Training Load Is Correlated with Changes in Creatine Kinase and Wellness over a 12-Week Multi-Stage Preparatory Training Block for a Major Competition in International Boxers

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Training Load Is Correlated with Changes in Creatine Kinase and Wellness over a 12-Week Multi-Stage Preparatory Training Block for a Major Competition in International Boxers

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Abstract: Background: There are no published data on the training-load magnitude or distribution in elite international-level boxers preparing for a major competition nor on the training load's relationship with objective and subjective training markers. Methods: Twelve elite boxers (eight males and four females) preparing for the 2018 Commonwealth Games were monitored during training for 12 weeks. The training load (TL), change in creatine kinase (ΔCK), and wellness variables were measured daily but were amalgamated into average weekly values over the 12-week period for weekly comparisons. The relationships between the TL, ΔCK, and wellness variables were also assessed. Results: The significant ($p < 0.001$) main effects of the week with large and moderate effect sizes were noted for the TL and ΔCK, respectively, with weeks 9 and 12 in the competition-specific and taper phases showing the greatest differences, respectively. For wellness, only the muscle condition showed a significant change over time ($p < 0.001$). There were significant ($p < 0.05$) small–moderate correlations between the TL, ΔCK, and wellness variables. Conclusions: This is the first study to describe the weekly training loads and responses to training of elite international boxers across a 12-week pre-competition training period in preparation for a major competition. The findings within this study report that elite international boxers have high chronic training loads that change between training blocks to put emphasis on different qualities. Monitoring the indirect muscle damage through CK may provide further information on the internal training responses in boxers.

Keywords: combat; elite athlete; monitoring; muscle damage; periodisation

1. Introduction

Amateur boxing is one of the oldest and most popular combat sports in the world [1]. It is defined as a stand-up fist fight between two opponents in an equal weight category and in accordance with the rules established by the Amateur International Boxing Association; elite-level bouts consist of three rounds, three minutes each, with a one-minute rest in-between [2]. The activity profile of elite amateur boxers is characterised by multi-directional, intermittent bouts of high-intensity activity interspersed by periods of active and passive recovery [3], with boxers required to maintain an activity rate of ~1.55 actions per second, consisting of ~21 punches, ~3.6 defensive movements, and ~56 vertical hip movements per minute, over the bout's duration [4].

The physical and physiological characteristics of elite amateur boxers display a propensity for relatively high lean muscle tissue, with elevated cardiorespiratory fitness, muscle contractile strength/power, and anaerobic power/capacity being the key components to success [1]. Achieving successful performance requires the optimal development of their technical, tactical, and physical abilities, and as is often the case with combat sports, usually, no single performance characteristic dominates [5]. The research to date has contributed to an increased understanding of the sport, with information presented on areas including physical and physiological attributes [1,6,7]; activity profiles and performance

aspects [3,4,8]; weight-making practices [9]; warm-up practices [10]; the impact of nutritional supplementation on performance [11]; and physiological responses to boxing-specific training modalities [12], simulated competition [13–15], and competition [16–18].

Despite general training principles and practices having been documented [19], there is limited information relating to how elite amateur boxers prepare for major competitions. Training camps have been described as consisting of four to ten weeks in duration, training five to six days per week with two or more sessions per day [20,21], which is consistent with the training practices reported in professional boxing (eight–twelve weeks) [22] and other combat sports, including judo, where a thirteen-week block periodisation approach has been described [23]. To the authors' knowledge, only one study has specifically quantified the weekly training loads that amateur boxers are exposed to in training [24]; however, in that study, the subjects were club-level youth boxers (14–16 years) and were not preparing for competition.

Athlete monitoring is considered an essential component in managing athletic preparation [25] and is aimed at eliciting positive adaptations for performance whilst avoiding negative outcomes, such as under-performance, injury, or poor wellbeing [26,27]. Due to the combative nature of boxing, it has been considered difficult to assess the exercise intensity during training using traditional objective methods such as heart rate monitors or other microtechnology devices (i.e., GPS, accelerometers, etc.), as these devices may interfere with training [28]. Thus, the session rating of perceived exertion (the session RPE) has been identified as a valid and reliable tool for classifying different-intensity training sessions in boxing [28] and has been recommended as a suitable alternative for combat sports [29] to quantify short- and long-term training loads.

The monitoring of the biochemical and perceptual responses to training is also of great interest to individuals working with combat sports. Indirect indices of muscle damage (ALT, alanine aminotransferase; AST, aspartate aminotransferase) have been shown to increase significantly following 3×3 min competition rounds in national-level boxers. Creatine kinase (CK) is a biomarker commonly used to indirectly assess muscle damage, particularly in team sports, displaying associations with changes in CK levels and physical performance [30,31]. It has also been investigated in boxing [18] and other combat sports following rapid-weight-loss practices [32] during the competitive season [33] and has been shown to be a sensitive objective marker in this context. However, currently, there are no reports of CK levels in elite boxers over a series of periodised training blocks nor their relationship with other training-load measures. Furthermore, an important aspect in providing a holistic view of monitoring training, performance, and recovery is the now-common use of athlete self-report measures, such as the completion of psychometric questionnaires [34]. Such questionnaires have also been shown to be sensitive and significantly correlated with changes in acute and chronic training loads in both team and combat sports [35,36].

Despite the increased prevalence of athlete monitoring in elite sports, the research on elite amateur boxing which has monitored the training load and the responses to the prescribed training loads during preparation for competition remains lacking. Therefore, the aims of the current study are (1) to describe the weekly variation in the training load in elite amateur boxers preparing for a major competition, (2) to outline the changes in objective and subjective monitoring variables in response to the training loads observed, and (3) to identify if relationships between the training-load, self-reported-wellness, and biochemical variables exist.

2. Results

2.1. Training Load and Duration

There was a significant main effect of the week on the training load ($p < 0.001$, X^2 88, df 11, $W_K = 0.67$, Figure 1). Post hoc comparisons showed significant differences between week 9 and all the other weeks, except for weeks 11 and 12, respectively ($p < 0.05$ for all). Week 12 was significantly different from all the other weeks, except for week 9 and week 11, respectively ($p < 0.05$ for all). Significant differences were also noted between week 11 and

weeks 1, 2, 3, 4, 5, and 6, respectively ($p < 0.05$ for all). Significant differences were reported between week 7 and weeks 3, 4, and 5; week 8 and weeks 3, 4, 5, and 6; and week 3 and week 10 ($p < 0.05$ for all).
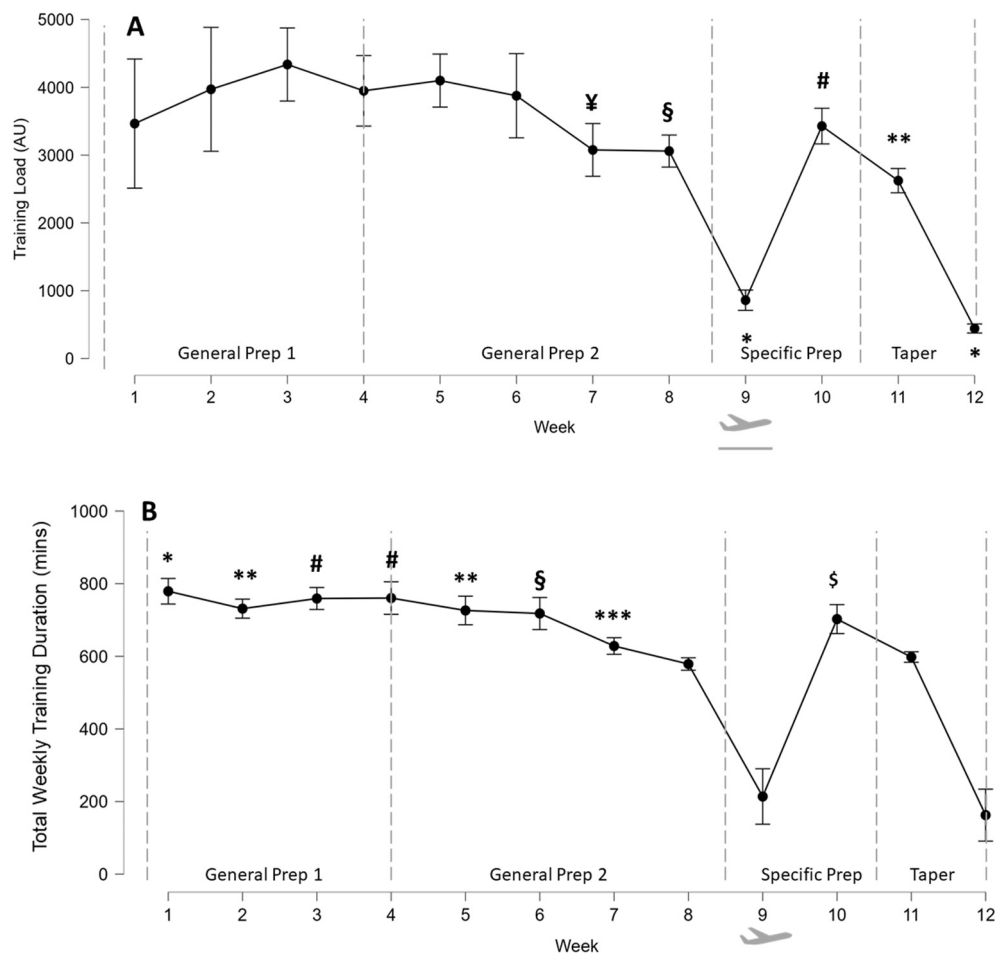

Figure 1. Changes in training load (**A**) and duration (**B**) over each of the phases over the course of the 12-week training camp. For (**A**), * represents significant difference ($p < 0.05$) with weeks 1–8 and 10, ** represents significant difference ($p < 0.05$) with weeks 1–6, ¥ represents significant difference ($p < 0.05$) with weeks 3–5, § represents significant difference ($p < 0.05$) with weeks 3–6, and # represents significant difference ($p < 0.05$) with week 3. For (**B**), * represents significant difference ($p < 0.05$) with weeks 2 and 5–12; ** represents significant difference ($p < 0.05$) with weeks 7–12; # represents significant difference ($p < 0.05$) with weeks 6–12; § represents significant difference ($p < 0.05$) with weeks 8, 9, and 12; *** represents significant difference ($p < 0.05$) with weeks 9 and 12; and $ represents significant difference ($p < 0.05$) with weeks 8, 9, and 12. Mean ± 95% C.I. Note: airplane icon denotes 32 h travel from home country to competition location (11 h time-zone difference).

There was a significant main effect of the week on the training duration ($p < 0.001$, X^2 121, df 11, $W_K = 0.92$, Figure 1B). Post hoc comparisons showed significant differences between week 1 and weeks 2 and 5–12 ($p < 0.05$ for all). Weeks 2 and 5 were significantly different from weeks 7–12 ($p < 0.05$ for all). Weeks 3 and 4 were significantly different ($p < 0.05$) from weeks 6–12. Significant differences were reported between week 6 and weeks 8, 9, and 12. Week 7 was significantly different from weeks 9 and 12, and week 10 was significantly different from weeks 8, 9, and 12 ($p < 0.05$ for all).

2.2. Creatine Kinase

The results demonstrated a significant main effect of the week ($p < 0.001$, X^2 44, df 11, $W_K = 0.45$). Post hoc comparisons revealed significant differences between week 9 and all the other weeks, except for weeks 5 and 12, respectively ($p < 0.05$ for all). Significant differences were also noted between week 5 and weeks 1, 2, 6, 7, 8, and 11; week 4 and week 6; and week 12 and weeks 1, 6, 7, 8, and 11 ($p < 0.05$ for all, Figure 2).
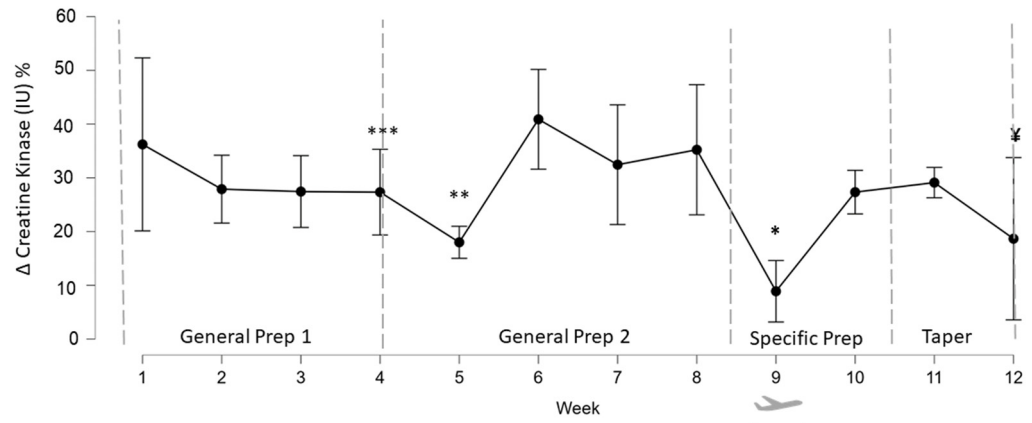

Figure 2. Changes in creatine kinase over the course of the 12-week training camp. * Significant difference ($p < 0.05$) with all weeks, except weeks 5 and 12. ** Significant difference ($p < 0.05$) with weeks 1, 2, 6, 7, 8, and 11. *** Significant difference ($p < 0.005$) with week 6. ¥ Significant difference ($p < 0.05$) with weeks 1, 6, 7, 8, and 11. Mean ± 95% C.I.

2.3. Wellness Perception

The results demonstrated no significant main effects of the week on the variation in sleep quality disturbance ($p = 0.746$), mood disturbance ($p = 0.825$), or total wellness disturbance ($p = 0.606$). However, there was a main effect of the week on the muscle condition ($p = 0.010$, X^2 36, df 11, $W_K = 0.29$, Figure 3). Post hoc comparisons showed that week 9 was significantly different from weeks 1–4, 6, and 9–11 ($p < 0.05$ for all). Furthermore, significant differences were also noted between week 1 and week 5 and between week 10 and week 11 ($p < 0.05$ for all).
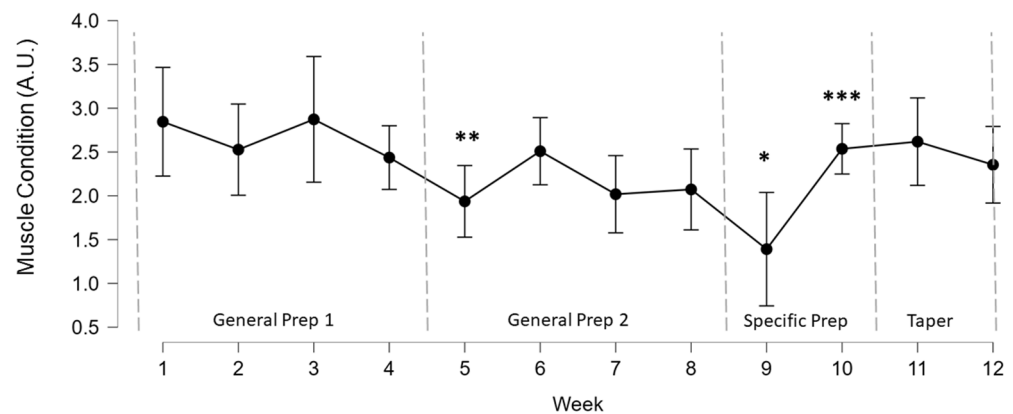
Figure 3. Changes in muscle condition over the course of the 12-week training camp. * Significant difference ($p < 0.05$) with weeks 1–6, 10, and 11. ** Significant difference ($p < 0.05$) with week 1. *** Significant difference ($p < 0.05$) with week 11. Mean ± 95% C.I.

2.4. Relationships between Training Load, Creatine Kinase, and Wellness Perception

There was a significant small positive correlation between the training load and change in CK (Figure 4). There were further significant small-to-moderate positive relationships between the training load; CK; and mood, muscle condition, and total wellness (Table 1).

These data suggest that increases in the training load and/or CK levels were met with an increase in the negative perception of the wellness measures.

Figure 4. Correlation between training load and change in creatine kinase levels over the 12-week training camp. Mean ± 95% C.I.

Table 1. Relationships between training load, Δ creatine kinase, and wellness perception.

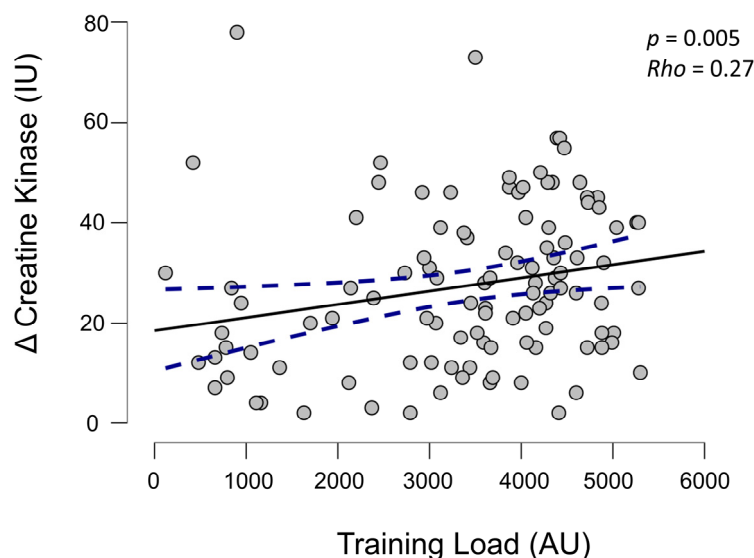|	Training Load	Δ Creatine Kinase	Mood	Muscle Condition	Sleep Quality	Total Wellness
Training Load		Figure 4	0.105 small ($p = 0.001$)	0.372 mod ($p < 0.001$)	0.038 ($p = 0.241$)	0.209 small ($p < 0.001$)
Δ Creatine Kinase	Figure 4		0.115 ($p = 0.35$)	0.302 mod ($p < 0.001$)	−0.014 ($p = 0.794$)	0.202 small ($p < 0.001$)

3. Discussion

The primary aim of this study was to describe the weekly variation in the training load (TL) in elite international boxers over a pre-competition training period and to monitor their individual responses through biochemical (creatine kinase) and psychometric (wellness) variables. The main findings in this study are that elite boxers are exposed to high weekly training loads (>3000 AU), much higher than previously reported in boxers [24], throughout the majority of the preparatory period in conjunction with significant elevations in CK, with no significant disruptions reported in their perceptual wellness.

Large TLs similar to those reported in this study have been reported previously in a variety of sports during intensified periods of training (e.g., pre-season); however, these were generally completed over shorter durations (~2–6 weeks), with greater variations reported in the total weekly training loads (TWTLs) [37–41]. In this study, high TWTLs were reported from the onset of training with little variation noted initially followed by a gradual reduction as the competition neared. This pattern of accumulating high chronic loads throughout the preparatory period followed by short dramatic reductions in the TWTL may represent a deliberate attempt at functional over-reaching, with previous research reporting that greater volumes and/or intensities in the preceding weeks elicit improved performance gains in endurance athletes [42]. The large reductions in the training load in week 9 signalled the end of the general prep period and also involved the team travelling internationally to Australia. The influence of time-zone transitions within competitive athletes has been shown to be associated with both jet-lag symptoms and alterations in

physiological function [43]; as such, the large reductions in week 9 were indicative of a deliberate attempt to support the athletes' acclimatization to the new time zone and climate. The final week, during the taper period, was associated with a large dramatic drop in the TWTL, with week 12 reflecting 13% and 17% of the TWTLs in weeks 10 and 11, respectively. Similar approaches to tapering have been reported in judo, with large reductions in the TWTL reported in the final pre-competition week [44]. This large-step taper approach may be attributable to the added requirement for combat-sport athletes to engage in rapid weight loss (RWL) practices over the period leading up to competition [45], with body mass (BM) losses of 3.6% reported during the final week in elite boxers [9]. A limitation in this study relates to the sole use of subjective measures (the session RPE) in quantifying the training load. Although this provides the reader with an insight into the internal training loads associated with training in elite amateur boxing, it does not provide any objective measures related to the external training load, defined as the physical work completed [46]. Previous studies on boxing and combat sports have reported on external loads using simulated training protocols [14,47,48]; however, no study to date has investigated the validity and reliability of external-load monitoring in practice within elite-amateur-boxing training environments. Furthermore, although the session RPE has been proposed as a reliable method for monitoring in boxing [28], there are a number of factors that have been shown to potentially influence an individual's perceived rating of exertion [49].

Intense exercise has been noted to elicit a prolonged state of muscle fatigue and damage [50], which, in turn, is associated with raised levels of serum CK [51]. Increases in CK levels have been reported previously in combat-sport athletes following competitive bouts [18,52] and during periods of RWL [32,53]. However, an important consideration when interpreting biochemical markers is whether the changes in the plasma volume were controlled/accounted for [9]. Differences in the methods used to achieve RWL have been found to impact plasma-volume changes differently [54]. In this study and in previous research assessing the effects of RWL [32,53], both the plasma volume and the method used to achieve RWL were not monitored/controlled, identifying a considerable limitation in accurately assessing the true effects of the RWL practices. Elevations in CK have been reported in longitudinal studies during intensified periods of training in both team and individual sports [39,55,56]; however, there is a paucity of this research within combat sports. In this study, variations in CK were noted throughout the 12-week period, with significant elevations reported first at the beginning of training (weeks 1 and 2), which may be attributed to new or unaccustomed training [47]. The second and third elevations occurred during the latter stages of general prep (week 6) and the specific period (weeks 10 and 11), which may be indicative of an increased exposure to combative training and/or a greater intensification and specialisation in training, which has been previously reported in track and field athletes [33]. Upon closer examination, we note that the results of this study are presented with wide confidence intervals in the majority of the variables throughout the 12-week period, suggesting large inter-individual differences. The careful examination of the subjects provided some explanation for this variance for both the males and females involved who competed in light (51 kg)- to heavy (91 kg+)-weight categories. This identifies another real-world challenge in boxing where teams consist of a cohort of physiologically and morphologically different individuals. To date, the majority of the research assessing the physiological and movement demands of elite boxing has been done on males and has not differentiated between heavier- and lighter-weight classes [8], with only one study found reporting the differences between the weight categories in post-bout blood lactate values [16]. Currently, it is unclear how similar/dissimilar the demands of boxing are with respect to sex and weight category. Differences have been noted in other sports, with unique movement characteristics reported in the lightest- and heaviest-weight categories compared with the other categories in judo [57] and differences reported in the head trauma risk/incidence in mixed martial arts with respect to both weight category and sex, respectively [58]. Sex differences have also been identified in the response to

unaccustomed exercise with respect to changes in serum CK and the delayed onset of muscle soreness (DOMS) [59]. A limitation of the current study is that the hydration status was not assessed concomitantly with the CK levels. There is the potential for CK levels to be affected by hydration, as it is a concentration-based blood measure. Despite this potential confounding factor, the week-to-week variation in the confidence-interval widths was relatively stable considering the aforementioned sex- and weight-based differences in the athlete population. This suggests that the CK levels may not have been hugely influenced by changes in hydration on the broader timescale of week-to-week changes. In addition, the athletes in the current study were incredibly experienced high-performance athletes with > 10 years of competition training experience. Therefore, each athlete's habitual fluid intake throughout the study would have been well established. However, both the athletes' hydration and RWL practices in week 12 (i.e., just prior to their first competition fight) may have had an increased risk of affecting their CK levels over this period. Indeed, Figure 2 shows a particularly large variation within this week despite lower training loads. Therefore, the authors encourage readers to cautiously interpret the CK data over this period.

Monitoring perceptual wellness has been reported to be the most commonly used tool in high-performance sports, with a greater preference for custom-designed questionnaires over those with published validity and reliability [60,61]. Perceptual-wellness variables have been found to be sensitive to the training load [62,63] and to impact training outputs [64]; however, contrasting findings have also been reported within the literature [65,66]. It is important to note that these custom designs vary in their rating scales and variables between studies [61], thus providing an inherent challenge when attempting to draw comparisons within the literature. In this study, moderate strength relationships were reported between the muscle condition and the TL and ΔCK, providing some support for the use of perceptual-wellness monitoring as a non-invasive assessment of the training status in elite boxers. Furthermore, although no significant changes were noted in perceptual wellness throughout the 12-week period, this may be explained by the results of previous research, which reported that the sensitivity of subjective variables to changes in the TL is not improved when compared to the load beyond the previous day [62]. A limitation in this study relates to the wellness variables being reported as weekly averages, which, in turn, may not be representative of the acute changes in the athletes' wellbeing. The results of this study provide some inference that custom-design questionnaires may be useful monitoring tools in boxing only when monitoring day-to-day changes. In relation to the other three wellness variables (mood, sleep, and total wellness), small strength relationships were reported with the TL and ΔCK, which may infer multiple/other influencing factors, with previous research noting disturbances in perceptual wellness during periods of RWL [67] and long-haul travel [68]. Previous research related to monitoring athletes through self-reporting has also identified a number of influencing factors associated with custom-design questionnaires' use [69], which, in conjunction with the need for/lack of validated short questionnaires [70], identifies a limitation in this study.

Limitations

The results of this study have provided new insights into the TLs and responses to training of elite boxers during a pre-competition training camp. It is important to emphasize that the results of this study relate to one condition (i.e., the subjects and training camp); therefore, more research is required to provide greater clarity with respect to the norms in the TL and the response to training within boxing. This has been done previously in team sports with respect to normal TWTLs in both the pre- and in-season periods [34,71]. Another identifiable challenge in boxing and other combat sports relates to the challenges in accurately assessing the sport-specific performance [72,73]. In this study, there were no sport-specific or general performance tests reported at the start or end of training, and this limited the ability to accurately assess the overall effectiveness of this training camp; it is unclear whether this approach to training helped or hindered performance. Previous

research has reported elevations in CK and improvements in performance following intensified training periods, leading the authors to conclude that the program was effective and that the elevations in CK did not negatively impact performance [39].

It is also important to consider whether significant elevations in CK are meaningful in boxing, and although a relationship between elevations in CK and reductions in neuromuscular fatigue and wellness have been reported in rugby [74], this has yet to be confirmed in boxing. A significant influence of the impacts on the changes in the CK concentration have been reported in rugby; however, more research is required in order to ascertain whether the increases in CK in boxing, where contact is inevitable, are the result of exercise-induced muscle damage (i.e., fatigue related) or significant (injury) and/or non-significant trauma (blocking punches). Previous research in Australian football determined the intra-individual upper limits of the normal responses to match play [50], and this may assist in overcoming the challenges previously mentioned, identifying elevations in CK which warrant greater attention and a heightened requirement for recovery.

The above issues and considerations are important for practitioners working in elite boxing, and they highlight the importance of considering the individual within this context, as both the demands and responses to training may vary greatly within a team.

4. Materials and Methods

4.1. Participants

Elite amateur boxers (n = 12, 8 males, 4 females, 24 ± 4.3 years, 68.1 ± 11.8 kg habitual weight, 64.5 ± 14.6 kg competition weight, 7 ± 4% body-mass reduction at competition weight, 174 ± 9.3 cm) participated in this study (males: 52 kg, 56 kg, 60 kg, 64 kg, 69 kg, 75 kg, 91 kg, and 91 + kg categories) (females: 48 kg, 51 kg, 57 kg, and 60 kg categories). Boxers were chosen to compete at the 2018 Commonwealth Games held in Brisbane, Australia, as representatives of their national team, with 8 of the 12 athletes winning medals at the Games. Boxers included in the study had >80% training compliance. Each participant gave written and informed consent, and this study was approved by the ethics committee at Ulster University and followed the principles of the Declaration of Helsinki.

4.2. Study Design

The current observational study formed part of the team's service provision during a twelve-week training camp in preparation for the 2018 Commonwealth Games. Training content was devised by the head coach and was not altered for the purposes of this study. The daily monitoring information collected was utilised by the head coach to inform day-to-day evaluation and adaptation of training prescription at both an individual and team level.

Training was divided into four phases of varied durations: general preparation (GP) (42 days), specific preparation (SP) (17 or 19 days), competition-specific preparation (CSP) (10 days), and tapering (T) (10 days). Following completion of GP and SP, eastward travel to Australia (>30 h, across ten time zones) preceded the completion of the CSP and T phases. Training was classified as either boxing-specific (school boxing, heavy bag, individual pads, school combat, sparring, and test match) or supplementary (running, indoor cycling, or strength training). Although modalities were completed consistently throughout each phase, test matches were completed exclusively during CSP whilst body-mass management (mixture of boxing-specific and supplementary training) was completed during CSP and T only. A sample weekly schedule for each phase is presented in Table 2.

Table 2. Sample weekly schedule for each training phase.

PHASE	TIME	MON	TUE	WED	THU	FRI	SAT	SUN
GP/SP	AM	Running	Strength	Running	Strength	Individual Pads	Recovery Run	Rest
	PM	Heavy Bag	School Combat	Heavy Bag	School Combat	Rest	Rest	Rest
CSP	AM	Strength	Running	Test Match	Rest	Test Match	Running	Test Match
	PM	School Combat	School Combat	Rest	Rest	Rest	Individual Pads	Rest
T	AM	Running	Rest	Rest	Running	Individual Pads	Rest	Rest
	PM	Individual Pads	Individual Pads	Individual Pads	School Boxing	School Boxing	Individual Pads	Individual Pads

GP/SP, general/specific preparation; CSP, competition-specific preparation; and T, tapering.

4.3. Training Load

Training load was quantified via the session RPE (s-RPE) method as proposed by Foster et al. [75]. Boxers were asked to rate their perception of training intensity 10–30 min after their training session. They were requested to ensure that their s-RPE referred to the mean intensity of the whole session rather than the most recent exercise intensity. The training intensity was measured using the modified Borg category ratio 10 RPE scale (CR-10) [76]. The reported s-RPE score was multiplied by the total session duration in minutes to indicate the session training load (TL). Daily training load (DTL) was calculated using the sum of all training sessions on a given day, and total weekly training load (TWTL) was the sum of all DTLs within a corresponding week. The athletes had been using these monitoring scales for a minimum of two years.

4.4. Creatine Kinase (CK)

Earlobe capillary blood was collected in a 32 μL heparinised Reflotron capillary tube (Selzer Labortechnik, Waghäusel, Germany) using standard sampling techniques. The blood sample was then applied to the CK test strip (Roche, Munich, Germany) and was immediately analysed for CK via a Reflotron Plus system (Roche, Germany). The reliability of this system was demonstrated previously [77]. Sampling frequency varied between training phases, with samples taken on a Monday, Wednesday, and Friday during general preparation and specific preparation; daily during competition-specific phase; and on alternate days during tapering.

Due to the significant variation noted in CK values between individuals [78], samples were taken at the onset of the training camp in a "rested state" in order to provide an indication of a baseline value for each athlete, and values were reported relative to the maximum variation delta [79]. To calculate this form of expression, the rested value was subtracted by the monitored value and then divided by the maximum delta of variation $[(\mathrm{Ck_{monitored}} - \mathrm{CK_{pre}})/\Delta \mathrm{CK} - \mathrm{max}] \times 100$.

4.5. Psychometric Self-Reported Wellness Data

Psychometric data were collected at ~8 am each morning and were part of the athletes' normal routine monitoring process. The boxers completed a short custom-designed questionnaire each morning via their smart phone, rating three sub-scales of wellness which comprised of "mood disturbance", "muscle condition disturbance", and "sleep quality disturbance". Each was quantified on a continuous 7-point Likert scale, where 0 arbitrary units represented the best possible rating if wellness and 6 arbitrary units represented the worst possible rating of wellness. The sum of all three sub-scales represented an individual's "total wellness disturbance" for a given day (scored out of 18). Based off day 1 and day 2 scores in week 1, intra-class correlation coefficient (ICC) and coefficient of variation

values for each wellness variable were as follows: mood disturbance (0.84, 8.4%), muscle condition (0.85, 5.9%), sleep quality (0.96, 7.7%), and total wellness (0.94, 5.7%).

4.6. Statistical Analysis

Statistical analysis was conducted using JASP (v. 0.17.3) following evaluation of parametricity using a Shapiro–Wilk test; all data were found to be non-parametric ($p < 0.05$). All data were assessed for weekly differences using the Friedman test (non-parametric one-way within-subjects repeated-measures ANOVA). Kendall's W (W_K) was used to estimate the effect size (0.1–<0.3, small; 0.3–<0.5, moderate; >0.5, large), and Conover–Iman tests were used for post hoc pairwise comparisons. Spearman's rank correlation coefficient was used to assess the relationships between training-load, CK, and wellness variables. A Bonferroni correction was used to adjust for multiple comparisons. Criteria to interpret the magnitude of the correlation (r) between different variables were as follows: ≤0.1, trivial; >0.1–0.3, small; >0.3–0.5, moderate; >0.5–0.7, large; and >0.7–1.0, very large. Data are presented as means ± 95% confidence intervals (CI)

5. Conclusions

The findings from this study report that the elite boxers were exposed to high weekly training loads (>3000 AU), demonstrating little variance over a 12-week training camp, with large dramatic reductions in the training load in the final week as the competition neared. Throughout the training period, there were significant elevations in the biochemical markers indicative of muscle damage without significant disruption to the perceptual wellness. Finally, this is the first study to identify the small-to-moderate strength relationships between the training load and both CK and the "muscle condition", providing some support for the use of CK and subjective monitoring within boxing.

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