic acids; TBI = traumatic brain injury*
	(Bennett et al., 2018)	n = 257 professional combat sport athletes (MMA = 123)	% of concussions from competition or training: 0 = 38.4%, 1-2 = 38.8%, ≥5 = 13.8%. % of concussions on record: 0 = 43%, 1-2 = 29.7%, ≥5 = 12.1%. Understanding of long term effects of concussion: slightly = 21%, somewhat = 24.1%, very well = 24.5%. RTP post concussion in same session: ≥1 = 40.2%.	Low occurrence of combat sport athletes hiding symptoms of concussions from coaches and/or medical professionals; love of fighting main driver for post concussion RTP (59.8%); low incidence of external influence on post concussion RTP; relatively high incidence of not trusting ringside physicians: never = 5%, rarely = 12.5%, sometimes = 25%. *Nb. RTP = return to play in either training or competition*
	(Mishra et al., 2019)	n = 252 professional combat sport athletes (MMA = 144), split by cognitively impaired (IMP) (age = 29.77 ± 6.22) and non-cognitively impaired (CON) (age = 29.2 ± 6.5).	Processing speed: IMP = 40.64 ± 8.44, CON = 57.66 ± 7.61 Psychomotor speed: IMP = 151.36 ± 21.4, CON = 181.89 ± 17.01.	IMP group displays white brain matter reorganisation due to repeat head contact trauma with correlations to neuropsychological scores.
	(Bryant et al., 2020)	n = 64 retired MMA and boxing competitors (age = 47.8 ± 9.53; # of bouts = 34 [23.5 – 50.5]; years competing = 11.5 ± 5.6). n = 442 active MMA and boxing competitors (age = 29 ± 5.44; # of bouts = 10 [3 – 20]; years competing = 5.3 ± 4.4).	Linear regressions between brain MRI and AFE Active: L and R hippocampus β = 7.68 – 8.6; L amygdala β = 3.58; posterior corpus callosum β = 3.55 Retired: L and R hippocampus β = 11.11 – 14.27; R amygdala β = 6.89; posterior corpus callosum β = 5.05	Younger age of first exposure (AFE) to combat sports participation is related to reductions in hippocampus volume, decreased processing speed and psychomotor speed. AFE also related to increased incidence of depressive symptoms and impulsivity.
	(Kristensen et al., 2021)	n = 36 international standard female amateur MMA competitors (age = 25.2 ±	Prior to knowing the definition of a concussion:	MMA competitors may not be aware that they have suffered concussions previously due to lack of education of what constitutes a concussion.

		5.5); years training combat sports (MMA, kickboxing and/or boxing) = 7.3 ± 5.5; number of previous bouts (MMA, kickboxing and/or boxing) = 12.4 ± 22.1; bouts lost to KO/TKO (MMA, kickboxing and/or boxing) = 0.4 ± 0.7.	Reported previous concussion = 16.7%; reported no previous concussion = 72.2%; didn't know if they'd been concussed = 11.1%. After knowing the definition of a concussion: Reported previous concussion = 30.6%; reported no previous concussion = 61.1%; didn't know if they'd been concussed = 8.3%.	
	(Fares et al., 2020)	n = 408 elite, professional MMA bouts in years 2016-2019 inclusive.	Head injuries = 35 per 100 AE; TBI = 16 per 100AE; Male head injuries = 37 per 100 AE; Female head injuries = 23 per 100 AE.	Head injuries have high prevalence in MMA, with a general trend of more injuries in heavier mass divisions.
	(Bernick et al., 2021)	n = 30 MMA bouts reviewed for occurrence of suspected concussions via video recording.	Concussions per minute = 0.085; Concussions per minute experienced by bout winner = 0.011; Concussions per minute experienced by bout loser = 0.159	Bout losers frequently sustain multiple concussions, bout winners tend to not sustain a concussion, and rarely more than one. Participant who sustained the first concussion of the bout lost 98% of the time.
	(Ross et al., 2021)	n = 503 MMA bouts, 167 professional, 336 amateur	285 bouts resulted in at least 1 injury. Professional bouts resulted in more fractures and lacerations than amateur bouts. Amateur bouts resulted in more contusions/haematomas, nose bleeds and concussions that amateur bouts. Bout losers experienced more concussions (47) than bout winners (2).	Amateur and professional bouts may result in different rates and types of injuries.
	(Fliotsos et al., 2021)	n = 2,208 professional MMA bouts	369 eye injuries occurred to 363 participants. Rate of eye injuries = 2.56-12.22 per year. Eyebrow and eyelid lacerations = 43%; Lacerations around the eye = 27%; Orbital fractures = 17%. 62.8% of participants suffering an eye injury lost their bouts.	Eye injuries in MMA are prevalent, generally mild but often occur to the bout loser.
	(Jansen et al., 2021)	n = 23 combat sports participants (26±4 years, males n = 19, females n= 4), training for MMA and boxing wearing IMM mouthguards. Boxing sparring sessions n = 14; boxing bouts n = 4; MMA	MMA bouts (males): No. impacts = 10±4.2 PLA (g) = 37.9[29.2-48.6] PAA (rad·s^{-1}) = 3,773[3,103-4,685] MMA sparring: No. impacts = 19±20.5 (males), 7.6±5.4 (females).	The number of head impacts per session similar between MMA and boxing. PLA also similar between MMA and boxing, but PAA significantly greater in MMA. Competition impacts result in greater PLA than sparring impacts. All PLA and PAA below the previously suggested thresholds for mTBI, but this does not take into account sub-concussive impacts related to onset of CTE.

		sparring sessions = 40; MMA bouts n = 2.	PLA (g) = 17.5[13.8-24.3] (males), 17.6[13.4-24.7] (females). PAA (rad·s^{-1}) = 1,766[1,359-2,3733] (males), 1,796[1,323-2,822] (females)	*Nb. IMM = impact monitoring mouthguard; PLA = peak linear acceleration; PAA = peak angular acceleration; mTBI = mild traumatic brain injury; CTE = chronic traumatic encephalopathy*
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 et al., 2016c)	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 et al., 2016b)	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 et al., 2016a)	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 et al., 2017b)	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 et al., 2017a)	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 et al., 2017b)	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: FlW = 11.4 ± 10.1; WW = 12.6 ± 13.	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.
	(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.
	(dos 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., 2019a)	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.

	(Miarka et al., 2020)	n = 304 rounds from professional MMA bouts	Total head strikes landed greater in bouts ending in unanimous decision versus split decision. Total head strikes landed at distance greater in bouts ending in unanimous decision versus split decision and submission. Total head strikes landed in the clinch greater in bouts ending in unanimous decision versus split decision and submission. Greater frequency of knockdowns in bouts ending in KO/TKO than decisions or submissions. No difference between bout outcomes in terms of total strikes.	Outcome of bout is affected by types of strikes landed and in which stage of opponent engagement.
	(Wild, 2020)	n = 1,815 professional MMA bours ending in KO/TKO	OR of athlete winning by KO/TKO when they are: Mildly outclassed (landing 35-45% of total strikes in the bout) = 1:43; Moderately outclassed (landing 20-34% of total strikes in the bout) = 1:131; Severely outclassed (landing <20% of total strikes landed in the bout) = 1:1,356	When facing an opponent with a greater level of striking skill, an MMA athlete's odds of winning by KO/TKO decrease in an exponential manner *Nb.: OR = odds ratio*
	(Lane and Briffa, 2020)	n = 548 professional MMA bouts	Probability of winning based on number of strikes attempted per second: Decision = >75%, 0.38 strikes·s^{-1} KO/TKO = >75%, 0.82 strikes·s^{-1} Submission = >75%, 0.8 strikes ·s^{-1}	Judges may be choosing bout winners based on their striking 'vigour' (strikes·s^{-1}) which is equally related to winning by KO/TKO or submission. Does not take into account effect of grappling techniques.
Athlete	(James et al., 2017a)	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·kg^{-1}·s^{-1}) at 50% BM load: HL = 143.03 ± 51.28; LL = 104.82 ± 25.73 (ES = 0.93); Jump squat peak power (W·kg^{-1}): HL = 44.45 ± 7.54, LL = 38.47 ± 6.74 (ES = 0.78); Jump squat peak velocity (m·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 =	Differences between groups: 20M sprint: ES = -0.49[-1.39, 0.49]; 10M sprint:	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]*

		6.14 ± 0.71) and LL (n = 8, amateur bouts only, MMA training age = 4.31 ± 1.53).	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	
	(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), $\dot{V}O_2$max (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.
Mass Regulation	(Barley et al., 2017)	n = 14 amateur MMA competitors, age = 23 ± 4, at least 2 years competitive experience	BM reduction due to dehydration = 4.8 ± 0.8%; Repeat sled push time mean: 3H post dehydration = -19 ± 15%, g = -1.229; 24H post dehydration = -14 ± 15%, g = -0.671; Hand grip: 3H post dehydration g = -0.243; Medicine ball chest throw: 24H post dehydration g = -0.253 *Nb. All results in comparison to control*	Acute dehydration reduces physical performance 3hrs and 24hours after weight reduction in MMA participants in comparison to control group. Vertical jump height and blood pressure not significantly affected at any time point.
	(Coswig et al., 2018)	n = 8 MMA competitive bout winners, age = 25.4 ± 6.1; n = 7 MMA competitive bout losers, age = 24.4 ± 6.8	Rapid weight loss (RWL) not significantly different between winners and losers (d = -0.09); Rapid weight gain (RWG) significantly greater for bout winners (d = 0.85). Correlation between RWG and high intensity (HI)movements (r = 0.54); Bout winners HI % = 12 [9, 21]; Bout losers HI % = 8 [3, 10] *Nb. HI % presented as Median [interquartial range]*	Amount of mass gained through RWG post RWL is related to success in MMA bouts, with HI time significantly different between bout winners and losers. No effect of amount of BM lost via RWL. Bout winners consumed more carbohydrate and total calories than bout losers both during RWL and RWG phases.
	(Brechney et al., 2019)	n = 75 competitive MMA participants (59 amateur and 16 professional), body mass	Bout winners: BM (kg) pre = 75.23 ± 9.81, official weigh-in = 68.81 ±	Bout losers reduced BM significantly less than bouts winners. No differences in the amount of BM regained by bout winners or losers. The amount of BM regained post weigh-in has no effect on winning or losing competitive bouts,

		(BM) self-reported 7 days prior to bout, measured directly at official weigh-in, and again immediately prior to bout.	9.61, immediately pre-bout = 73.39 ± 9.49. Bout losers: BM (kg) pre = 78.22 ± 12.34, official weigh-in = 69.73 ± 9.64, immediately pre-bout = 74.86 ± 10.4.	but the amount of BM lost during the weight cut has a negative effect on winning.
	(Kirk et al., 2020b)	n = 62 professional MMA bouts (n = 62 winners and n = 62 losers); body mass (BM) recorded 24-36 hours prior to competition post rapid weight loss (RWL), and again the day of competition post rapid weight gain (RWG)	Bout winners in-competition BM (kg) = 77.3 ± 13.8; BM regained between weigh-ins (kg) = 6.9 ± 2.9, 10.1 ± 0.04%). Bout losers in-competition BM (kg) = 76.4 ± 13.4; BM regained between weigh-ins (kg) = 6 ± 2.8, 9.1 ± 0.05%).	No statistical differences between winners or losers in terms of in-competition BM or BM regained via RWG for bouts ending due to strikes, submission or decision. Participants tend to enter competition 1-2 divisions heavier than their official weigh-in BM.
	(Faro et al., 2021)	n = 1,400 MMA bouts (n= 448 elite; 210 = national; 742 = regional); body mass (BM) recorded 24-36 hours prior to competition post rapid weight loss (RWL), and again the day of competition post rapid weight gain (RWG)	RWG (kg) winners - losers: Elite = 6.01 [4.3-7.7] – 6 [3.8-7.3]; National = 6.7 [5.7-8] – 5.8 [4.2-7.2]*; Regional = 5.4 [4.2-7.2] – 5.1 [3.4-6.8]. Cohort overall = 5.7 [4.2-7.3] – 5.4 [3.7-7.1]*. Odds of winning +4% for each 1% of RWG above opponent	Significant difference between winners and losers in terms of RWG, but only at national level, not at elite or regional. *Nb. RWL = rapid wight loss; RWG = rapid weight gain; data reported as median [interquartile range]*
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 = 7 male professional MMA competitors, age = 25.7 ± 5	Post intervention changes ES in favour of INT group: Est. $\dot{V}O_2$max = 0.69; Bench press 1RM = 0.82; Back squat 1RM = 1.17; Dead lift 1RM = 1.63; CMJ height = 0.70; CMJ power = 0.70; 10m sprint time = 0.54	Specific S&C programme alongside MMA training significantly improves estimated $\dot{V}o_2$max, 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*
	(Chernozub et al., 2018)	n = 30 male MMA competitors, age = 21 ± 1.2, split into two groups n= 15 based on using a striking	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	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.

		based approach (STR) or a wrestling (WRE) based approach to bouts.	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]**	*** 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 A:R and metabolic requirements of sport	Suggested training structure based on A:R studies in MMA and general S&C research *Nb. A:R = activity-to-recovery 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*
	(Ruddock et al., 2021)	N/A#	Narrative review and expert opinion of research related to HIIT training in combat sports	Provide recommendations for the implementation of HIIT training into a combat sport (including MMA) training camp *Nb. HIIT = high intensity interval training*
Nb. #No experimental cohort used				

Appendix B

MMA coach interview guide

Using a semi-structured approach, the main questions (or similar) will be asked, *with the points beneath each one being potential areas to navigate during the interview:*

1. Tell me about your story and how you came to be involved in MMA? TO BE SPLIT ACROSS ALL THREE SESSIONS – ICEBREAKER EACH TIME
   - How did you first become involved in MMA?
     i. As a fan?
     ii. As a competitor?
     iii. As a coach?
     iv. How did you progress from one to another?
   b. What do you see as your main role as an MMA coach?
   c. What has influenced your choices and practices in your coaching (Pedagogy)?
     i. How were you coached?
     ii. Do you have a coaching mentor?
     iii. Were/Have you coached in any other sports?
     iv. Do you study coaches (others from MMA/from other sports)?
     v. Any other influences (business/other professions, etc.)?
2. Can you describe a typical coaching session for you? (What is it like? Who is there? What do you do?)
   a. …who do you tend to work with?
     i. How would describe them (athletes/recreational trainers/fighters)
     ii. Do you view either as a priority over the other?
   b. …how do you plan your coaching sessions?
     i. Do you cater towards individuals within a group?
     ii. Does this change between recreational and competitive groups?
     iii. Where do you tend to do your planning?
     iv. What do you tend to think about during planning?
     v. Do you tend to focus on a particular discipline within MMA for your training sessions and coaching? If so, what influences you to do this?
3. How do you go about preparing a fighter for competition?
   a. How long is a typical camp? What is your thinking behind this?
     i. How do you monitor training intensity? What is your thinking behind this?
        -Does this change as you prepare someone for competition?
     ii. How do you monitor improvements (in tech/skill/fitness/etc.)? What is your thinking behind this?
     iii. Do you incorporate strength or fitness/conditioning to your training? If so, how?
     iv. Do you employ/hire any 'specialists' to assist with your fighter preparation? (S&C, dietician, etc.)
   b. …is there anything that constrains your practice?
     i. What would you like to do?
     ii. If resources/money were no object what would you do?
4. What have been the most successful moments in coaching for you?
   a. Can you describe a time when you were really satisfied with your coaching/an outcome of your coaching?
   b. Which is more a sign of success ***for you***? - to have a small group of successful fighters or a large group of recreational participants?

Appendix C

Hand notation sheet designed and used for recording content and duration of MMA technical/tactical training sessions

Club:
Date:
Time:

Name of person completing collection form:
N of coaches: Coach Codes:
Number of fighters: Fighter Codes:

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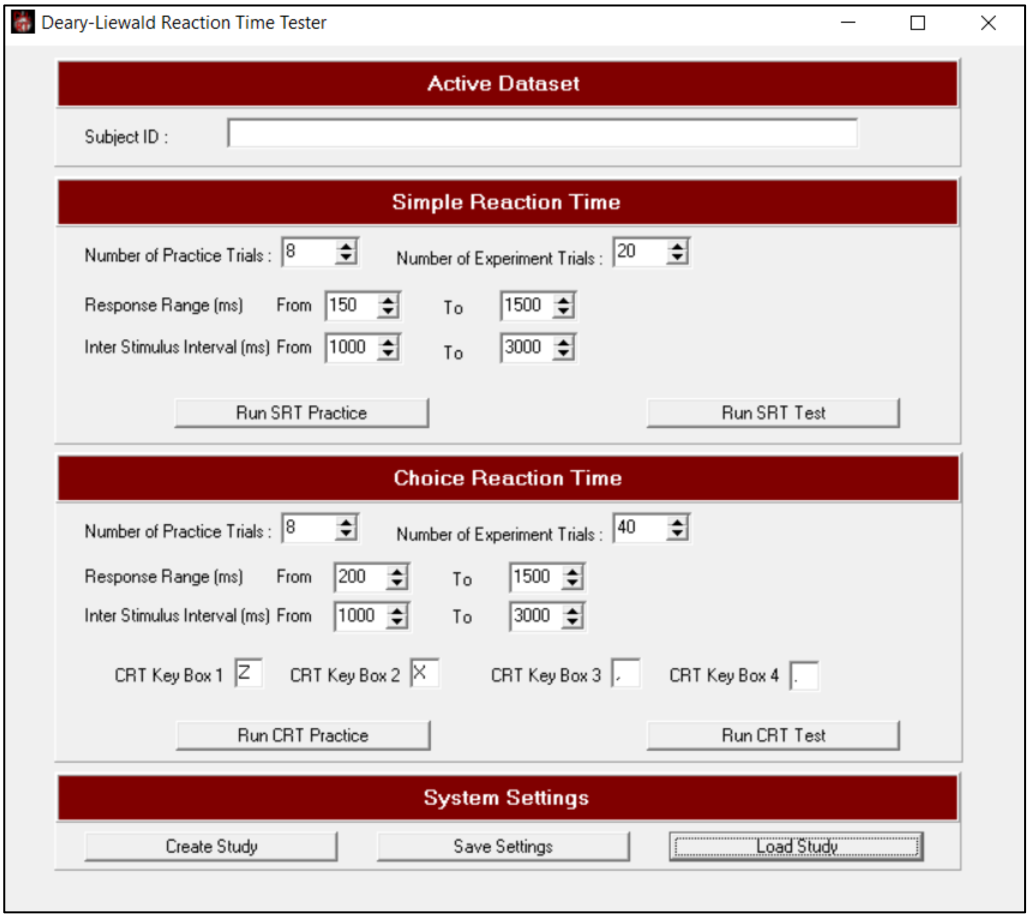
		Striking Technical		Wrestling Technical			Sub Grappling Technical		Sparring						Circuits		S&C Upper		S&C Lower		S&C	
Time	Warm up	Boxing	K1	Open	Wall/Fence	With strikes	For position	For sub	Boxing	K1	Wrestling	Sub Grappling	Sub Grappling w Strikes	MMA	Cardio	Musc Endurance	Strength	Endurance	Strength	Endurance	Technical	Plyometrics

Appendix D

Settings used for Deary-Liewald choice reaction time test



Appendix E

Descriptive data for external load, internal load, perceived intensity and duration of MMA training categories (mean±SD)

	Warm up	Striking drills	Wrestling drills	BJJ drills	Striking sparring	Wrestling sparring	BJJ sparring	MMA sparring	Session overall
Duration (mins)	10 ± 4.8	26.2 ± 21.7	22.4 ± 14.3	28.6 ± 8.6	10.7 ± 7.5	10.4 ± 5.6	16.2 ± 10.2	16.4 ± 6.3	76.2 ± 21.7
PLd_{ACC} (AU) [a]	44 ± 36.3	114.9 ± 88.6	103.6 ± 71.3	93.4 ± 47.4	82.7 ± 50.6	57.3 ± 30.5	84.9 ± 37.1	125 ± 58.8	310.6 ± 112
$PLd_{ACC}\cdot min^{-1}$ (AU) [a]	5.3 ± 3.3	5.5 ± 2.1	4.9 ± 1.5	3.2 ± 1	7.3 ± 1.9	5.6 ± 1.5	4.8 ± 1.1	7.3 ± 1.6	4.5 ± 1.4
RPE (AU)	3.1 ± 1.3	3.6 ± 1.4	4.6 ± 1.4	4.3 ± 1.2	5.6 ± 1.7	6.6 ± 1.4	5.8 ± 1.5	7.1 ± 1.4	5.8 ± 1.7
segRPE/sRPE (AU)	33.8 ± 22.6	94.4 ± 88.6	103.5 ± 70.7	122.8 ± 54.6	61.3 ± 51.5	69.8 ± 45.8	92.5 ± 55.3	116.8 ± 50.1	448.6 ± 191.1*

Nb. PLd_{ACC} *= accumulated Playerload;* $PLd_{Acc}\cdot min^{-1}$ *= accumulated Playerload per minute; RPE = rating of perceived exertion; segRPE = segmented sessional rating of perceived exertion; sRPE = sessional rating of perceived exertion; a = decisive differences between categories; * = sRPE*

Appendix F

Mean training category duration (mins) and internal load (AU) by day

	Mon		Tues		Wed		Thurs		Fri		Sat		Sun	
	Duration	**segRPE/sRPE**	**Duration**	**segRPE/sRPE**	**Duration**	**segRPE/sRPE**	**Duration**	**segRPE/sRPE**	**Duration**	**segRPE/sRPE**	**Duration**	**segRPE/sRPE**	**Duration**	**segRPE/sRPE**
Warm Up [a,c]	8.8 ± 4.7	25.6 ± 18.6	12.5 ± 4.2	46.8 ± 24.2	6.4 ± 2.3	16.3 ± 9.8	11.8 ± 4.8	43.7 ± 18.6	6 ± 0	22 ± 9.2	6 ± 1.4	6 ± 1.4	0	0
N		13		17		16		12		3		2		0
Wrestling Drills	25.6 ± 12.1	120.1 ± 70.9	17 ± 10.3	92 ± 59	20.9 ± 18.3	87.9 ± 80.1	21.4 ± 8.7	131.4 ± 73.6	0	0	27.3 ± 18.5	100.3 ± 57.8	0	0
N		16		9		17		5		0		3		0
Striking Drills	30.2 ± 25.9	84.5 ± 104	30.2 ± 21.1	131.2 ± 87.9	15.7 ± 13.5	43.7 ± 47.4	25.5 ± 23.7	92.1 ± 80.8	9.1 ± 1.6	33.5 ± 9.3	6	30	0	0
N		15		19		6		10		8		1		0
BJJ Drills	24.1 ± 10.7	95.4 ± 48.5	28.6 ± 5.8	156 ± 91.9	31.1 ± 5.9	116.2 ± 47.7	27.3 ± 13	133.6 ± 89.2	0	0	0	0	0	0
N		9		5		9		7		0		0		0
Striking Sparring [a,d]	17 ± 6.3	92 ± 54	13.5 ± 6.4	89.3 ± 64.1	4.6 ± 3.6	21.4 ± 13.1	14.5 ± 0.7	87.5 ± 24.7	4.3 ± 3.1	27.5 ± 22.1	0	0	0	0
N		10		4		5		2		8		0		0
BJJ Sparring [b,d]	18.3 ± 9.2	116.3 ± 71.4	12 ± 0	92 ± 6.9	13.9 ± 9.5	77.5 ± 52.1	17.3 ± 8.1	101.3 ± 29.9	60	360	45	135	0	0
N		9		3		19		4		1		1		0
Wrestling Sparring	11 ± 7.6	74.2 ± 55.5	13.6 ± 3.6	100 ± 23.2	8.3 ± 5.9	54.3 ± 59.9	16.3 ± 8.1	114.3 ± 75.5	10.8 ± 4.1	74.2 ± 17.9	7.3 ± 4.5	41.7 ± 27.6	0	0
N		6		5		11		3		10		3		0
MMA Sparring [a,e]	3 ± 0	21 ± 4.2	0	0	11 ± 0	77 ± 22	17.5 ± 5	126 ± 0	20.2 ± 2.1	143. 5 ± 32.6	0	0	0	0
N		2		0		3		2		11		0		0
Session Overall	77.1 ± 22.1	426.5 ± 156.1 *	68.1 ± 18.6	410.9 ± 156.1*	80.1 ± 22.5	466.1 ± 216.9*	74.8 ± 17	421.2 ± 157.6*	86.8 ± 28.6	616.5 ± 208.2*	63.3 ± 5.8	296.7 ± 55.1*	0	0
N		26		20		20		14		11		3		0

*Nb. N = number of individual sessions completed in this category on this day; segRPE = segmented sessional rating of perceived exertion; sRPE = sessional rating of perceived exertion; * = sRPE* a = *decisive differences in duration between days;* b = *strong differences in duration between days;* c = *decisive differences in segRPE between days;* d = *moderate differences in segRPE between days;* e = *very strong differences in segRPE between days.*

Appendix G

Mean training category external load by day (AU)

	Mon		Tues		Wed		Thurs		Fri		Sat		Sun	
	PLd_{ACC}	**$PLd_{ACC}{\cdot}min^{-1}$**	**PLd_{ACC}**	**$PLd_{ACC}{\cdot}min^{-1}$**	**PLd_{ACC}**	**$PLd_{ACC}{\cdot}min^{-1}$**	**PLd_{ACC}**	**$PLd_{ACC}{\cdot}min^{-1}$**	**PLd_{ACC}**	**$PLd_{ACC}{\cdot}min^{-1}$**	**PLd_{ACC}**	**$PLd_{ACC}{\cdot}min^{-1}$**	**PLd_{ACC}**	**$PLd_{ACC}{\cdot}min^{-1}$**
Warm Up [a]	26.9 ± 24.5	6.2 ± 4.9	66.9 ± 41.2	5.9 ± 2.5	32.4 ± 25.3	4.3 ± 2.4	53.7 ± 30.9	5 ± 2.4	3.6 ± 0.4	2.3 ± 0.2	0	0	0	0
Wrestling Drills [d]	119.3 ± 66.9	4.9 ± 1.1	119 ± 85.8	6.3 ± 1.2	74.3 ± 68.1	4 ± 1	114. 9 ± 71.6	5.3 ± 1.5	24.2 ± 2	8.4 ± 0.7	107.1 ± 0.2	3.2 ± 0.6	0	0
Striking Drills	138.4 ± 107.3	5.5 ± 1.2	140.6 ± 76.6	5.5 ± 2.4	89.7 ± 92.3	4.9 ± 1.3	108 ± 66.8	5.6 ± 2.8	44.2 ± 20.8	6.4 ± 2.6	0	0	0	0
BJJ Drills [b d]	79.4 ± 29.6	3.2 ± 0.7	91.2 ± 21	3.5 ± 0.8	73.1 ± 20.5	2.4 ± 0.4	141.8 ± 73.7	4.3 ± 0.8	0	0	0	0	0	0
Striking Sparring [c]	109 ± 23	6.9 ± 1.5	107 ± 39.8	7.2 ± 1.1	40.6 ± 41.6	6.9 ± 2.4	164.6 ± 29.6	10.9 ± 0.9	41.8 ± 33.6	7.3 ± 2.2	0	0	0	0
BJJ Sparring [e]	73.2 ± 43.2	4.6 ± 0.9	62.6 ± 27.5	6.2 ± 0.7	87 ± 36.3	4.4 ± 1	92.1 ± 36.9	5.6 ± 0.6	0	0	113.8	1.8	0	0
Wrestling Sparring	55.7 ± 41.4	5.1 ± 1.4	67.6 ± 20	5 ± 1	56 ± 41.4	6.6 ± 1.5	67.6 ± 71.5	3.9 ± 2.1	57.1 ± 25.2	5.1 ± 1	35 ± 16.6	6.5 ± 1.5	0	0
MMA Sparring [c f]	24.7 ± 6.3	6.2 ± 1.6	0	0	67.6 ± 21.7	5.9 ± 1.8	124.9 ± 3.5	8.9 ± 0.3	162.3 ± 28.3	8 ± 0.9	0	0	0	0
Session Overall [d]	329.7 ± 98.5	4.6 ± 1	342. 1 ± 129.7	4.5 ± 1.7	284 ± 107.1	3.6 ± 1	322.8 ± 135.1	4.7 ± 1.4	285 ± 44.1	5.9 ± 0.8	150.2 ± 20.4	3.4 ± 0.4	0	0

Nb. N = number of individual sessions completed in this category on this day; a = *strong differences in* PLd_{ACC} *between days;* b = *moderate differences in* PLd_{ACC} *between days;* c = *decisive differences in* PLd_{ACC} *between days;* d = *decisive differences in* $PLd_{ACC}{\cdot}min^{-1}$ *between days;* e = *strong differences in* $PLd_{ACC}{\cdot}min^{-1}$ *between days;* f = *moderate differences in* $PLd_{ACC}{\cdot}min^{-1}$ *between days;* PLd_{ACC} *= accumulated Playerload;* $PLd_{ACC}{\cdot}min^{-1}$ *= accumulated Playerload per minute*