The relationships between external and internal training loads in mixed martial arts

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Original investigation

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Abstract

Purpose: As a multi-disciplined combat sport, relationships between external and internal training loads and intensities of mixed martial arts (MMA) have not been described. The aim of this study was to determine the external loads and intensities of MMA training categories and their relationship to internal loads and intensities. Methods: 20 MMA athletes (age=23.3±5.3, mass=72.1±7.2kg, stature=171.5±8.4cm) were observed for 2 consecutive weeks. Internal load and intensity (sRPE) were calculated using Foster's RPE for the session overall (sRPE-TL) and segmented RPE (segRPE-TL) for each training category: warm-up; striking drills; wrestling drills; Brazilian jiujitsu (BJJ) drills; striking sparring; wrestling sparring; BJJ sparring; MMA sparring. External load and intensity were measured via Catapult Optimeye S5 for the full duration of each session using Playerload (PLd_{ACC}) and PLd_{ACC} per minute ($PLd_{ACC}\cdot min^{-1}$). Differences in loads between categories and days was assessed via Bayesian ANOVA ($BF_{10}\geq3$). Predictive relationships between internal and external variables were calculated using Bayesian regression. Results: Session overall sRPE-TL=448.6±191.1AU; PLd_{ACC}=310.6±112AU. Category segRPE-TL range=33.8±22.6AU (warm-up) – 122.8±54.6AU (BJJ drills). Category PLd_{ACC} range=44±36.3AU (warm-up) – 125±58.8AU (MMA sparring). Neither sRPE-TL nor PLd_{ACC} changed between days. PLd_{ACC} was different between categories. Evidence for regressions was strong-decisive except for BJJ drills (BF_{10}=7, mod). R^2 range=.50-.77, except for warm up (R^2=.17), BJJ drills (R^2=.27), BJJ sparring (R^2=.49) and session overall (R^2=.13). Conclusions: Whilst MMA training categories may be differentiated in terms of external load, overall session external load does not change within or between weeks. Resultant regression equations may be used to appropriately plan MMA technical/tactical training loads.

List of Abbreviations

BF – Bayes factor: the magnitude to which the data support the hypothesis over the null hypothesis (BF_{10}) or vice versa (BF_{01})

BJJ – Brazilian jiujitsu

MMA – mixed martial arts

PLd_{ACC} – accumulated Playerload: the external load of the training session or training category as measured by Catapult accelerometery

$PLd_{ACC}{\cdot}min^{-1}$ – accumulated Playerload per minute: the external intensity of the training session or training category as measured by Catapult accelerometery

sRPE – sessional rating of perceived exertion: the internal intensity of the session as perceived by the participant

segRPE – segmented sessional rating of perceived exertion: the internal intensity of the training category as perceived by the participant

sRPE-TL – sessional rating of perceived exertion training load: the internal load of the session as perceived by the participant

segRPE-TL – segmented sessional rating of perceived exertion training load; the internal load of the training category as perceived by the participant

Introduction

Quantifying and predicting an athlete's adaptive response to training plays a key role in optimising performance and minimising fatigue[1]. This process requires differentiation between external loads placed on the athlete during training and their physiological internal loads experienced in response[2]. As no single method can currently accurately predict the athlete's training dose-response[3], a combination of internal and external load measurements is recommended[4]. The specific contexts of certain sports can render measurement of internal and external load difficult or impractical in an applied setting. An example of such a sport is mixed martial arts (MMA), which is characterised by its combination of striking and grappling techniques incorporated from other combat sports such as muay Thai, wrestling and Brazilian jiujitsu (BJJ). In addition to being able to strike the opponent's head, torso and limbs with the feet, hands, elbows and knees, participants are permitted to use grappling manoeuvres to attain a more dominant position in either standing or grounded phases[5]. Given these unique movement requirements, it would be important for athlete support personnel to understand how to appropriately program the loads of the different training categories within and between weeks to enable load undulations aimed at optimising performance[6].

Internal loads in team sports and track and field events are traditionally quantified using a range of directly measured variables including heart rate, gas analysis and blood sampling[1,7,8]. Direct measures have been used in simulated MMA bouts to provide an understanding of the internal effects of MMA competition[5]. The invasiveness of these methods, however, preclude their regular use in training. Estimating internal load via sessional rating of perceived exertion (sRPE-TL) has therefore become more common in combat sports. Previous reports demonstrate sRPE-TL of boxing training sessions to range between 78-264.3 AU, with taekwondo training sessions range = 200.8 – 256.7 AU[9]. In contrast, the grappling sport of BJJ sRPE-TL is reported as ~50-70 AU per session[10]. We recently presented novel data highlighting an MMA training period consisting of static internal training load between weeks (~1,500-2,000 AU). There was also an absence of statistically relevant changes in internal load between days (~100-500 AU) in 6 of the 8 weeks observed. This resulted in no changes to fatigue during the 8-week period[11]. We 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[11], which may explain the absence of physiological adaptations to MMA technical/tactical training[12].

Knowledge of MMA external training load, and how it relates to internal load, may facilitate more appropriate programming to enable a balanced training-recovery-adaptation cycle[2]. Unfortunately, there is no accepted method of measuring external load in this population. Proxy external load via time motion analyses (TMA) has been reported from competition, finding that participants display an activity:recovery ratio = 1:3[13], with each round being distinct in terms of technical actions and pacing[14]. No such data has been provided from training due to the time-consuming nature of this method making its application impractical in such an environment. Accelerometry has been suggested as a potential solution to this problem[15], with the Catapult Playerload metric being found to be correlated ($r = .70$-$.84$) to subjective and objective internal load in other contact and non-contact sports[7,8,16]. Summated from the magnitude of changes in accelerations in the three cardinal planes[17], Playerload is proposed as a global score of external load and intensity[18]. We have previously demonstrated the high reliability of Playerload in measuring isolated MMA related movements[19,20], in addition to providing insight into the external load of simulated bouts[21,22]. The relationship between Playerload and internal load, however, has not yet been examined in an MMA training environment. We did report a nearly perfect relationship between Playerload and lactate in simulated bouts ($r = .99$), but a small sample size ($n = 6$) rendered this result non-significant[21]. Given that Playerload is capable of distinguishing between training modes and intensities in boxing[23], it may be a practical method of monitoring external load and intensity in MMA training.

Therefore, the aim of this study was to use Playerload to measure the external load and external intensity of MMA training and determine whether external loads of MMA training change between days. A secondary aim was to examine to what extent Playerload relates to internal load and internal intensity. Following on previous data from our research group[11], we hypothesised that within week changes in external load would be absent in MMA. Based on evidence from other contact and combat sports[7,8,16] we also hypothesised that Playerload would share a predictive relationship with internal load and internal intensity.

Methods

A cohort of 20 experienced (≥4 official MMA bouts; n=16 Tier 3 athletes, n=4 Tier 4 athletes[24]) male (n=14) and female (n=6) MMA competitors (age = 23.3±5.3 years; habitual mass = 72.1±7.2kg; stature = 171.5±8.4cm) from 4 different MMA clubs were recruited for this study following ethical approval (Liverpool John Moores University Ref: 19/SPS/007, date: 1st February 2019) in keeping with Declaration of Helsinki Ethical guidelines and the United Kingdom's Data Protection Act 2018. Participants were observed participating in their normal MMA training without intervention for two consecutive weeks, during a period when none of the participants were preparing for competitive bouts. Training sessions were planned and conducted by 1-2 coaches at each club (total coaches = 6; 4 = full time professional MMA coaches; 2 = part time MMA coaches leading session planned by their club's full time coach). The content of each training session was recorded in terms of duration for the training categories described in Table 1 inclusive of rest periods:

Table 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.

Definitions made in agreement with independent MMA coach and used previously[7]; 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 jiu-jitsu; MMA = mixed martial arts.

RPE was used to measure the internal intensity of each training category (segmented RPE = segRPE[25]) and the session as a whole (sessional RPE = sRPE) for each participant individually using the Foster sRPE 0-10 scale[26] 10-30 minutes after the end of the entire training session[27]. Internal load for each training category (segRPE-TL)[25] and the session as a whole (sRPE-TL)[26] were calculated using the following equation:

$$\text{segRPE-TL or sRPE-TL (AU)} = \text{segRPE or sRPE} * \text{duration (mins)}$$

External load (Playerload = PLd_{ACC}) and external intensity (Playerload per minute = $PLd_{ACC}{\cdot}min^{-1}$) were measured in AU via Catapult Optimeye S5 100Hz tri-axial accelerometers (Catapult Innovations, Australia) for the full duration of each training session. 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[28]. Each participant was assigned their own individual unit for the full duration of data collection adhering to guidelines for the use of accelerometery in sport[29].

Statistical Analyses

Inference in each of the following tests was based on the calculation of Bayes factors (BF), to provide support for the hypothesis (BF_{10}) or the null hypothesis (BF_{01}) respectively. 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-TL, PLd_{ACC} and $PLd_{ACC}\cdot min^{-1}$ were compared between days for Week 1 and Week 2. Daily session and category duration, segRPE-TL, sRPE-TL and external load variables were then averaged between the two weeks to allow between days comparisons to be made. External load and external intensity differences between training categories were also assessed.

Relationships between variables (training loads, training intensities, training durations) were determined using Bayesian Kendall's Tau-b correlation with a stretched beta prior width = 1 and 95% credible intervals due to all variables being found to be non-parametric via Shapiro Wilk test ($p \leq .05$). Predictive relationships between variables were calculated using Bayesian linear regression with a JZS default prior r = 0.354. Due to default priors being used, BF robustness checks were performed on all tests. Where a result was found to cross a BF threshold, both thresholds are reported. 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)

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[30]. Though not reported in the text, any result found to have $BF_{10} \geq 3$ was also found to have acceptably low probability of type 1 error ($p < .05$). Correlation thresholds were set at: trivial $T \leq 0.09$; small $T \geq 0.1$; moderate $T \geq 0.3$; large $T \geq 0.5$; very large $T \geq 0.7$; nearly perfect $T \geq 0.9$; perfect $T = 1$[31]. ω^2 thresholds were set at: small $\omega^2 \geq 0.01$; moderate $\omega^2 \geq 0.06$; large $\omega^2 \geq 0.14$[32]. All statistical tests were completed using JASP 0.14.1 (JASP Team, Amsterdam, Netherlands).

Results

Comparisons between days and categories

Session overall displayed mean PLd_{ACC} = 310.6±112 AU whilst mean sRPE-TL = 448.6±191.1 AU. Tables displaying specific means±SD of each variable for each category per day averaged and each category overall can be viewed in Supplementary File 1. As seen in Figure 1 the only difference in any variable between days within weeks occurred in Week 2 $PLd_{ACC}\cdot min^{-1}$ (Figure 1d) 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 2 displays training duration (2a), internal load (2b), external load (2c) and external intensity (2d) per category by day.

Training duration comparisons

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 being 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.

Internal Load Comparisons

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-TL were also observed between Mondays and Tuesdays and Thursdays and Saturdays (post-hoc BF_{10} = 3-4). Daily differences in striking sparring segRPE-TL 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, ω^2 < .01). MMA sparring was found to be distributed differently between days, with the majority of sessions and greatest mean segRPE-TL 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.

External load and external intensity comparisons

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). 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 external intensity, 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 external intensity 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 external intensity 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 external intensity 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) $PLd_{ACC} \cdot min^{-1}$ despite no overall differences being found for these categories.

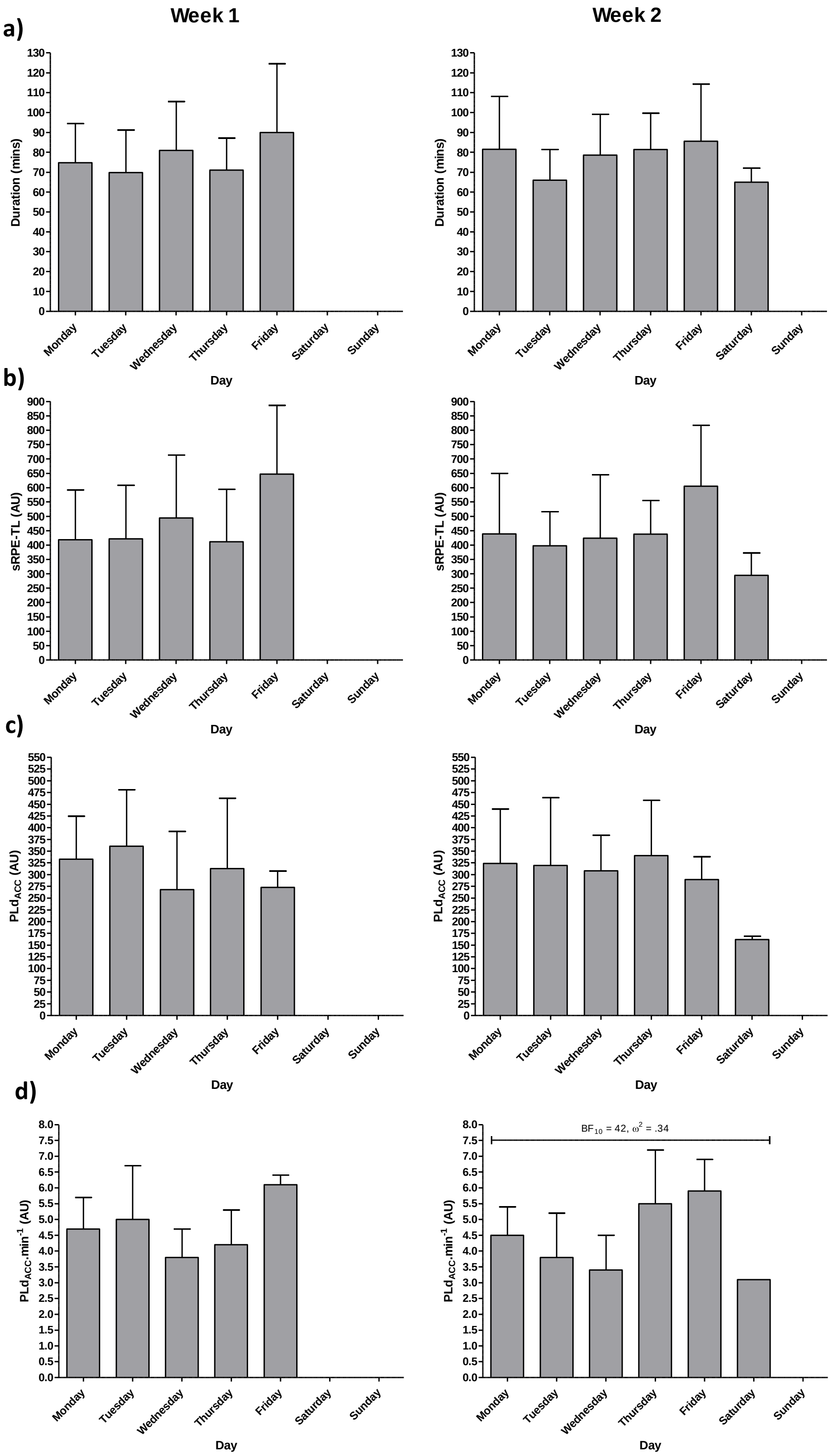


Figure 1 – Mean±SD a) duration (mins), b) internal load, c) external load, and d) external intensity (all AU unless stated) between days within weeks. *Nb. PLd$_{ACC}$ = accumulated Playerload; PLd$_{ACC}$·min $^{-1}$ = accumulated Playerload per minute; sRPE-TL = sessional rating of perceived exertion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

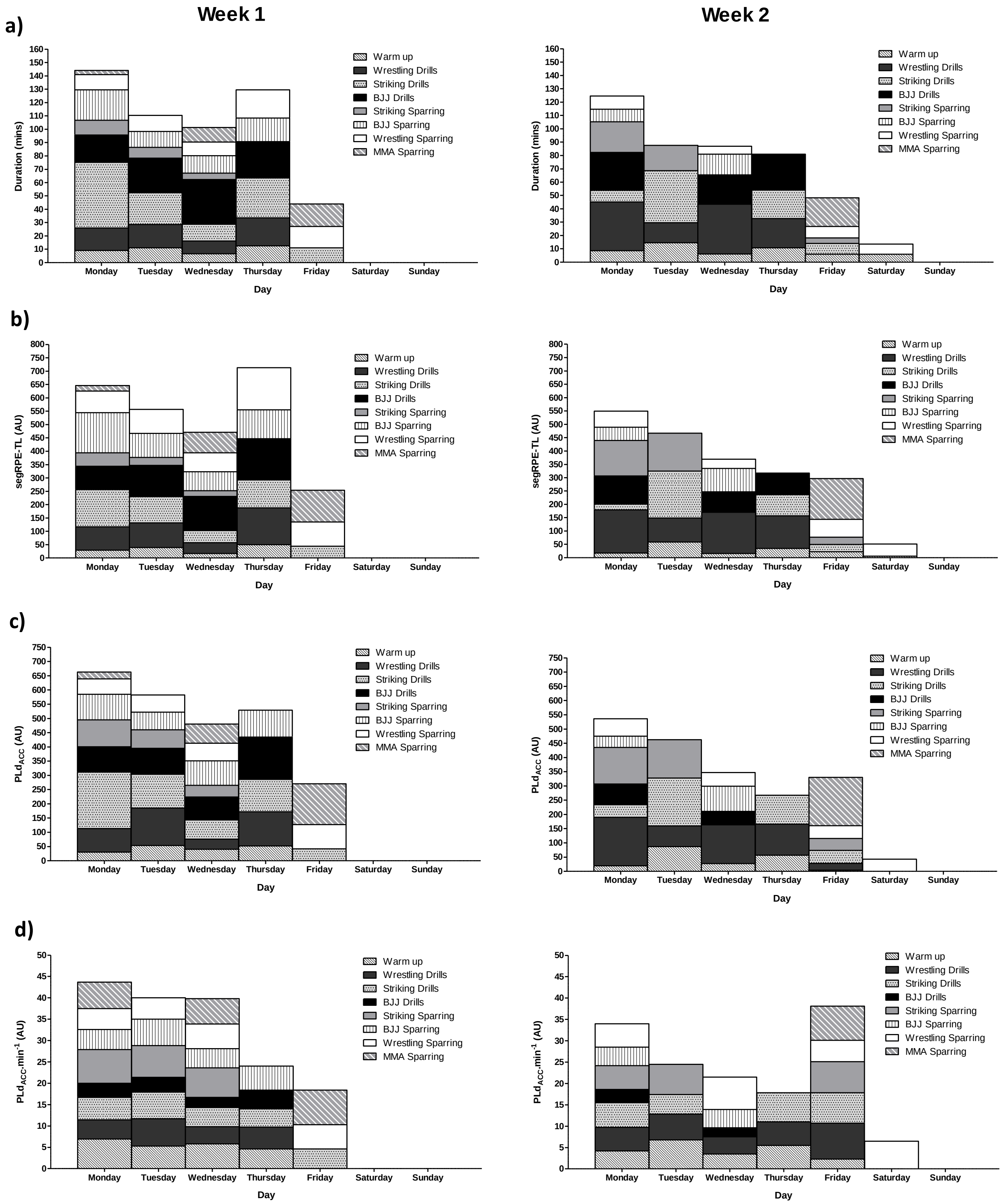
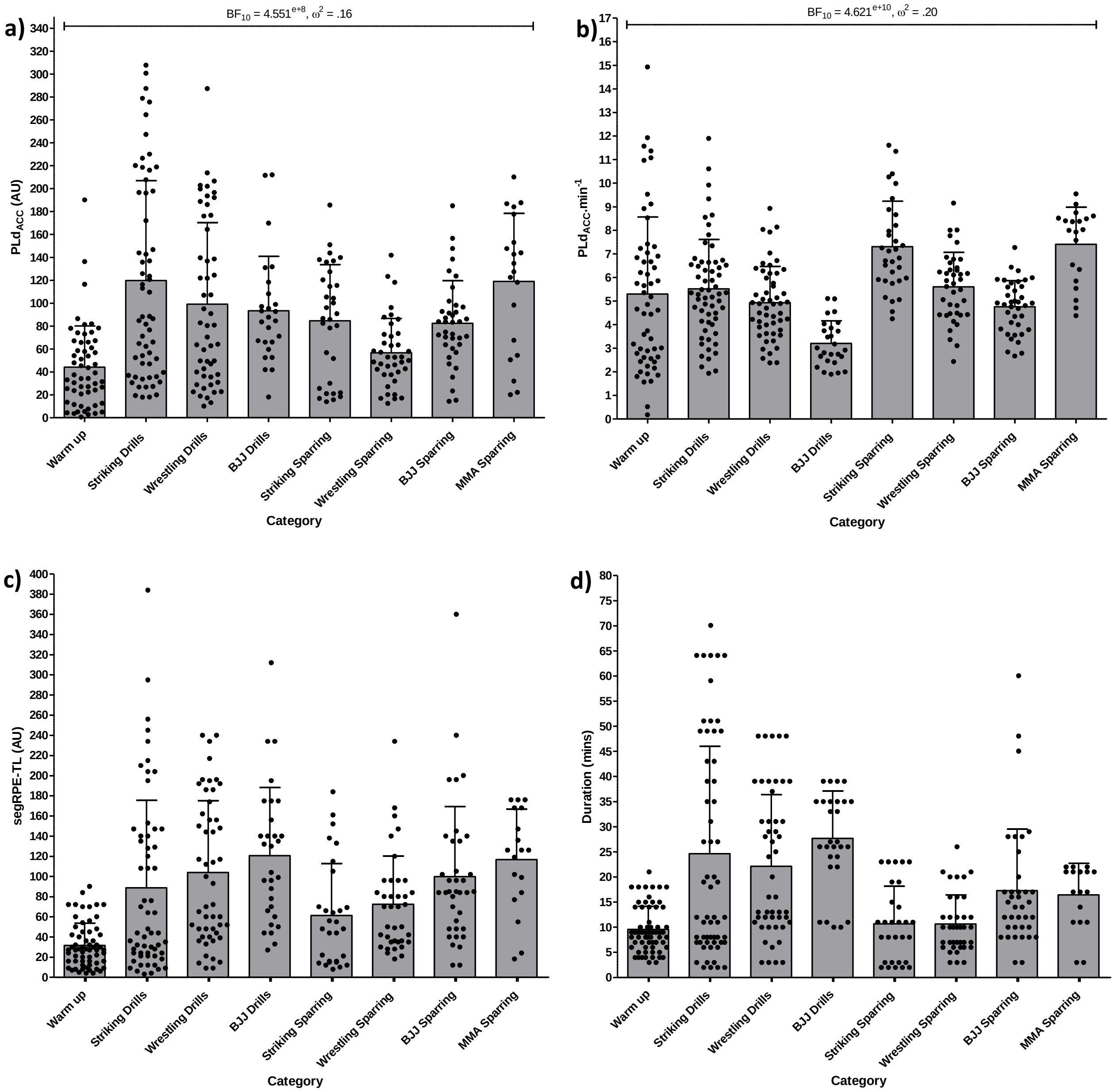


Figure 2 – Mean category a) duration (mins), d) internal load, c) external load and d) external intensity (all AU unless stated) by category between days within weeks. *Nb. PLd_{ACC} = accumulated Playerload; PLd_{ACC}·min $^{-1}$ = accumulated Playerload per minute; sRPE-TL = sessional rating of perceived exertion training load; segRPE-TL = segmented sessional rating of perceived exertion training load.*

External load and external intensity between training categories

Differences between categories can be viewed in Figure 3. External load (3a) 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 external load than all other categories apart from warm up (BF_{10} = 9 – 8,698). BJJ sparring displayed lower external load than striking drills (BF_{10} = 3) and MMA sparring respectively (BF_{10} = 7).

External intensity (3b) was also different between categories with a large effect (BF_{10} = 4.621^{e+10}, ω^2 = .20). BJJ drills caused least $PLd_{ACC}\cdot min^{-1}$ 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 external intensity than striking sparring. Striking sparring also produced greater external intensity 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 more $PLd_{ACC}\cdot min^{-1}$ than all other categories with the exception of striking sparring (BF_{10} = 6–2.213^{e+11}). Differences between categories in terms of internal load (3c) and duration (3d) have previously been evidenced[11] so have not been retested here. Data for these variables as collected for the current study are displayed for complete reporting (Figure 3c and 3d).



307 **Figure 3 – Mean±SD a) external load, b) external intensity, c) internal load (all AU) and d)
308 duration (mins) of each training category.** *Nb. PLd_{ACC} = accumulated Playerload; $PLd_{ACC}{\cdot}min^{-1}$ =
309 accumulated Playerload per minute; segRPE-TL = segmented sessional rating of perceived exertion training
310 load; differences between internal load and duration of categories not tested*

Relationships between external and internal loads, intensities, and durations

Correlations between internal and external loads can be viewed in Figure 4. All MMA category correlations were moderate-to-large, with the exception of BJJ related categories which both displayed lower boundaries below the small threshold. Similarly, warm up and session overall correlations are small-to-moderate only. The data also support predictive relationships between PLd_{ACC} and segRPE-TL/sRPE-TL in all categories (Table 2), though this support was only moderate-to-strong for warm up and BJJ drills. In terms of internal and external intensity, only three categories displayed statistically relevant correlations between segRPE and $PLd_{ACC}\cdot min^{-1}$, with these being small-to-moderate (Figure 4).

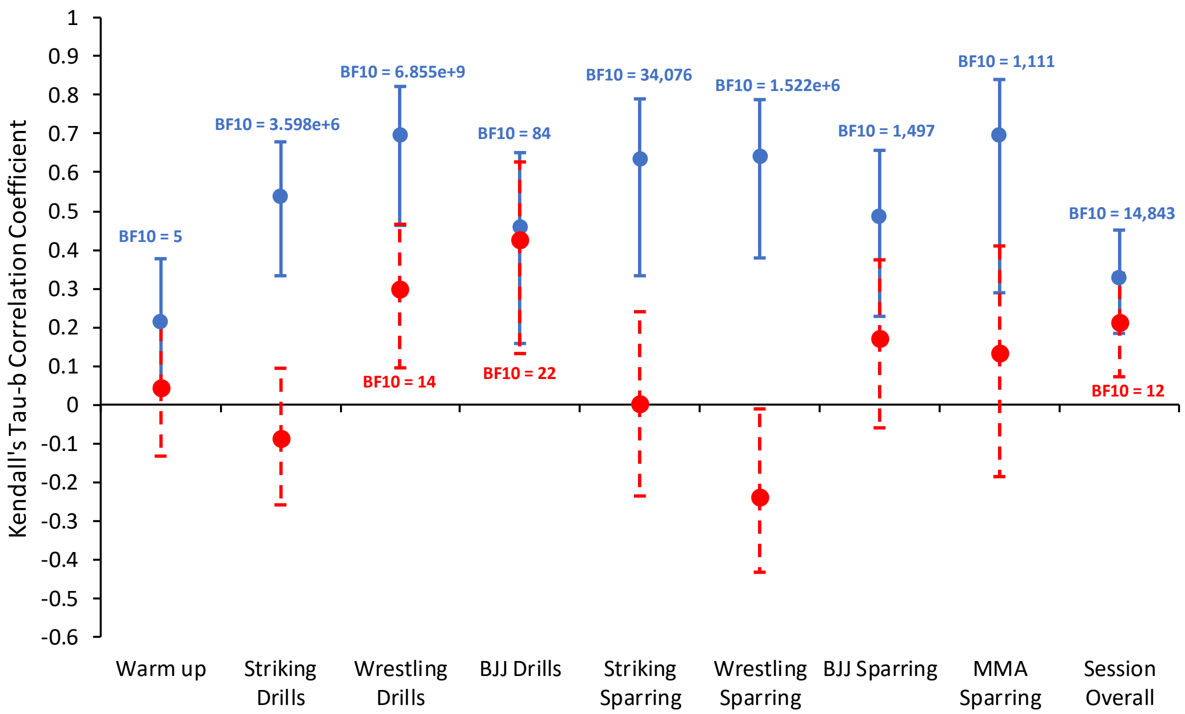


Figure 4 – Kendall's Tau-b correlations between: internal load (segRPE-TL/sRPE-TL) and external load (PLd_{ACC}); internal intensity (segRPE/sRPE) and external intensity ($PLd_{ACC}\cdot min^{-1}$). *Nb. Blue dots show correlations between internal load (segRPE-TL/sRPE-TL) and external load (PLd_{ACC}), with statistically relevant BF annotated above; Red dots show correlations between internal intensity (segRPE/sRPE) and external intensity ($PLd_{ACC}\cdot min^{-1}$), with statistically relevant BF listed below; Individual training categories display Tau-b between PLd_{ACC}/$PLd_{ACC}\cdot min^{-1}$ and segRPE-TL/segRPE; session overall displays Tau-b between PLd_{ACC}/$PLd_{ACC}\cdot min^{-1}$ and sRPE-TL/sRPE. Error bars = 95% credible intervals.*

Table 2 – Bayesian regression parameters for estimating MMA external load (PLd_{ACC}) from internal load (segRPE-TL/sRPE-TL)

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 external training load and training duration (Figure 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 external load and duration (Table 3). Correlations between internal load and training duration were all moderate or greater, with only the lower bounds of BJJ drills and session overall falling below the moderate threshold (Figure 5).

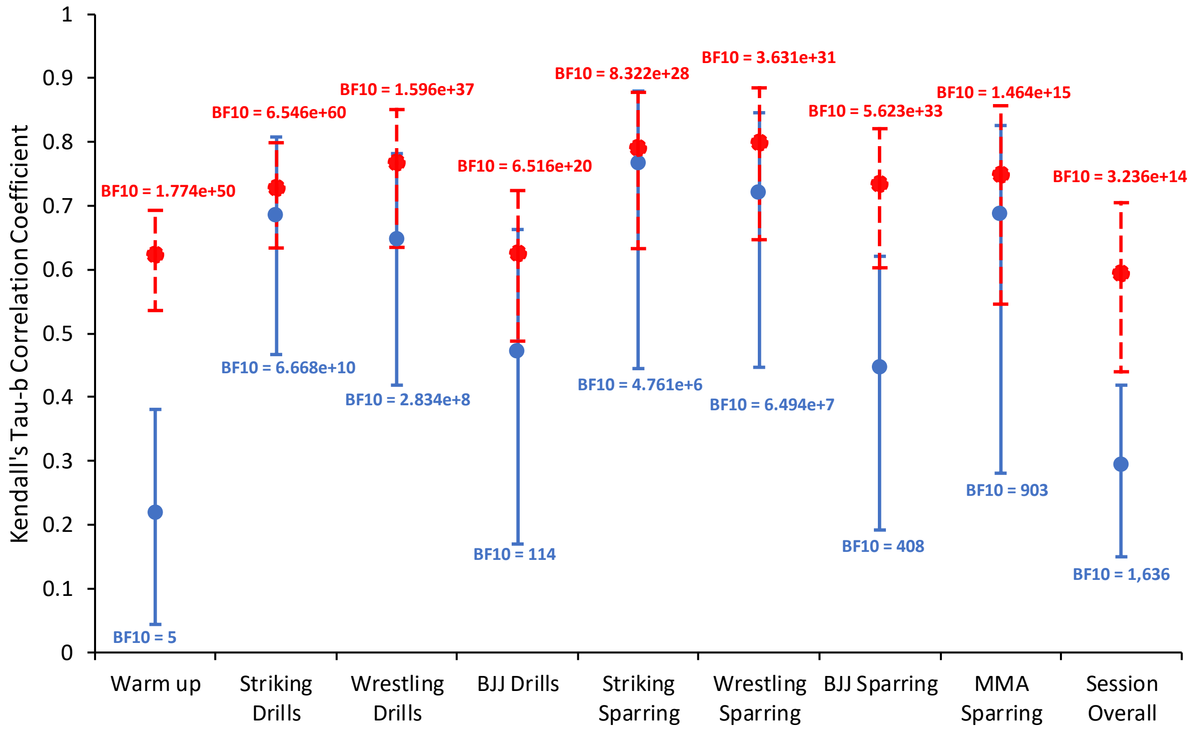


Figure 5 – Kendall's Tau-b correlations between MMA training loads (PLd_{ACC}/segRPE-TL/sRPE-TL) and training duration (mins). *Nb. Blue dots show correlations between external load (PLd_{ACC}) and duration (mins), with statistically relevant BF annotated below; Red dots show correlations between internal load (segRPE-TL/sRPE-TL) and duration (mins), with statistically relevant BF annotated above; Individual training categories display Tau-b between segRPE-TL and duration; session overall displays Tau-b between sRPE-TL and duration; Error bars = 95% credible intervals.*

Table 3 – Bayesian regression parameters for estimating MMA 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*

Category correlations between internal load and internal intensity (Figure 6) were all found to be moderate with the exception of MMA sparring which was not statistically relevant. The lower bound for striking sparring also fell below the trivial threshold. External loads were found to have small-to-moderate correlations with external intensity for most categories, with the exception of striking drills, wrestling sparring and BJJ sparring which were not statistically relevant (Figure 6).

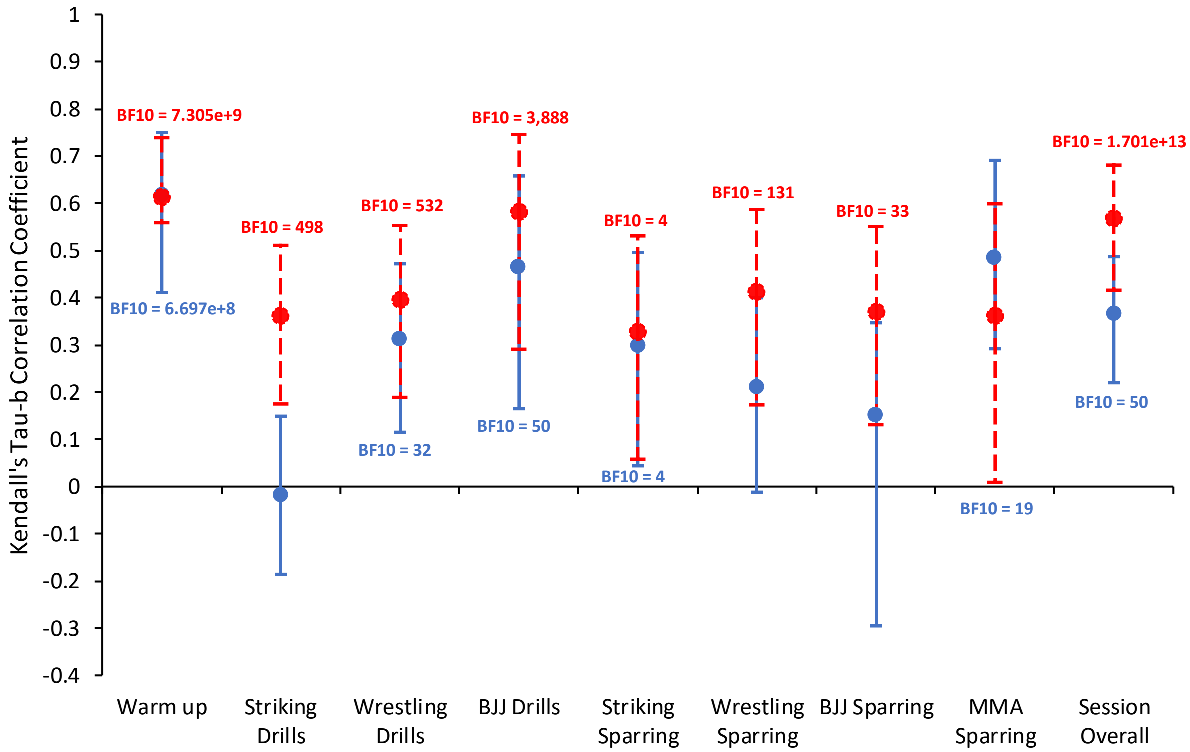


Figure 6 – Kendall's Tau-b correlations between MMA training loads (PLd_{ACC}/segRPE-TL/sRPE-TL) and training intensities ($PLd_{ACC}\cdot min^{-1}$/segRPE/sRPE). *Nb. Blue dots show correlations between external load (PLd_{ACC}) and external intensity ($PLd_{ACC}\cdot min^{-1}$), with statistically relevant BF annotated below; Red dots show correlations between internal load (segRPE-TL/sRPE-TL) and internal intensity (segRPE/sRPE), with statistically relevant BF annotated above; For internal load and intensity relationships, individual training categories display Tau-b between segRPE-TL and segRPE; session overall displays Tau-b between sRPE-TL and sRPE; Error bars = 95% credible intervals.*

Discussion

The aim of this study was to measure the external load and external intensity of MMA training via Playerload and determine its relationship to internal load and internal intensity. We found MMA training categories display differing external loads and intensities to each other, indicating Playerload can distinguish between MMA training modes. The external load 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. Fewer relationships were found between internal and external intensities, with only wrestling drills, BJJ drills and session overall being statistically relevant. Both internal and external load are related to duration, with external load correlations being slightly weaker than those of internal load. Relationships between load and intensity appeared similar for both internal and external variables. Exceptions to this were striking drills, wrestling sparring and BJJ sparring for external variables, and MMA sparring for internal variables, where no relationships were found. 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, neither internal nor external training load changed between days. These data provide a novel understanding of relationships between internal and external MMA training variables. This understanding may be used to develop training practices that provide within and between week undulations in training load, which are currently absent in this population[11].

Our data show a static training load across the week. This is despite more intense sparring sessions being completed at the end of the week and coaches potentially limiting the duration of high intensity categories. Though providing evidence of purposeful session planning, this approach leads to equal training loads between sessions. This may explain the absence of between week changes in training load and fatigue previously reported[11]. This may be rectified by MMA coaches collaborating with sport science practitioners to record the Playerload and sRPE-TL/segRPE-TL of their athletes using the methods detailed here. Coaches may use this information to plan microcycles based on technical and tactical requirements alongside physiological needs[33]. For example, a high load week may consist of more instances of wrestling or sparring categories, with fewer drill-based categories. Conversely, a low load week may only include drill-based categories and BJJ sparring. The volume of each category may be determined by choosing the desired sRPE-TL for the day or week and calculating the category external loads and durations needed to achieve this internal load. Predicting MMA athlete's internal load from the planned external load or training category durations within each session may allow overreaching and restitution weeks to occur and for pre-bout tapering to be applied[6,11]. In lieu of being able to record such data for their athletes, coaches and practitioners may instead plan session content and category duration using the regression data reported in Tables 2 and 3, and the means in Supplementary File 1.1. Though there would potentially be differences between populations and cohorts, use of the regression equations reported here may provide a starting point for coaches to estimate the expected external-internal load responses to their planned training content.

External loads and intensities were found to differ between categories, as 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-TL and PLd_{ACC}, with all other categories being large. This is similar to team sports where skill-based training displays a reduced relationship between internal load and accelerometer derived external load in comparison to open or mixed mode training[34]. Such disparities between training modes may be caused by each category's different ambulatory requirements. Repeated foot-ground contacts increase accelerometer readings due to ground reaction forces acting on the torso and the unit individually[35]. This effect is increased for whole body actions of greater intensity or velocity[28], explaining the differences between striking drills and striking sparring. Though both categories include foot-ground contacts, striking drills are performed at a lower intensity[11] leading to lower PLd_{ACC}. Grappling-based modes, however, have very different movement requirements, often with little if any ambulation occurring and a high incidence of isometric actions. These modes would therefore consist of reduced PLd_{ACC} but without a concomitant change in segRPE-TL. As an example of this effect, BJJ drills had the highest segRPE-TL amongst drill categories, but the lowest PLd_{ACC}. Striking drills show the opposite pattern, with high PLd_{ACC} but low segRPE-TL. This is despite drill categories having similar durations. Amongst sparring categories, BJJ sparring and striking sparring have comparable PLd_{ACC}, but BJJ sparring results in greater segRPE-TL with a weaker relationship to external load than seen in striking sparring. Therefore, internal load of BJJ related categories may be more affected by isometric contractions and physical bearing of opponent mass rather than changes in movement. Added to this would be the mental strain of skill learning, which also cannot be measured by accelerometry but stills affects RPE[33,36]. These different contributions to training load further reinforces the need for multiple, complimentary measures in practice[1]. This is particularly the case for MMA's diverse skill and physiological training requirements[5].

The 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-TL and Playerload[8,16]. PLd_{ACC} being indicative of the amount of active movement time in MMA[22] may explain this result. To allow analysis of the full training sessions, all rest periods were included. The intermittent nature of drill-based coaching sessions means natural breaks between periods of active movement occurred. This reduces changes in acceleration as measured by Playerload but does not necessarily reduce sRPE-TL/segRPE-TL. This finding mirrors association football, where PLd_{ACC} and sRPE-TL display a large correlation (r = .79) when sRPE-TL is calculated from the number of minutes played, but reduces (r = .55) when total duration of the match is used[37]. Each full MMA session contained multiple incidences where participants were being coached or taking on fluids without movement. This may cause reduced external load but not internal load. Whilst internal and external loads were related in all categories, this did not occur for internal and external intensity. Only two training categories and session overall displayed relationships between intensity markers. This supports previous findings of athlete internal responses varying following equivalent external stimuli[2], and reinforces the notion of these factors being conceptually distinct[38].

External load having comparable relationships to both internal load and training duration requires further investigation to determine whether PLd_{ACC} more reflects the intensity of the task, or simply time on task. It may be that coaches have preconceptions of which training modes are more intense and therefore limit the durations of these categories to avoid athlete fatigue. This may cause effects of external loads 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-TL/sRPE-TL only present due to mathematical coupling caused by the shared variable of duration[39] which is highlighted as a potential confound for training load research in general[34]. Due to this effect, the proportions to which intensity and duration contribute to training load is a source of debate. Data from both rugby codes demonstrated 70-74% of training load variance can be attributed to changes in duration, with intensity explaining 24-34%[40]. A similar finding may be indicated here due to stronger correlations between load/duration than load/intensity. Internal load as represented by sRPE-TL will always have a strong relationship to duration owing to the latter being the multiplier in the sRPE-TL equation[26]. This effect appears to be less for external load, as evidenced here by weaker PLd_{ACC}/duration relationships. Relatively wide error bars also reveal more uncertainty in this relationship compared to internal load/duration. These correlations are, however, still stronger and more consistent between categories than those reported for external intensity/external load. As such, duration does appear to have a greater influence than intensity on external load in MMA training.

The nearly perfect relationship between PLd_{ACC} and total active time but not inactive time in MMA sparring[22], alongside the differences between categories in the current study, does support intensity affecting PLd_{ACC}. Unfortunately, due to the aforementioned uncertainties in the strength of correlations and the potential effects of mathematical coupling, the relative contributions of intensity and duration to PLd_{ACC} cannot be fully elucidated from these data. If PLd_{ACC} is more reliant on duration, it may still be an acceptable global indicator of overall activity, but may not be entirely sufficient for coaches to plan for the differing internal responses to sessions and categories of greater/lesser intensity[11,41]. The co-influence of duration and intensity on PLd_{ACC}, therefore, needs to be examined in future duration-matched studies before the use of this variable for MMA training can be fully understood. Currently, coaches may be advised to use the data regarding category intensities reported here and previously[11] to inform which categories could be planned to be of long and short durations. This would also enable more intense categories to be programmed alongside less intense categories within sessions and between adjacent sessions. Durations of each category may then be planned as suggested previously in this manuscript.

These results do have some limitations. The cohort were mostly Tier 3 athletes, with the training sessions planned and delivered by a small number of coaches. This may limit the generalisability of the data across populations and performance levels. The data were also limited to a two-week period of collection, meaning the stability of these findings over time is not fully known. Training load, duration and content was, however, previously found to be static over an eight-week period, with no differences between bout preparation and regular training in a similar MMA population[11]. This may suggest that these outcomes may be robust over different time periods and training conditions.

Conclusions

In conclusion, we present the external loads and external intensities of MMA training sessions and modes for the first time. MMA categories are distinguished by different external and internal loads, allowing coaches to plan training load distribution in advance. PLd_{ACC} has a moderate-to-large predictive relationship with segRPE-TL/sRPE-TL for most MMA training categories, which provides regression equations for use in periodised planning thus enabling overreaching and restitution weeks to be incorporated. BJJ related categories only display a moderate relationship between these variables, likely due to isometric contractions and opponent mass bearing not being reflected by accelerometry, but still contributing to RPE.

Few relationships were found between internal and external intensities, demonstrating that these are measuring different facets of the training prescription and should be considered separately. Training duration appears to have a greater effect than intensity on load. Whilst the effect of duration on internal load in MMA appears relatively strong, the relationship between duration and external load is less clear. Future studies should therefore determine the relative contributions of intensity and duration on PLd_{ACC} to fully develop its use in MMA training environments.

Practical Applications

These data support the use of the PLd_{ACC}-segRPE-TL model in monitoring the loads of MMA training sessions, which in turn may be used to plan more appropriate loading patterns within and between micro/mesocycles. Researchers should collaborate with coaches to investigate the use of this model in managing the fatigue-recovery-adaptation cycle by calculating the duration-external load-internal load relationship of individual MMA athletes.

Alternatively, coaches may use the regression equation data presented here as a starting point for their training load planning. It should be noted that this would require a certain level of understanding of statistical modelling or mathematics on the part of the coaches. Accordingly, it may be appropriate for educational resources to be designed and offered to MMA coaches with the aim of developing sufficient skills in this area to use these data effectively in their training programming.

Statements and Declarations

The authors have no relevant financial or non-financial competing interests to report. 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. The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

References

1. Halson SL. Monitoring training load to understand fatigue in athletes. Sports Med 2014;44:139–47.

2. Impellizzeri F, Marcora S, Coutts A. Internal and external training load: 15 years on. Int J Sports Physiol Perform 2018.

3. Bourdon PC, Cardinale M, Murray A, Gastin P, Kellmann M, Varley MC, et al. Monitoring athlete training loads: consensus statement. Int J Sports Physiol Perform 2017;12:S2–161.

4. Wing C. Monitoring Athlete Load: Data Collection Methods and Practical Recommendations. Strength Cond J 2018;40:26–39.

5. Kirk C, Clark D, Langan-Evans C, Morton J. The physical demands of mixed martial arts: A narrative review using the ARMSS model to provide a hierarchy of evidence. J Sport Sci 2020;38:2819–41.

6. Turner A. The science and practice of periodization: a brief review. Strength Cond J 2011;33:34–46.

7. Casamichana D, Castellano J, Calleja-Gonzalez J, San Román J, Castagna C. Relationship between indicators of training load in soccer players. J Strength Cond Res

2013;27:369–74.

8. Scott BR, Lockie RG, Knight TJ, Clark AC, de Jonge XAJ. A comparison of methods to quantify the in-season training load of professional soccer players. Int J Sports Physiol Perform 2013;8:195–202.

9. Slimani M, Davis P, Franchini E, Moalla W. Rating of Perceived Exertion for Quantification of Training and Combat Loads During Combat Sport-Specific Activities: A Short Review. J Strength Cond Res 2017;31:2889–902.

10. Campos F, Correa JCM, Canevari VC, Branco BH, Andreato LV, de Paula Ramos S. Monitoring internal training load, stress-recovery responses, and immune-endocrine parameters in Brazilian jiu-jitsu training. J Strength Cond Res 2020.

11. Kirk C, Langan-Evans C, Clark D, Morton J. Quantification of training load distribution in mixed martial arts athletes: A lack of periodisation and load management. PLoS One 2021;16.

12. Kostikiadis IN, Methenitis S, Tsoukos A, Veligekas P, Terzis G, Bogdanis GC. The effect of short-term sport-specific strength and conditioning training on physical fitness of well-trained mixed martial arts athletes. J Sports Sci Med 2018;17:348–58.

13. Coswig V, Ramos S de, Del Vecchio F. Time-motion and biological responses in simulated mixed martial arts sparring matches. J Strength Cond Res 2016;30:2156–63.

14. Antoniettô NR, Bello F, Carrenho AQ, de Carvalho Berbert P, Brito CJ, Amtmann J, et al. Suggestions for professional mixed martial arts training with pacing strategy and technical-tactical actions by rounds. J Strength Cond Res 2019

15. Worsey M, Espinosa H, Shepherd J, Thiel D. Inertial sensors for performance analysis in combat sports: A systematic review. Sports 2019;7.

16. Svilar L, Castellano J, Jukic I. Load monitoring system in top-level basketball team: Relationship between external and internal training load. Kinesiology 2018;50:25–33.

17. Bredt S da GT, Chagas MH, Peixoto GH, Menzel HJ, de Andrade AGP. Understanding Player Load: Meanings and Limitations. J Hum Kinet 2020;71:5–9.

18. Boyd LJ, Ball K, Aughey RJ. The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. Int J Sports Physiol Perform 2011;6:311–21.

19. Hurst HT, Atkins S, Kirk C. Reliability of a portable accelerometer for measuring workload during mixed martial arts. J Athl Enhanc 2014;5.

20. Kirk C, Malone J, Angell P. Intra-unit reliability and movement variability of submission grappling external load as measured by torso mounted accelerometery. Biol Sport 2023;40:457–64.

21. Kirk C, Hurst HT, Atkins S. Measuring the workload of mixed martial arts using accelerometry, time motion analysis and lactate. Int J Perform Anal 2015;15:359–70.

22. Kirk C, Atkins S, Hurst HT. The pacing of mixed martial arts sparring bouts: A secondary investigation with new analyses of previous data to support accelerometry as a potential method of monitoring pacing. Hum Move 2020;21:88–96.

23. Finlay MJ, Greig M, McCarthy J, Page RM. Physical response to pad-and bag-based boxing-specific training modalities. J Strength Cond Res 2020;34:1052–61.

24. McKay A, Stellingwerff T, Smith E, Martin D, Mujika I, Goosey-Tolfrey V, et al. Defining training and performance caliber: a participant classification framework. Int J Sports Physiol Perform 2021;17:317–31.

25. Haile L, GallagherJr. M, Robertson RJ. Perceived Exertion Laboratory Manual. Springer; 2016.

26. Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, et al. A new approach to monitoring exercise training. J Strength Cond Res 2001;15:109–15.

27. Uchida MC, Teixeira LF, Godoi VJ, Marchetti PH, Conte M, Coutts AJ, et al. Does the timing of measurement alter session-RPE in boxers? J Sports Sci Med 2014;13:59.

28. McLean BD, Cummins C, Conlan G, Duthie G, Coutts AJ. The fit matters: influence of accelerometer fitting and training drill demands on load measures in rugby league players. Int J Sports Physiol Perform 2018;13:1083–9.

29. Malone JJ, Lovell R, Varley MC, Coutts AJ. Unpacking the black box: applications and considerations for using GPS devices in sport. Int J Sports Physiol Perform 2017;12:S2–18.

30. Wetzels R, Wagenmakers E-J. A default Bayesian hypothesis test for correlations and partial correlations. Psychon Bull Rev 2012;19:1057–64.

31. Hopkins W. A scale of magnitudes for effect sizes [Internet]. 2002 [cited 2019 28–5];Available from: http://sportsci.org/resource/stats/effectmag.html

32. Field A. Discovering Statistics Using IBM SPSS Statistics. 5th ed. Sage; 2018.

33. Farrow D, Robertson S. Development of a skill acquisition periodisation framework for high-performance sport. Sports Med 2017;47:1043–54.

34. McLaren SJ, Macpherson TW, Coutts AJ, Hurst C, Spears IR, Weston M. The relationships between internal and external measures of training load and intensity in team sports: A meta-analysis. Sports Med 2018;48:641–58.

35. Edwards S, White S, Humphreys S, Robergs R, O’Dwyer N. Caution using data from triaxial accelerometers housed in player tracking units during running. J Sports Sci 2018;:1–9.

36. Robertson RJ, Noble BJ. Perception of physical exertion: Methods, mediators, and applications. Exerc Sport Sci Rev 1997;25:407–52.

37. Pustina AA, Sato K, Liu C, Kavanaugh AA, Sams ML, Liu J, et al. Establishing a duration standard for the calculation of session rating of perceived exertion in NCAA division I men's soccer. J Trainology 2017;6:26–30.

38. Jeffries AC, Marcora SM, Coutts AJ, Wallace L, McCall A, Impellizzeri F. Development of a revised conceptual framework of physical training for use in research and practice. Sports Med 2021;:1–16.

39. Archie Jr J. Mathematic coupling of data: a common source of error. Ann Surg 1981;193:296.

40. Weaving D, Dalton-Barron N, McLaren S, Scantlebury S, Cummins C, Roe G, et al. The relative contribution of training intensity and duration to daily measures of training load in professional rugby league and union. J Sports Sci 2020;38:1674–81.

41. Seiler S. What is best practice for training intensity and duration distribution in endurance athletes? Int J Sports Physiol Perform 2010;5:276–91.

SUPPLEMENTARY FILE 1

Supplementary File 1.1 - Descriptive data for external load, internal load, external intensity, internal 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
segRPE/sRPE (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-TL/sRPE-TL (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; segRPE/sRPE = category internal intensity; segRPE-TL = segmented sessional rating of perceived exertion training load; sRPE-TL = sessional rating of perceived exertion training load; a = decisive differences between categories; * = sRPE-TL*

Supplementary File 1.2 - Mean training category duration and internal load by day

	Mon		Tues		Wed		Thurs		Fri		Sat		Sun	
	Duration	**segRPE-TL/ sRPE-TL**	**Duration**	**segRPE-TL/ sRPE-TL**	**Duration**	**segRPE-TL/ sRPE-TL**	**Duration**	**segRPE-TL/ sRPE-TL**	**Duration**	**segRPE-TL/ sRPE-TL**	**Duration**	**segRPE-TL/ sRPE-TL**	**Duration**	**segRPE-TL/ sRPE-TL**
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-TL = segmented sessional rating of perceived exertion training load; sRPE-TL = sessional rating of perceived exertion training load; * = sRPE-TL* a *= decisive differences in duration between days;* b *= strong differences in duration between days;* c *= decisive differences in segRPE-TL between days;* d *= moderate differences in segRPE-TL between days;* e *= very strong differences in segRPE-TL between days.*

Supplementary File 1.3 - Mean training category external load and external intensity 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*