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The Relationships Between External and Internal Training Loads in Mixed Martial Arts

The influence of aerobic capacity on the loads and intensities of mixed martial arts sparring bouts

Christopher Kirk[1]*, David Clark[2], Carl Langan-Evans[3]

[1]Sheffield Hallam University, Sport and Human Performance Research Group, Collegiate Hall, Sheffield, United Kingdom, S10 2BP

[2]Robert Gordon University, School of Health Sciences, Aberdeen, United Kingdom, AB10 7AQ

[3]Liverpool John Moores University, Research Institute for Sport and Exercise Sciences, Tom Reilly Building, Liverpool, United Kingdom, L3 3AF

*Corresponding author: Christopher Kirk 0000-0002-6207-027X C.Kirk@shu.ac.uk @ChrisKirk_ASP

DC - 0000-0002-6661-6137 @DaveRC_SpSci

CLE - 0000-0003-1120-6592 @CLESpoSci

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Abstract

The influence of aerobic variables on mixed martial arts (MMA) performance are currently unknown. This study aimed to compare the laboratory measured aerobic variables of MMA participants to the external load and intensity of MMA sparring bouts to determine the effect of aerobic capacity on performance. Ten participants (age = 24±2.8 years; mass = 74.3±8.2kg; stature = 176.8±7.9cm) completed: a treadmill graded exercise test to measure $\dot{V}O_2max$, VT_1 and VT_2; 3x5mins sparring bout equipped with a Catapult Optimeye S5 accelerometer recording Playerload (PLd_{ACC}) and Playerload per minute ($PLd_{ACC}\cdot min^{-1}$), with sessional rating of perceived exertion (sRPE) recorded as internal intensity. Median $\dot{V}O_2max$ ($53.3 ml\cdot kg\cdot min^{-1}$) was used to split the cohort into top 50% and bottom 50%. Pearson's r correlations ($BF_{10} \geq 3$) were calculated between GXT and sparring variables. $\dot{V}O_2max$ ($53.1 \pm 5.9 ml\cdot kg\cdot min^{-1}$) was found to have very large ($r \geq .70$) linear relationships with PLd_{ACC} (161.4±27.2 AU) and $PLd_{ACC}\cdot min^{-1}$ (10.7±1.8AU). Top 50% group maintained moderate sRPE (4-6AU) and greater $PLd_{ACC}\cdot min^{-1}$ throughout the bout, with bottom 50% group's sRPE moving from moderate to high (>7AU) indicating $\dot{V}O_2max < 53 ml\cdot kg\cdot min^{-1}$ is related to increased internal intensity. These data support the aerobic nature of MMA and may provide aerobic capacity targets for athletes and coaches to aim for during competition preparation.

Introduction

Mixed martial arts (MMA) is a combat sport where two participants engage in a combination of striking and grappling actions. The aim is to render the opponent unable to continue either due to a knockout/technical knockout, or by causing them to 'submit' due to joint manipulations or choke holds (Kirk, Clark, Langan-Evans, & Morton, 2020). Professional bouts consist of 3 x 5 min rounds interspersed by 1 min recovery, with amateur bouts being 3 x 3 min rounds. If neither competitor has defeated the other by the end of the scheduled rounds, the winner is decided by judge's decision (ABC, 2018; IMMAF, 2017).

Previous data support the view of MMA being a high intensity aerobic endurance event (Draper & Marshall, 2013) with maximal heart rate (HR) >90% between rounds (Petersen & Lindsay, 2020), and post bout lactate ranging 9-20 mmol·L (Kirk, Clark, et al., 2020). Whilst the specific energy system requirements of MMA are currently unknown, related combat sports have been found to elicit aerobic energy contributions of 60-70% (Campos, Bertuzzi, Dourado, Santos, & Franchini, 2012; Doria et al., 2009; Rodrigues-Krause et al., 2020). Additionally, James, Haff, Kelly, & Beckman (2018) provided evidence that more successful MMA athletes may be distinguished by their lower body force production and repeat sprint ability (RSA). Elite standard heavyweight

MMA athletes also display greater relative bench press 1 repetition maximum than professional standard lightweights (Folhes, Reis, Marques, Neiva, & Marques, 2022). These differences in force capacities between performance standards are reflected in studies finding that high impulse actions may be decisive for success in competition (Del Vecchio, Hirata, & Franchini, 2011; Kirk, 2018). These results collectively indicate that MMA athletes require a sufficiently developed cardio-respiratory system to ensure they have the capacity to perform repeated high impulse actions for up to 9-15 mins.

Previous studies (Alm & Yu, 2013; de Oliveira et al., 2015; Schick et al., 2010) demonstrated that MMA athletes may be classified as 'recreationally trained' or 'trained' based on their maximal aerobic capacity ($\dot{V}O_2max$) (De Pauw et al., 2013). The specific relevance of $\dot{V}O_2max$ to MMA performance is, however, currently unknown. As such, it is also unclear to what extent MMA athletes are meeting the physiological demands of the sport. The resulting void in the understanding and planning of their training has been highlighted previously (Kirk, Clark, et al., 2020). Direct measurement of most physiological and/or metabolic variables in an MMA performance setting is not possible due to the restrictive nature of the equipment used for collecting these data with a proxy measure of performance therefore being required. Playerload (PLd) as recorded from torso-mounted accelerometery has previously been found to be reliable ($ICC_{(3,1)}$ = .78-.98) for measuring external load (accumulated Playerload = PLd_{ACC}), and external intensity (accumulated Player load per minute = $PLd_{ACC}\cdot min^{-1}$) of MMA technical actions (Hurst, Atkins, & Kirk, 2014; Kirk, Malone, & Angell, 2023). These variables have previously been recorded from MMA sparring bouts (Kirk, Hurst, & Atkins, 2015), whilst providing insight of the pacing profile of such bouts (Kirk, Atkins, & Hurst, 2020). Recent MMA training data from our research group also revealed the strong relationships between PLd metrics and internal load estimated via rating of perceived exertion (RPE) (Kirk, Langan-Evans, Clark, & Morton, 2024).

Whilst PLd (Kirk et al., 2015) and RPE (Folhes, Reis, Marques, Neiva, & Marques, 2023; Petersen & Lindsay, 2020) have previously been reported from MMA sparring bouts, it is unknown if or how these are influenced by aerobic capacity. Comparisons of these variables to laboratory measured aerobic variables may therefore provide an understanding of the influence of aerobic capacity on MMA performance, which has been observed in other sports (Helgerud, Engen, Wisløff, & Hoff, 2001; Ross, Gill, Cronin, & Malcata, 2015), including the combat sport of boxing (Guidetti, Musulin, & Baldari, 2002). Understanding the effect of aerobic capacity on MMA performance would allow a more objective estimation of sport and athlete requirements. In addition, such data may enable development of MMA specific sport performance outcome measures that could be monitored and targeted within the training environment (Jeffries et al., 2021).

To that end, the primary aim of this study was to examine any predictive relationships between MMA participant's aerobic capacities as measured under laboratory conditions, and the external load/intensity of MMA sparring bouts. A secondary aim was to explore if MMA participants with varied aerobic capacities display distinct load and intensity characteristics in sparring bouts.

Methods

The following study was a cross-sectional observational design. A cohort of n = 10 tier 3 highly trained/national level (McKay et al., 2021) male MMA athletes (age = 24±2.8 years; body mass = 74.3±8.2kg; stature = 176.8±7.9cm; career MMA bouts = 9.9±3.5; 3 = flyweights; 4 = bantamweights; 3 = welterweights) took part in the following protocols after providing informed and written consent in keeping with institutional ethical procedures (ER41737813, 3rd May 2022) and the UK Data Protection Act 2018. Participants were required to be active male MMA competitors with a minimum of 4 competitive bouts, and to be a minimum of 18 years old and free from injury at the time of recruitment. Participants had all previously competed in a range of national and international amateur and professional MMA organisations and were all actively training for competitive MMA bouts a minimum of four times per week at the time of data collection. Required sample size was derived a priori using G*Power 3.1.9.7 for a bivariate normal model using the following parameters: correlation = 0.7 (very large - chosen to ensure a meaningful relationship between variables subject to multiple external and internal factors could be identified); $\alpha = 0.05$; $\beta = .85$; sample size required = 10. Following recruitment each participant met with the researchers on two separate occasions: once to complete an MMA sparring bout; once to complete a $\dot{V}O_2max$ test. The specifics of each meeting are described below.

MMA Sparring Bouts

Each participant took part in a 3 x 5 mins sparring bout with 60 s rest between rounds using MMA rules modified for participant safety (no elbows or knees to the head) conducted at the participant's club training venue. These sparring bouts replaced the participants scheduled sparring session for that week, with all data being recorded by the lead author. Participants were paired with an opponent chosen by their own coach from their club training partners from the same competitive body mass division and of a similar competitive standard. Eight of the participants sparred against people who were not participating in the study. Two of the study participants sparred against each other as they trained at the same club and matched each other in terms of body mass division and competitive standard. All sparring participants were asked to perform at the intensity they would normally use in training based sparring bouts two weeks prior to a competitive bout. No other instructions regarding strategy or tactical approach were provided. Participants were 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) worn in the manufacturer's harness, sized to ensure a tight fit on the T3-4 vertebrae in keeping with recommended practice (McLean, Cummins, Conlan, Duthie, & Coutts, 2018). Accelerometery was used to measure participant external load by recording the PLd_{ACC} of the entire bout, and external intensity via $PLd_{ACC}\cdot min^{-1}$ as applied previously (Kirk, Atkins, et al., 2020), with both variables being measured in arbitrary units (AU). PLd represents the sum of the magnitude of changes in accelerations in the three cardinal planes, thus provides a proxy measure of a participant's external load and external intensity (Bredt, Chagas, Peixoto, Menzel, & de Andrade, 2020; McLean et al., 2018). Participants were assigned their own individual accelerometer calibrated to the manufacturer's specifications adhering to guidelines for the use of accelerometery in sport (Malone, Lovell, Varley, & Coutts, 2017). The switch on and switch off times of each unit were recorded during each session, as were start/end times of each round.

Participant sessional rating of perceived exertion (sRPE) was collected immediately after each round and 10 mins after the end of the bout using the Foster 0-10 scale (Foster et al., 2001). sRPE was used to estimate the internal intensity of each round of the sparring bout and the bout as a whole. Internal load of each round and the bout as a whole was estimated by calculating each participant's sRPE training load (sRPE-TL). sRPE-TL is the product of sRPE and 17 (the duration of the sparring bouts inclusive of the 1 min rest period between rounds). Internal intensity of each round was categorised as follows: low (RPE $\leq$ 4); moderate (RPE 5 - 6); high (RPE $\geq$ 7) as applied previously (Kirk, Langan-Evans, Clark, & Morton, 2021; Seiler & Kjerland, 2006).

Aerobic Capacity Graded Exercise Test

A treadmill-based graded exercise test (GXT) was conducted to determine participant absolute $\dot{V}O_2max$ ($L\cdot min^{-1}$) and relative $\dot{V}O_2max$ ($ml\cdot kg\cdot min^{-1}$), ventilatory thresholds (VT_1 and VT_2, both $L\cdot min^{-1}$ and % of $\dot{V}O_2max$), and velocity at $\dot{V}O_2max$ ($v\dot{V}O_2max$, $km\cdot h^{-1}$). Each participant completed their $\dot{V}O_2max$ test on separate days to the other participants, with the tests conducted by the lead author at an accredited exercise physiology laboratory between the hours of 09:00am and 11:00am. Tests were completed with a minimum of 48 hours and a maximum of 96 hours separation from the specific participant's sparring bout. 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 (Meyer, Georg, Becker, & Kindermann, 2001). After being equipped with the Hans Rudolph 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). This laboratory specific protocol has been designed 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. 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 $ml \cdot kg \cdot min^{-1}$) despite increased intensity. $\dot{V}O_2max$ 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 $beats \cdot min^{-1}$ of the participant's predicted HRmax (Cooke, 2009). All participants reached $\dot{V}O_2max$ according to these criteria with the average time taken to attain $\dot{V}O_2max = 21.3 \pm 2$ mins. 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, Iannetta, Maturana, Kowalchuk, & Murias (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 & 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).

Statistical Analyses

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 with all variables being normally distributed. Inference in each of the following tests was based on the calculation of Bayes factors (BF) used to provide support for either the hypothesis (BF_{10}) or the null hypothesis (BF_{01}) respectively (van Doorn et al., 2019).

Relationships between GXT and sparring variables were determined using Bayesian Pearson's r correlation coefficient with a stretched beta prior width = 1. Pearson's r results are reported as point estimate[95% credible interval]. Any variables found to have statistically relevant linear relationships were also analysed via Bayesian linear regression with a Jeffrey-Zellner-Siow (JZS) default prior r = 0.354 to determine the strength of any predictive relationships (van Doorn et al., 2019). It should be noted, the predictive equation for Bayesian regression is modified from frequentist regression and is expressed:

$$y = bo + b1 * x1$$

Where: y = estimated dependent outcome variable score; b0 = intercept constant; b1 = regression coefficient; x1 = score difference for the independent variable predictor (= independent variable – independent variable mean)

Any between round changes in PLd_{ACC}, $PLd_{ACC}\cdot min^{-1}$, or sRPE of each round of sparring were determined using Bayesian repeated measures ANOVA for the whole cohort. To investigate the potential influence of varied aerobic capacities on performance, the median $\dot{V}O_2max$ of the cohort was determined, with this figure being used to split participants into two groups: top 50%, and bottom 50%. Between group differences in terms of in PLd_{ACC} and sRPE (between sparring rounds) and $PLd_{ACC}\cdot min^{-1}$ (between mins of sparring) were determined using Bayesian repeated measures ANOVAs. All ANOVAs were conducted with a default prior r = 0.5, and a default t test with a Cauchy prior as post hoc analysis. Effect size for each ANOVA was calculated using omega squared (ω^2).

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 (van Doorn et al., 2019). Due to default priors being used, BF robustness checks were performed (van Doorn et al., 2019). 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 ($p < .05$) unless stated otherwise. ω^2 thresholds were set at: very small ≤ .01; small ≤ .06; medium ≤ .14; large > .14. Correlation (r) 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). All analyses were completed using JASP 0.18.1 (JASP Team, Netherlands).

Results

Table 1 displays the mean±SD of each variable from sparring bouts and GXT. Relative $\dot{V}O_2max$ was found to have very large, strongly supported correlations to PLd_{ACC} (r = .759[.183-.922]; BF_{10} = 13) and $PLd_{ACC}\cdot min^{-1}$ (r = .761[.186-.923]; BF_{10} = 13). These correlations were found to be linear (Figures 1a and 1b), with each enabling moderately supported, large regression equations for: predicting relative $\dot{V}O_2max$ from PLd_{ACC} (BF_{10} = 5, R^2 = .576) or $PLd_{ACC}\cdot min^{-1}$ (BF_{10} = 5, R^2 = .580); predicting Pld_{ACC} (BF_{10} = 5, R^2 = .576) or $PLd_{ACC}\cdot min^{-1}$ (BF_{10} = 5, R^2 = .580) from relative $\dot{V}O_2max$.

$\dot{V}O_2$ at VT_1 (Figure 1c) had a very large curvilinear relationship to PLd_{ACC} (r = .729[.148-.910]; BF_{10} = 9) and $PLd_{ACC}\cdot min^{-1}$ (r = .729[.148-.909]; BF_{10} = 9). $\dot{V}O_2$ at VT_2 (Figures 1d) also had a moderately supported curvilinear relationship to PLd_{ACC} (r = .696[.117-.896]; BF_{10} = 7), and $PLd_{ACC}·min^{-1}$ (r = .697[.119-.896]; BF_{10} = 7).

Participant's $v\dot{V}O_2max$ (Figures 1e) had a very large, strongly supported relationship to both PLd_{ACC} (r = .777[.208-.929]; BF_{10} = 16) and $PLd_{ACC}·min^{-1}$ (r = .777[.208-.929]; BF_{10} = 16), with these relationships also being curvilinear.

There were no statistically relevant correlations between sRPE or $PLd_{ACC}/PLd_{ACC}·min^{-1}$, and no correlations between sRPE/sRPE-TL and GXT variables.

Table 1 - Mean±SD of each variable from sparring bouts and graded exercise test

	Full Cohort	**Top 50% Group**	**Bottom 50% Group**
Sparring Bout Variables			
PLd_{ACC} (AU)	161.4±27.2	175.7±17.7	147.1±29
$PLd_{ACC}·min^{-1}$ (AU)	10.7±1.8	11.7±1.2	9.8±1.9
sRPE (AU)	6.7±1.3	5.8±1.1	7.6±0.9
sRPE-TL (AU)	113.9±22.7	98.6±18.6	129.2±15.2
Graded Exercise Test Variables			
Absolute $\dot{V}O_2max$ ($L·min^{-1}$)	3.9±0.4	4.1±0.5	3.8±0.4
Relative $\dot{V}O_2max$ ($ml·kg·min^{-1}$)	53.1±5.9	57.7±3.6	48.5±3.5
$v\dot{V}O_2max$ ($km·h^{-1}$)	16.1±1.9	17.1±1.1	15.1±2
VT_1 ($ml·kg·min^{-1}$)	25.5±5.5	26.6±3.2	22.4±6.8
VT_2 ($ml·kg·min^{-1}$)	39.9±4.5	41.4±3.4	38.4±5.2
VT_1 (% of $\dot{V}O_2max$)	46.1±9.5	46.4±8.3	45.8±11.6
VT_2 (% of $\dot{V}O_2max$)	75.2±6.9	71.6±5.7	78.8±6.5

Nb. PLd_{ACC} = accumulated Playerload; $PLd_{ACC}·min^{-1}$ = accumulated Playerload per minute; sRPE = sessional rating of perceived exertion; sRPE-TL = sessional rating of perceived exertion training load; $v\dot{V}O_2max$ = velocity at $\dot{V}O_2max$; cohort split into 50% groups by cohort median $\dot{V}O_2max$ = 53.3$ml·kg·min^{-1}$

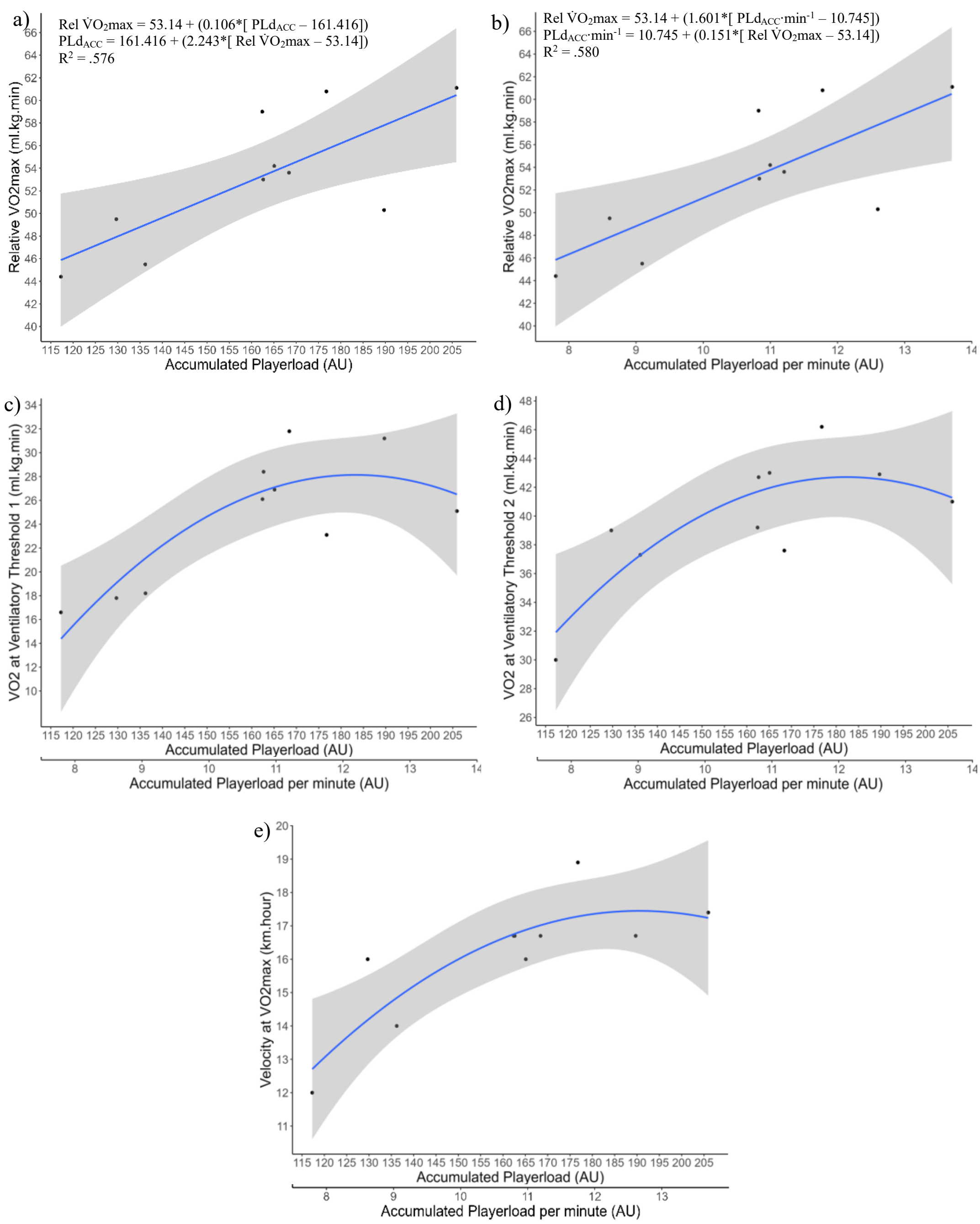

Figure 1 – Bayesian Pearson's r correlations (±95% credible intervals) between graded exercise test derived variables and MMA sparring bout external load and external intensity. Nb. The x axes of c), d) and e) provide scale for both PLd_{ACC} and $PLd_{ACC} \cdot min^{-1}$.

sRPE (Figure 2a) was found to increase in each round of the sparring bout with a large effect (BF_{10} = 975, ω^2 = 0.39). Post hoc analyses found this was due to round 1 having a moderate difference to round 2 (BF_{10} = 9) and a very strong difference to round 3 (BF_{10} = 42). Round 2 was also found to have a very strong difference to round 3 (BF_{10} = 52). PLd_{ACC} (Figure 2c) and $PLd_{ACC}\cdot min^{-1}$ (Figures 2e) both displayed linear reductions with each subsequent round, but these were not statistically relevant.

The median $\dot{V}O_2max$ of the cohort was found to be 53.3 $ml\cdot kg\cdot min^{-1}$. A cut off of 53 $ml\cdot kg\cdot min^{-1}$ was therefore used to divide the group into the top 50% and bottom 50% for $\dot{V}O_2max$. Round*group repeated measures ANOVA found decisive sRPE differences between groups per round with a large effect (BF_{10} = 143, ω^2 = 0.15). The top 50% group's sRPE remained in the moderate intensity boundary throughout the bout. The bottom 50% group's sRPE moved from the boundary of low/moderate intensity in round 1, to the boundary of moderate/high intensity in round 2, and then high intensity in round 3 (Figure 2b). No differences were found between groups per round for either PLd_{ACC} or $PLd_{ACC}\cdot min^{-1}$ (Figures 2d and 2f).

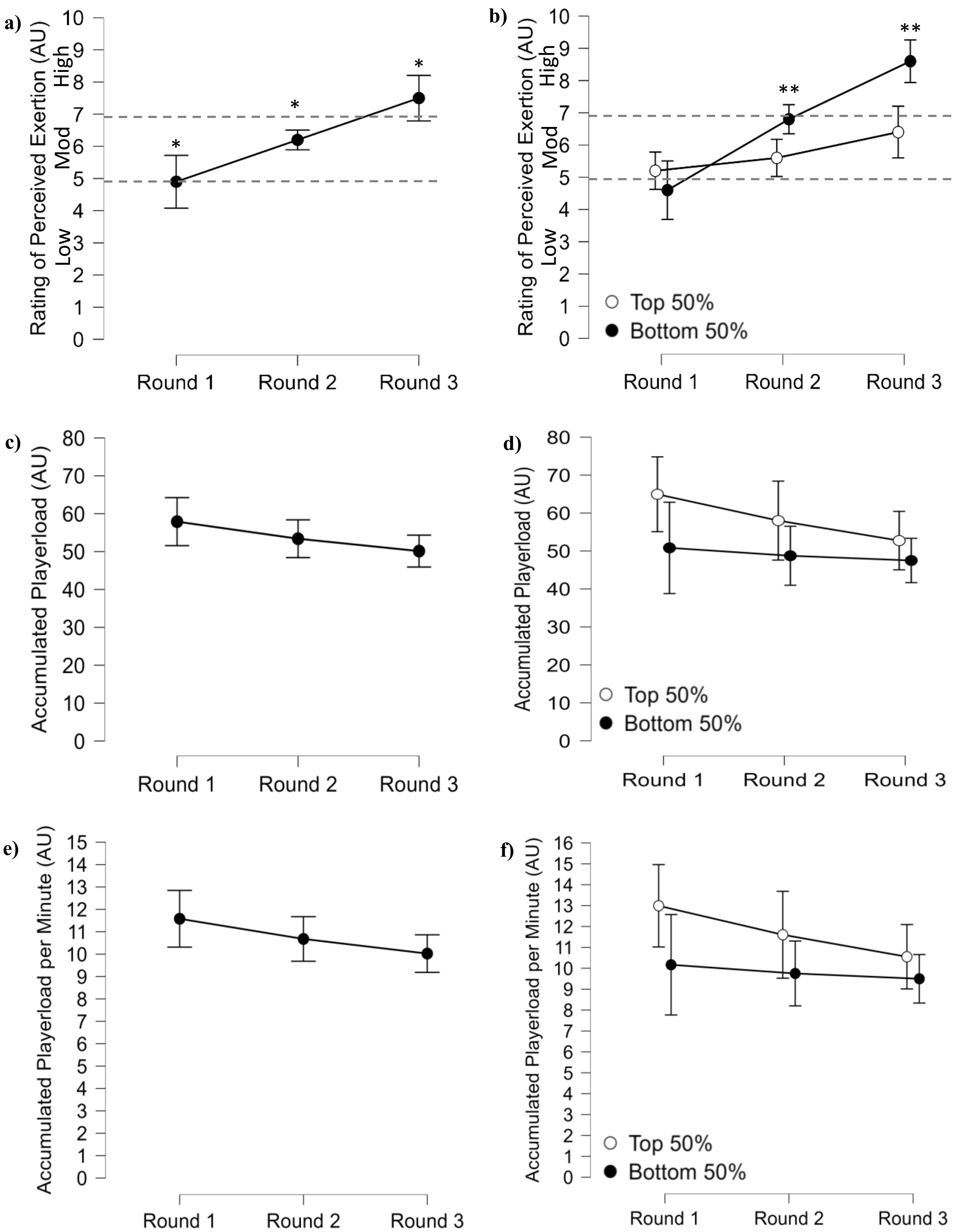

Figure 2 – Mean±95% credible intervals by sparring bout round: a) and b) sessional rating of perceived exertion; c) and d) accumulated Playerload; e) and f) accumulated Playerload per minute. Nb. a), c) and e) display the whole cohort; b), d) and f) display the cohort split by 50% top and 50% bottom $\dot{V}O_2max$; sRPE displays decisive statistical differences between rounds (*) and between groups (**); No statistically relevant differences between rounds or groups for Playerload variables.

When analysed across the whole cohort there were strong differences between minutes in terms of PLd_{ACC} (BF_{10} = 15, ω^2 = 0.09) with a medium effect (Figure 3a). Post hoc differences were found between minute 1 and: minute 2 (BF_{10} = 18); minute 8 (BF_{10} = 10); minute 10 (BF_{10} = 14); minute 12 (BF_{10} = 183); minute 13 (BF_{10} = 30); minute 15 (BF10 = 24). Minute 3 had differences to: minute 12 (BF_{10} = 3); minute 13 (BF_{10} = 3). Minute 4 had differences to: minute 10 (BF_{10} = 4); minute 12 (BF_{10} = 7). Minute 6 had differences to: minute 7 (BF_{10} = 3); minute 8 (BF_{10} = 10); minute 10 (BF_{10} = 68); minute 12 (BF_{10} = 253); minute 13 (BF_{10} = 198); minute 15 (BF_{10} = 5). Minute 11 had differences to: minute 12 (BF_{10} = 3). When splitting the cohort into top and bottom 50% $\dot{V}O_2max$ groupings (Figure 3b), there was a moderate minute*group difference with a medium effect (BF_{10} = 3, ω^2 = .11). Post hoc between groups differences were decisive with a medium effect, though with an increased probability of type 1 error due to reduced sample size per group (BF_{10} = 380, ω^2 = .12, p = 0.10).

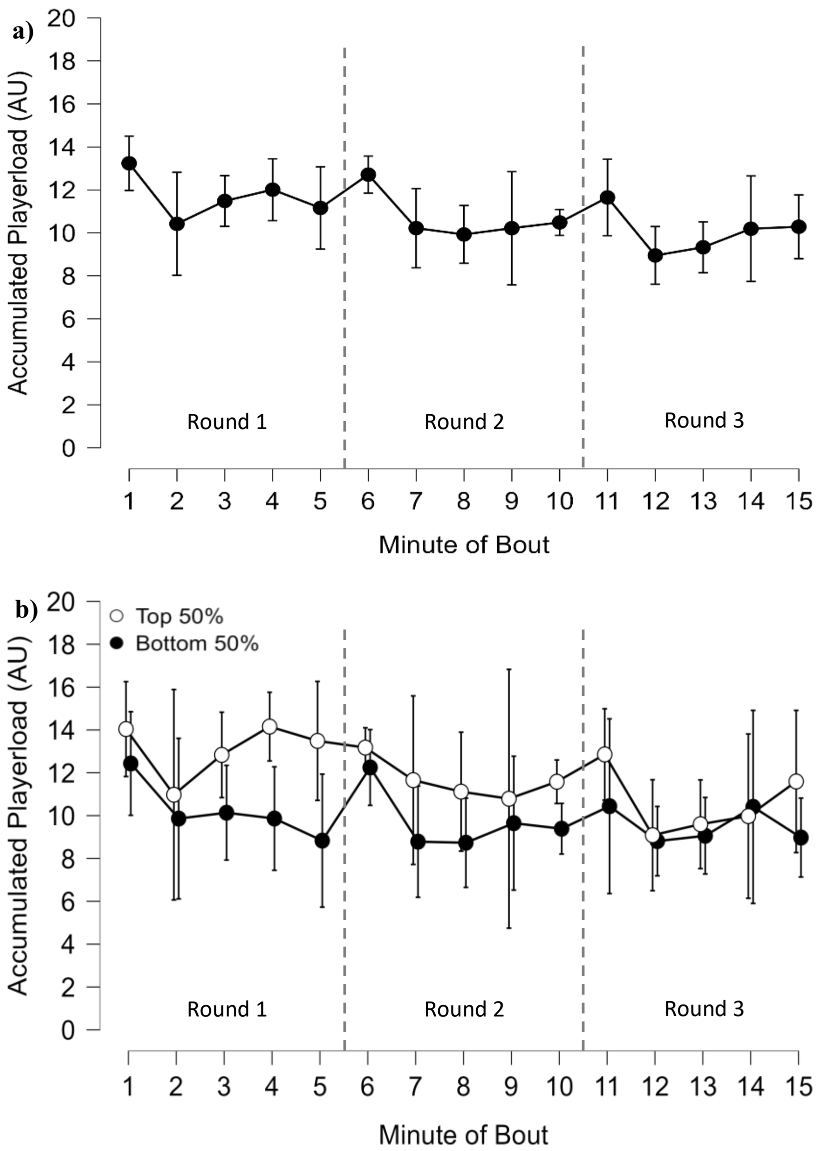

Figure 3 – Mean±95% credible interval of accumulated Playerload (AU) of each minute of MMA sparring bouts. Nb. a) displays the whole cohort with strong differences between mins; b) displays the cohort split by 50% top and 50% bottom $\dot{V}O_2max$ with decisive post hoc differences between groups.

Discussion

The primary aim of this study was to identify relationships between MMA participant's aerobic capacities as measured under laboratory conditions, and the load/intensity of MMA sparring bouts. Following comparisons of laboratory and field-based measurements of aerobic capacity and external load and intensity, large predictive relationships between $\dot{V}O_2max$ and Playerload variables were found. There were also large, curvilinear relationships between Playerload variables, MMA athlete's ventilatory thresholds, and their running velocity at $\dot{V}O_2max$. A secondary aim was to explore if MMA participants with varied aerobic capacity display distinct load and intensity characteristics in sparring bouts. The presented data support this hypothesis, with a $\dot{V}O_2max$

≥53ml·kg·min^{-1} being associated with increased Playerload and reduced sRPE in sparring bouts. These results may provide the first quantified evidence of the effect of aerobic capacity on MMA performance.

MMA has previously been suggested to be predominantly anaerobic due to individual decisive actions lasting ~3 – 9 s (Del Vecchio et al., 2011; Tack, 2013). 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; Kirk et al., 2015; Miarka, Brito, Moreira, & Amtmann, 2018). Under these conditions, each subsequent set of high impulse actions in the absence of adequate recovery would increase athlete reliance on aerobic energy resynthesis (Ruddock et al., 2021; Spencer, Bishop, Dawson, & Goodman, 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 MMA 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, da Silva Santos, Chaabene, Pieter, & Franchini, 2014; Ovretveit, 2018). This influence is revealed in the data presented here, with greater aerobic capacity being predictive of both PLd_{ACC} and PLd_{ACC}·min^{-1}. With $\dot{V}O_2max$ being a proxy of the upper limit of energy resynthesis (Bassett & Howley, 2000), it stands to reason that the MMA athlete with superior aerobic capacity would be capable of more physical activity during a bout. The increased upper limit of energy resynthesis provided by a greater $\dot{V}O_2max$ would enable more activity in the metabolic high intensity zone, and therefore performance of more techniques related to winning. Previous time motion analyses support this, showing winners of competitive MMA bouts to have greater activity levels compared to losers (Antoniettô et al., 2019; Miarka et al., 2018). There is also evidence of this having an effect over time in related combat sports, with the ranking of international amateur boxers having strong relationships to $\dot{V}O_2max$, VT_1 and VT_2 (Bruzas et al., 2014).

The median $\dot{V}O_2max$ threshold of 53.3 ml·kg·min^{-1} was found to differentiate between participants in terms of PLd_{ACC} between mins and sRPE between rounds. The overall cohort displayed sRPE drift across all three rounds in keeping with expectations (Fusco et al., 2020). When split into groups above and below the median threshold, however, the top 50% group remained within the moderate intensity zone throughout the bout. The bottom 50% group's sRPE increased with each round, being on the upper threshold of low intensity in round 1, the upper threshold of moderate intensity in round 2, and entirely in the high intensity zone in round 3. Increased RPE earlier in a performance has been related to the onset of fatigue and proximity to exhaustion, with the product of RPE and time left in the event being termed the 'hazard score' (Azevedo, Silva-Cavalcante, Lima-Silva, & Bertuzzi, 2021; Renfree, Martin, Micklewright, & Gibson, 2014). An athlete's perception of such hazard has been suggested to affect their pacing, with a higher hazard score being related to a shorter ‘fast start’ period and a lower intensity ‘end spurt’(Azevedo et al., 2021; De Koning et al., 2011; Schallig et al., 2018). This phenomenon appears to be present in Figure 3b, where the top 50% group were able to maintain a higher external intensity than the bottom 50% group throughout rounds 1 and 2. The bottom 50% group were able to match the top 50% group’s ‘fast start’ for a few minutes in rounds 1 and 2 only. Though both group’s PLd_{ACC} were generally equal in each minute of round 3, the top 50% group still only had a moderate sRPE ~ 6AU in this round. As such, the top 50% group were able to display an ‘end spurt’ at the end of round 3, whilst the bottom 50% group were not. Both groups experienced reduced PLd_{ACC} as the bouts progressed, which is to be expected due to the effects of fatigue on external intensity as measured by accelerometery (Kirk, Atkins, et al., 2020). The differences in sRPE and external intensity between groups may be due to aerobically fitter participants having faster O_2 kinetics at the onset of exercise, and increased reliance on fat metabolism during periods of low intensity and rest (Jones & Burnley, 2009). These adaptations would result in glycogen being spared for higher intensity work for longer durations (Jones & Carter, 2000). Whilst these data cannot be directly related to successful performance, the previously mentioned time motion studies support bout winners being able to maintain higher activity levels during later rounds of competitive bouts (Antoniettô et al., 2019; Miarka et al., 2018). There is also some evidence that elite standard lightweight MMA athletes attain greater offensive activity with lower RPE than professional standard lightweights (Folhes et al., 2023). These results, therefore, provide evidence of the positive influence of aerobic capacity on MMA performance.

MMA and combat sports performance may be predominated by time spent above the second metabolic threshold, whether this is demarcated by VT_2 (de Lira et al., 2013), or by the lactate turning point (Kirk, Clark, et al., 2020). This may due to repeated high intensity actions related to success making the participant’s physiology a more metabolically acidic environment (Keir et al., 2021). The data reported here support this somewhat, with higher values of $\dot{V}O_2$ at VT_1 and VT_2 having a positive relationship to external load and intensity, suggesting that as load and intensity increases so too does homeostatic disturbance. The curvilinear nature of this relationship, however, shows that there is a ‘ceiling’ to this effect in MMA. Higher ventilatory thresholds appear to be related to increased activity in sparring up to a certain point, after which PLd_{ACC} and $PLd_{ACC}\cdot min^{-1}$ continue to increase independent of ventilatory changes. This may be explained by PLd representing the sum of the magnitude of change in accelerations (Bredt et al., 2020). It may be the case that participants capable of greater force or velocity actions may record higher PLd performing certain actions with minimal or no effect on ventilatory markers due to enhanced movement economy (Folland, Allen, Black, Handsaker, & Forrester, 2017). This may be the case for participants of a certain level of aerobic capacity as indicated by the plateauing of the relationship lines in Figure 1. These plateaus might suggest that VT_1 ~28ml·kg·min^{-1} and VT_2 ~42·ml·kg·min^{-1} represent thresholds after which no further increase in PLd may be achieved without adaptations to other physiological factors such as the neuromuscular and anaerobic energy systems (Folland et al., 2017; Spencer et al., 2005). Aerobically fitter participants are more likely to also have more developed anaerobic capacities (Spencer et al., 2005), which in turn would enable more repeated high impulse actions to occur throughout MMA bouts. These data may, therefore, evidence the importance of both aerobic and anaerobic energy resynthesis on MMA performance for the first time.

It may be argued that these $\dot{V}O_2$max, VT_1 and VT_2 'thresholds' are low when compared to those in other sports (De Pauw et al., 2013). Despite such seemingly low aerobic capacity requirements, current literature indicates that many MMA athletes do not achieve even these thresholds (Kirk, Clark, et al., 2020). As such, these data may further support claims that MMA training practices are insufficient for meeting competition demands (Kirk et al., 2021). It would be recommended, therefore, for MMA coaches and athletes to use a periodised program of aerobic endurance training both during and between competition training periods. Such training should include low-moderate intensity endurance exercise (Jones & Carter, 2000) and 'long' high intensity interval training (HIIT) sessions (Laursen & Buchheit, 2019; Ruddock et al., 2021) to provide the required adaptations to both central and peripheral components of the cardiorespiratory system. 'Game based' HIIT training may be programmed in the two-four weeks immediately prior to competition to enhance muscle buffering capacity required for repeated high impulse actions during performance (French, 2019; Ruddock et al., 2021).

In conclusion, MMA participant's external load and external intensity were found to be related to their aerobic capacity and ventilatory thresholds. $\dot{V}O_2$max has a linear, predictive relationship with PLd_{ACC} and PLd_{ACC}·min^{-1}. These relationships may be used by coaching and support staff to estimate changes in fitness and/or performance capacity during training periods using the provided regression equations. A $\dot{V}O_2$max of 53.3 ml·kg·min^{-1} differentiates MMA athletes in terms their response to sparring, with participants above this value being capable of performing at a higher external intensity with lower internal intensity than those below. As such, using this value as a threshold in addition to VT_1 ~28ml·kg·min^{-1} and VT_2 ~42·ml·kg·min^{-1} may provide a quantifiable performance outcome measure to be used as a potential minimum aerobic capacity to be attained from training (Jeffries et al., 2021). This secondary finding will, however, require further investigation with larger cohort and across multiple performance tiers before using these as definitive training targets.

Limitations

Limitations of this study are that these data were collected from sparring bouts and not from competitive bouts. It is recognised that competition may induce distinct physiological arousal responses due to different stimuli from the competitive environment and the participants likely committing to their techniques more than they would in sparring against their training partners. Participant's competitive strategy during the sparring bouts may also have influenced their external load and/or intensity. The cohort consists of males only, and female $\dot{V}O_2$ responses to both conditions may differ. As such, the reported regression equations would only be suitable for use with male athletes. The cohort consisted of a relatively narrow age and body mass range, and all were tier 3 athletes. MMA participants from different age ranges, different body mass divisions and higher/lower tiers may produce different results to those reported here. Splitting the cohort into 50% $\dot{V}O_2$max groups reduced n to 5 in each group. This may result in increased probabilities of type 1 and 2 errors in a frequentist understanding of inference. With the reported BFs remaining robust under different priors, and BF potentially yielding lower type 1 error rates compared to frequentist methods (Kelter, 2021), the results should instead be interpreted on the strength of the presented evidence (Wagenmakers et al., 2015). Equally, as the overall population of MMA athletes is small, this sample cohort is argued to be representative of the population's reported characteristics (Kirk, Clark, et al., 2020). Whilst these results may be sufficiently robust, however, it is still recommended these analyses be repeated with larger samples sizes to improve our collective understanding of the observed effects.

Disclosure statement

No funding was received for this work. The authors report there are no competing interests to declare. For the purpose of open access, the author has applied a Creative Commons Attribution (CC BY) licence to any Author Accepted Manuscript version arising from this submission. Data are available on request. For purposes of future prior construction all variable descriptives and effect size estimations with 95%CI are available: OSF LINK TO BE ADDED ON ACCEPTANCE.

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