SEONZ
SPORT & EXERCISE SCIENCE
NEW ZEALAND

The Journal of Sport and Exercise Science, Vol. 9, Issue 2, 19-29 (2025)

www.jses.net

JSES
ISSN: 2703-240X

Investigating the effects of rapid weight-loss and weight regain on neuromuscular performance prior to an international-level championship fight in an elite, professional boxer – A case study

Freddy Brown[1*], Rhys Morris[2]

[1]*School of Life Sciences, Coventry University, UK*
[2]*Department of Sport Sciences, Nottingham Trent University, UK*

ARTICLE INFO

Received: 14.10.2024
Accepted: 01.08.2025
Online: 05.12.2025

Keywords:
Boxing
Rapid weight-loss
Power

ABSTRACT

Professional boxing is a weight-categorised combat sport in which strength and power are key determinants of success. Coupled with the use of day-before weigh-in schedules, these demands encourage fighters to undergo rapid weight-loss (RWL - from hypohydration and energy restriction) to "make weight" before refuelling and rehydrating before competition. However, no research has investigated the effects of RWL and subsequent recovery on pre-competition performance. This case study therefore assessed neuromuscular performance in a 25-year-old professional super-welterweight boxer (154 lb or 69.9 kg) immediately before an "intercontinental" championship fight, comparing performance indices to those recorded over the preceding six-week "training camp." Isometric mid-thigh pull, and anthropometry were monitored weekly for 5 weeks, along with countermovement (CMJ) and squat jump performance (SJ), which were quantified from jump heights, propulsive power and impulse, then used to construct 95% confidence intervals (CIs). Subsequently, performance and salivary hormones (cortisol and IgA) were quantified at the competition venue throughout 5 days of RWL, and pre-competition. Dietary intakes were confirmed from menus and ingredient lists. The boxer reduced body mass from 80.3 to 75.9 kg over 5 weeks of training, before losing a further 6 kg (7.9% body mass) from RWL to make the championship limit. All neuromuscular performance measures declined below CIs immediately before RWL, other than CMJ height and SJ impulse. Conversely, only CMJ and SJ impulse declined before weigh-in. After 36 h refeeding and rehydration (~10 $g \cdot kg^{-1} \cdot d^{-1}$ carbohydrate), the boxer increased body mass to 79.4 kg, re-establishing performance in all metrics before competition. Salivary IgA and cortisol concentrations peaked immediately before weigh-in and competition, respectively. These are the first data reporting the effects of RWL and subsequent regain on pre-competition performance in an elite boxer, and suggest that deficits in neuromuscular performance may be ameliorated by 36 h rehydration and refeeding.

1. Introduction

Professional boxing is a full-contact combat sport where victory is earned by landing "clean and effective" punches to achieve a knockout, technical knockout, or a points decision. Bouts are scored by awarding completed rounds according to the power and number of punches landed, as well as the judges' perceptions of "effective aggression", "ring generalship", and defensive ability (Association of Boxing Commissions, 2005). Strength and power are therefore key determinants of success (Chaabène et al., 2015; Halperin, Hughes, & Chapman, 2016; Ruddock, Wilson, Thompson, Hembrough, & Winter, 2016). Importantly, boxing is a weight categorised sport, with professional bouts contested in 17 weight classes to avoid extreme disparities in size and strength (Association of Boxing Commissions, 2005). Accordingly,

*Corresponding Author: Freddy Brown, Ph.D. School of Life Sciences, Coventry University, UK, ad1385@coventry.ac.uk

boxers frequently aim to compete in a weight category below their natural weight ("making weight") to avoid conceding physical advantages (Halperin et al., 2016; Morton, Robertson, & Sutton, 2010; Pettersson, Ekström, & Berg, 2013) for the purpose of this article 'weight' is being used colloquially for 'body mass' in keeping with SI units). As well as striving to optimise body composition throughout training, boxers commonly undertake an additional period of rapid weight-loss (RWL) in the days before weigh-in (Langan-Evans, Close, & Morton, 2011; Morton et al., 2010; Reale, Slater, & Burke, 2017b), involving the deliberate depletion of muscle glycogen, total body water and gut-weight (Reale, Slater, & Burke, 2017a; Reale et al., 2017b). As weigh-ins for championship boxing matches are conducted ~36 h before competition (Association of Boxing Commissions, 2005), aggressive rehydration and carbohydrate replenishment strategies may permit boxers to regain 5–10% of their weight before the enter the ring (Baribeau et al., 2023). However, the extreme levels of hypohydration (~10% body mass; Coswig, Fukuda, & Del Vecchio, 2015) and energy restriction (multiple days ≤ 500 kcal·d^{-1}; Castor-Praga et al., 2023) commonly associated with RWL pose serious risks to both health and performance (Barley, Chapman, & Abbiss, 2018; Kasper et al., 2019). Indeed, whilst exercising in the heat is a common method used to facilitate hypohydration and RWL (Park, Alencar, Sassone, Madrigal, & Ede, 2019; Reale, Slater, & Burke, 2018a), instances of heat injury are not uncommon (Barley, Chapman, & Abbiss, 2019), with rare accounts of resulting fatalities providing a sobering reminder of the risks involved (Control & Prevention, 1998; Zhuo, Li, & William, 2019). There is no consensus on what degree of RWL may be carried out safely (Burke, Slater, Matthews, Langan-Evans, & Horswill, 2021; Linden, 2021; Peacock et al., 2022).

To date, few studies have investigated the effects of RWL and subsequent regain on professional boxing performance (Baribeau et al., 2023; Daniele, Weinstein, Wallace, Palmieri, & Bianco, 2016). In first instance, Daniele et al. (2016) reported no differences in body mass between winners and losers at a mandatory second weigh-in (+24 h) in 142 professional boxers (126 men, 16 women) competing in IBF World Championship bouts. Conversely, a recent study on 1392 male professional boxers by Baribeau et al. (2022) reported that winners regained significantly more body mass than losers (8.0% ± 3.0% vs 6.9% ± 3.2%, $p < 0.01$), prior to a second weigh-in on arrival at the competition venue. However, neither prior RWL, nor body mass immediately pre-competition was quantified in either paper. Moreover, as decisions in boxing depend upon judges' subjective perceptions of skill and dominance (Dunn, Humberstone, Iredale, Martin, & Blazevich, 2017), analysis of winning/losing only is insufficient to describe the physiological effects of RWL.

As the generation of punch force originates in the lower-body (Lenetsky et al., 2020; Stanley, Thomson, Smith, & Lamb, 2018), measures of lower-limb neuromuscular function may offer non-invasive/non-fatiguing performance markers for use at competition. Indeed, the analysis of force-time data from vertical jumps and isometric lower-limb contractions is common for monitoring adaptation and fatigue in team sports (Bishop et al., 2022; Harper, Cohen, Rhodes, Carling, & Kiely, 2022). Furthermore, the increased availability and affordability of portable hormonal assays (Coad, Mclellan, Whitehouse, & Gray, 2015), offers more potential insight for competition readiness. For example, salivary measures of cortisol (elevations of which are associated with a catabolic environment and impaired recovery status) and immunoglobulin A (sIgA; a marker of immune function and exercise-induced physiological stress) have been validated for monitoring athletic recovery (Lee et al., 2017; Turner, Loosemore, Shah, Kelleher, & Hull, 2021). Due to the limited research on the impact of RWL and subsequent recovery immediately pre-competition, the present case study aimed to assess the effects of RWL, and subsequent weight regain on neuromuscular performance and hormonal markers in an elite professional boxer before a championship bout. Additionally, as all food was provided in the competition venue/hotel throughout RWL and recovery, performance changes with RWL were assessed in the context of a rigorous dietary analysis.

2. Methods

2.1. Design

Following institutional ethics approval (P121420) a 25 year-old, elite-level (McKay et al., 2021), male professional super welterweight boxer (competition weight 154 lb or 69.9 kg; habitual weight ~81 kg; stature 183cm) was monitored throughout a six-week "training camp." Subsequently, he competed for an "intercontinental title" over 10 × 3 min rounds (Table 1). Vertical jump performance, lower-body strength in the isometric mid-thigh pull (IMTP), and anthropometry were monitored weekly in the UK for 5 weeks ("block A"), with averages and SDs used to construct 95% confidence intervals (CI), using a *t*-distribution (Smithson, 2003). The final week involved travel to competition (Dallas, Texas), and 5 days' RWL ("block B"), during which performance was assessed and compared to derived 95% CIs using what is known as an A-B research design (Figure 1; Kinugasa, 2013; Kinugasa, Cerin, & Hooper, 2004). The final weekly monitoring session of the boxer's training camp (6 days before competition) also served to quantify performance at the start of RWL (D-6), from which point urinary measures of hydration, sIgA, and cortisol were also assessed. The day before weigh-in (D-2), the boxer commenced deliberate hypohydration from the early evening, after which jump performance was assessed. Jump performance and hydration were then evaluated immediately before the weigh-in (D-1), and on the day of competition (D0). Performance changes during RWL were deemed significant if mean values crossed the 95% CI. Due to logistical constraints, and perceived injury-risk, IMTP was not measured during RWL.

2.2. Procedures

Resting metabolic rate (RMR) was determined at baseline (MetaLyzer 3B System; Cortex, Leipzig, Germany) and used as a lower threshold for planned energy intake throughout training (Morton et al., 2010). Lower body performance was monitored throughout training camp from countermovement jump (CMJ) and squat jump (SJ) force-time indices, using the in-built software of a commercially available force plate sampling at 1000 Hz (Hawkins Dynamics, Westbrook, ME). Jump heights (cm), as well as peak and mean propulsive power (W) were derived from the impulse-momentum relationship. These metrics were deemed important, considering their utility for monitoring performance in sports where athletes may not be experienced or technically proficient in jumping,

Table 1: Weekly performance scores and anthropometric data over training camp.

	Training camp								Pre-competition		
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6 (D-6)	Average	CI (+/-)	D-2	D-1	D0 (BOX)
Body mass (kg)	80.3	79.4	78.8	77.9	76.9	75.9	78.2 ± 1.6		72.7	69.9	79.4
Σ8 Skinfolds (mm)	49.6	45.2	-	42.3	39.8	37.1	42.8 ± 4.8				
CMJ (cm)	39.6 ± 0.7	38.5 ± 0.3		43.5 ± 2.2	41.4 ± 2.1	38.4 ± 0.8	40.2 ± 2.2	2.9	45.4 ± 1.6↑	40.3 ± 1.2	41 ± 0.9
CMJ_{imp} (N·s)	451 ± 9	471 ± 12		478 ± 13	477 ± 10	451 ± 18	466 ± 14	18.3	477 ± 3	445 ± 8↓	478 ± 2
CMJ_{impNet} (N·s)	224 ± 2	226 ± 1		238 ± 6	232 ± 5	209 ± 2↓	226 ± 11	15.2	231 ± 4	215 ± 3	229 ± 2
CMJ_{PP} (W)	4438 ± 57	4352 ± 56		4649 ± 150	4436 ± 125	3885 ± 68↓	4352 ± 283	407.8	4508 ± 77	4266 ± 79	4373 ± 101
NCMJpp ($W \cdot kg^{-1}$)	55.5 ± 0.7	53.1 ± 0.8		57.3 ± 1.8	54.7 ± 1.7	51.2 ± 1.1↓	54.3 ± 2.3	3.6	58.5 ± 1 ↑	56.1 ± 1	54.4 ± 1.3
CMJ_{MP} (W)	2280 ± 56	2272 ± 41		2433 ± 117	2332 ± 78	2024 ± 52↓	2268 ± 151	239.2	2324 ± 66	2131 ± 57	2269 ± 31
$NCMJ_{MP}$ ($W \cdot kg^{-1}$)	28.5 ± 0.7	27.7 ± 0.5		30 ± 1.4	28.8 ± 1	26.7 ± 0.8↓	28.3 ± 1.2	2.5	30.2 ± 0.9↑	28 ± 0.8	28.2 ± 0.4
$CMJF_{pk}$ (N)	1775 ± 9	1755 ± 16		1768 ± 26	1760 ± 40	1561 ± 34↓	1724 ± 91	110.0	1672 ± 23	1678 ± 20	1712 ± 8
$CMJF_{pkNet}$ (N)	990 ± 10	950 ± 18		972 ± 26	965 ± 39	816 ± 37↓	939 ± 70	86.5	917 ± 22	932 ± 20	923 ± 9
$CMJV_{Pk}$ ($m \cdot s^{-1}$)	2.9 ± 0.1	2.8 ± 0.1		3 ± 0.1	2.9 ± 0.1	2.8 ± 0.1	2.9 ± 0.1	0.1	3.1 ± 0.1 ↑	2.9 ± 0.1	2.9 ± 0.1
SJ (cm)	35.3 ± 1.6	35.8 ± 2.5		38.3 ± 2.2	35.5 ± 3.3	31.7 ± 0.7↓	35.3 ± 2.4	2.9	42.9 ± 1.5↑	36.9 ± 1.9	36.6 ± 0.7
SJ_{imp} (N·s)	534 ± 36↓	558 ± 14		561 ± 68	568 ± 29	571 ± 22	558 ± 15	18.3	564 ± 27	506 ± 10↓	604 ± 29↑
SJ_{impNet} (N·s)	214 ± 4	218 ± 8		224 ± 6	215 ± 9	192 ± 3↓	212 ± 12	15.2	224 ± 4	205 ± 4	216 ± 2
SJ_{PP} (W)	4307 ± 176	4466 ± 274		4660 ± 247	4316 ± 351	3777 ± 101↓	4305 ± 328	407.8	4741 ± 55↑	4265 ± 150	4441 ± 94
NSJ_{MP} ($W \cdot kg^{-1}$)	53.2 ± 2.4	54.5 ± 3.4		57.3 ± 3.1	53.1 ± 4.5	49.4 ± 1.2↓	53.5 ± 2.9	3.6	61.5 ± 0.7↑	56.2 ± 2.3	55.2 ± 1.1
SJ_{MP} (W)	1485 ± 190	1431 ± 99		1498 ± 318	1380 ± 197	1031 ± 39↓	1365 ± 193	239.2	1472 ± 169	1443 ± 62	1254 ± 110
NSJ_{MP} ($W \cdot kg^{-1}$)	18.3 ± 2.4	17.5 ± 1.2		18.4 ± 3.9	17 ± 2.4	13.5 ± 0.5↓	16.9 ± 2	2.5	19.1 ± 2.2	19 ± 1	15.6 ± 1.4
SJF_{pk} (N)	1861 ± 49	1923 ± 43		1959 ± 79	1862 ± 43	1727 ± 25↓	1866 ± 89	110.0	1862 ± 23	1803 ± 37	1884 ± 27
SJF_{pkNet} (N)	1067 ± 53	1118 ± 43		1162 ± 80	1065 ± 47	976 ± 24↓	1078 ± 70	86.5	1106 ± 22	1059 ± 37	1095 ± 26
SJV_{Pk} ($m \cdot s^{-1}$)	2.7 ± 0.1	2.7 ± 0.1		2.8 ± 0.1	2.7 ± 0.1	2.6 ± 0.1↓	2.7 ± 0.1	0.1	3 ± 0.1↑	2.8 ± 0.1	2.8 ± 0.1
IMTP (N)		3186 ± 40		2993 ± 38	3018 ± 39	2915 ± 38↓	3028 ± 39	162			
NIMTP ($N \cdot kg^{-1}$)		40.2 ± 0.8		38.4 ± 2.6	39.2 ± 1	38.4 ± 1.8	39.1 ± 0.8	1.2			

Note: Days D-6 to D-1 indicate days until competition, with D0 (Box) indicating competition day; CMJ = Countermovement jump height; CMJ_{imp} = Countermovement jump propulsive impulse; CMJ_{impNet} = Countermovement jump net propulsive impulse CMJ_{PP} = Countermovement jump peak propulsive power; $NCMJ_{PP}$ = Countermovement jump normalised peak propulsive power; CMJ_{MP} = Countermovement mean propulsive power; $NCMJ_{MP}$ = Countermovement jump mean normalised peak propulsive power; $CMJF_{pk}$ = Countermovement jump peak propulsive force; $CMJF_{pkNet}$ = Countermovement jump peak net propulsive force; $CMJV_{pk}$ = Countermovement jump peak velocity; SJ = Squat jump height; SJ_{imp}= Countermovement jump propulsive impulse; SJ_{impNet} = Squat jump net propulsive impulse; SJ_{PP} = Squat jump peak propulsive power; NSJ_{PP} = Squat jump normalised peak propulsive power; SJ_{MP} = Squat mean peak propulsive power; NSJ_{MP} = Squat jump normalised mean propulsive power; SJF_{pk} = Squat jump peak propulsive force; SJF_{pkNet} = Squat jump peak net propulsive force; SJV_{Pk} = Squat jump peak velocity; IMTP = Isometric mid-thigh pull peak force; NIMTP = Normalised IMTP; Week 3 data missing due to the boxer travelling for sparring.

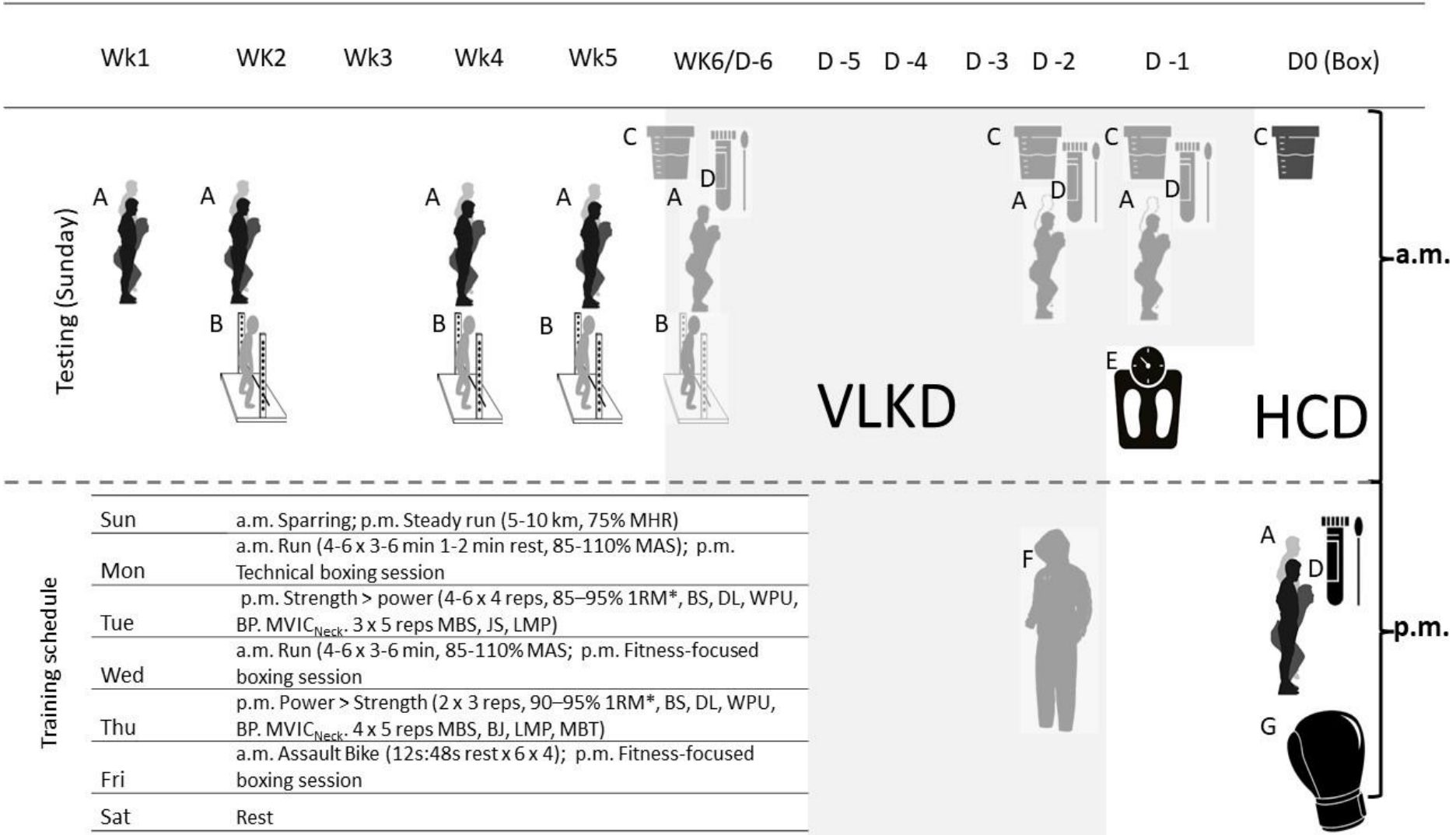

Figure 1: Study design. *Note:* MHR = Maximal heart rate; MAS = Maximum aerobic speed; Reps = repetitions; 1RM* = Predicted 1 repetition-maximum; BS = Back squats; DL = Deadlift; WPU = Weighted pull-up; BP = Bench-press; $MVIC_{Neck}$ = Maximal isometric voluntary contraction of the neck (flexion, side flexion left and right); MBS = Medicine-ball slams; JS = Jump squats; LMP = Landmine-press; BJ = Box jump; VLKD = Very low calorie diet and water loading (8L D-6/D-5/D-4; 4L D-2; 1L D-1). HCD = High carbohydrate diet. (A) Countermovement jump and squat jump testing; (B) Isometric mid-thigh pull testing; (C) Urinary hydration testing (specific gravity and osmolarity); (D) Salivary hormonal assays (cortisol and IgA); (E) Championship weigh-in; (F) Hypohydration protocol (athlete's own) consisting of exercise in plastic clothing, bathing, and towel wrapping; (G) Competition (intercontinental title bout over 10 × 3 min rounds.

with the use of both CMJ and SJ chosen to assess muscle function both with and without the use of the stretch-shortening cycle (Gross & Lüthy, 2020; Loturco et al., 2016). Additionally, impulse (N·s) was calculated as the integral of force over time, as commonly used to assess physiological capacity for high intensity sports specific actions, such as throwing or punching performance (Bartonietz, 1996; Lenetsky et al., 2020; Zaras et al., 2014). Jumps were performed with arms akimbo following 4 s quiet standing and reported as mean ± SD from three attempts. Throughout training, IMPT (peak force; N) was assessed from a 5 s maximal effort. The athlete was familiar with all performance tests from previous training camps, as evident from between-session coefficients of variation from 2.3–4.6% for all metrics, comparing performance for each repetition between two measurements taken at similar weights. Skinfolds (Σ8; mm) were assessed by an experienced level 1 anthropometrist using a Harpenden skinfold caliper (British Indicators Ltd., West Sussex, UK), having demonstrated CVs < 5%. Body mass (kg) was taken following a morning void (Seca 880, Digital Scales, Seca Ltd, Birmingham, UK). Hydration was assessed from urine osmolarity (Vitech Scientific, West Sussex; mOsm·L^{-1}) and specific gravity (9SA-BR32T Refractometer, Cole-Parmer Instruments, St Neots, Cambridgeshire, UK), from the first morning void, as commonly reported in combat athletes (Matthews & Nicholas, 2017; McDermott et al., 2017).

Physiological stress was monitored further throughout RWL from salivary hormones at the start and completion of RWL (two days, at either end) of RWL, as well as immediately pre-competition. Cortisol (nmol/L) and immunoglobulin A (sIgA; µg/mL) were assessed using portable, lateral-flow immunochromagraphic assays (IPRO Interactive, Wallingford, UK), as described previously (Coad et al., 2015). These tests demonstrated excellent reliability and validity compared to existing point-of-care methods (r = 0.98; 95% CI [0.96, 0.99]; Dunbar, Jehanli and Hazell, 2015), whilst reliability was also assessed by taking duplicate samples at baseline, which demonstrated a within-day precision of 2.4% for sIgA and 4.3% for cortisol. Subsequent measures were taken from single readings due to financial and logistical constraints.

2.3. Nutritional strategy

Based on prior competitive experience, the athlete and his coach targeted a morning weight of 75 kg for the week of competition, before losing the rest through RWL. This degree of RWL (< 7%) has previously been reported in combat athletes (Kasper et al., 2019; Kirk, Langan-Evans, & Morton, 2020; Matthews & Nicholas, 2017), necessitating the loss of 5 kg in 5 weeks. Energy requirements were estimated from predictive equations derived from boxers (Ismail, WD, & Zawiah, 1997) and nutritional guidance based on a deficit of 1100 kcal per day, assuming an energy requirement of approximately 7700 kcal per 1 kg reduction in body mass (Heymsfield et al., 2012). The intakes initially prescribed would have provided energy in excess of RMR at all points before RWL (Langan-Evans et al., 2011; Morton et al., 2010). However, to account for the possibilities of underreporting (Ferraris, Guglielmetti, Trentani, & Tagliabue, 2019) or energy restriction leading to a subsequent reduction in energy expenditure (Betts et al., 2014; Lebron, Stout, & Fukuda, 2024) the athlete was advised to adjust intake (by first looking to reduce sources of fat from the day's intake, before adjusting portions/frequency of starchy carbohydrates) to achieve weekly/daily weight targets. A high protein diet (≥ 1.8 g·kg^{-1}) was prescribed to optimise lean mass throughout energy restriction (Aragon et al., 2017; Helms, Zinn, Rowlands, & Brown, 2014). A low/moderate carbohydrate intake of 2–4 g·kg^{-1} was made necessary by the required energy deficit, with the athlete consuming higher carbohydrate meals and snacks between training sessions on days of high-intensity training (Figure 1), to optimise carbohydrate availability (Marquet et al., 2016). To aid monitoring throughout training (Evenepoel et al., 2020), the boxer weighed food before cooking, then recorded food intake using a mobile phone application (MyFitnessPal, San Francisco, California, USA).

During RWL, the athlete consumed a very low carbohydrate (120 g·d^{-1}, declining to 20 g·d^{-1}) and sodium intake (500–1000 mg·d^{-1}) and increased fluid intake to 4–8 L·d^{-1} as part of their habitual "water-loading" protocol, with the aim of reducing water retention (Kasper et al., 2019; Reale, Slater, Cox, Dunican, & Burke, 2018b). This strategy was based upon the boxer's own acquired knowledge, with the support team recording physiological responses with the aim of assessing the efficacy and safety of RWL. The athlete consumed 8 L·d^{-1} from D-6 to D-4, and 4 L on D-3, before reducing intake to only 1 L on D-2, prior to commencing deliberate hypohydration in the evening. This started with the boxer skipping and shadow-boxing wearing a combination of a plastic "sweat suit" and tracksuit, before undertaking a combination of hot water immersion (as hot as the athlete could tolerate for 10 min), alternating with periods of being wrapped in towels (5 min) while hot water was replaced (Kasper et al., 2019). The athlete got to within 1 kg of the target weight before sleep, completing the weight-cut (skipping) the following morning (D-1). Fluid intake over this phase was confirmed by the athlete drinking known volumes from a marked bottle. Following weigh-in, the boxer was instructed to rehydrate by drinking a volume of 40 mM sodium solution (SOS Hydration, London, UK) which exceeded measured fluid losses (Merson, Maughan, & Shirreffs, 2008), before subsequently resuming his habitual intake of ~3–4 L day (a minimum of 3L, or 40 ml·kg^{-1}·d^{-1}, drinking more according to thirst; Vivanti, 2012). Over the 36 h between weigh-in and competition, the athlete was advised to consume an intake of ~10 g·kg·d^{-1} carbohydrates to replenish muscular glycogen (Morton et al., 2010). Food was provided in known quantities at the competition venue, with detailed ingredient lists provided by the head chef for analysis. Additional food bought at a local supermarket was analysed using the nutritional information on food packets.

3. Results

At baseline, the athlete's body mass, stature, and RMR were 80.3 kg, 1.82 m, and 2042 kcal·d^{-1}, respectively, with all other performance and anthropometric data reported in Table 1. Body mass was reduced to 75.9 kg over the initial 5-week camp (block A), alongside a reduction in skinfolds from 49.6 mm to 37.1 mm (Table 1). Confirming the suitability of the A-B design employed, all performance measures appeared to plateau over this phase (Table 1). Descriptive improvements in jump metrics from weeks 1–4 (6.4–9.8%) were followed by declines over the following 2 weeks, with all values falling to -10.1 to -0.7% immediately

before RWL commenced, except for a significant 7.1% improvement in SJ impulse. Conversely, IMPT declined from baseline, reaching a minimum of 2915 N (-8.5%) which fell below the 95% CI at week 6. Conversely, descriptive declines (40 to 38 $N \cdot kg^{-1}$, or -4.3%) in normalised IMTP performance were maintained within the 95% CI (38–42 $N \cdot kg^{-1}$).

The water-loading phase resulted in a 1.4 kg (1.8%) reduction in body mass over 5 days (75.9–74.5 kg), before a further 4.6 kg (6.2%) was lost following exercise and hot water immersion. The boxer subsequently made championship weight (Figure 2). Average daily fluid and sodium intakes over the 5 days were 5.28 L and 815 mg, respectively (Table 2). Performance throughout RWL is presented in Figure 2. With the exception of CMJ height and SJ impulse, all neuromuscular performance measures declined below the 95% confidence interval by the final testing session of camp (D-6; Figure 1), prior to the commencement of rapid weight loss (RWL). Conversely, both SJ and CMJ height were significantly higher than average training performance at D-2 (the evening before the weigh in), as well as SJ peak power, as measured immediately after an acute body mass reduction from 74.5 kg to 72 kg. Propulsive impulse for both CMJ and SJ then declined before weigh-in. In the 36 h following weigh-in, the boxer consumed 5453 $kcal \cdot d^{-1}$ (80.9 $kcal \cdot kg^{-1} \cdot d^{-1}$), consisting of 140 $g \cdot d^{-1}$ protein (2 $g \cdot kg^{-1} \cdot d^{-1}$) 728 $g \cdot d^{-1}$ carbohydrate (10.4 $g \cdot kg^{-1} \cdot d^{-1}$) and 242 $g \cdot d^{-1}$ fat (3.5 $g \cdot kg^{-1} \cdot d^{-1}$), with 14827 $mg \cdot d^{-1}$ sodium (Table 2). Body mass increased by 9.5 kg (13.6%), with the athlete entering the ring at 79.4 kg. Urine osmolarity and SG increased from the day before weigh-in (560 $mOsmol \cdot kg^{-1}$, 1.016 kg m^{-3}) to the morning of the weigh-in (1020 $mOsmol \cdot kg^{-1}$, 1.027 kg m^{-3}), and was 970 $mOsmol \cdot kg^{-1}$/1.026 kg m^{-3} on the morning of competition. Following the pre-fight warm-up, neuromuscular performance was restored to baseline levels for all measures, other than a significant improvement in SJ propulsive impulse (Figure 2). Hormonal markers varied over RWL, with sIgA peaking before weigh-in, and the maximum cortisol concentration recorded immediately pre-competition.

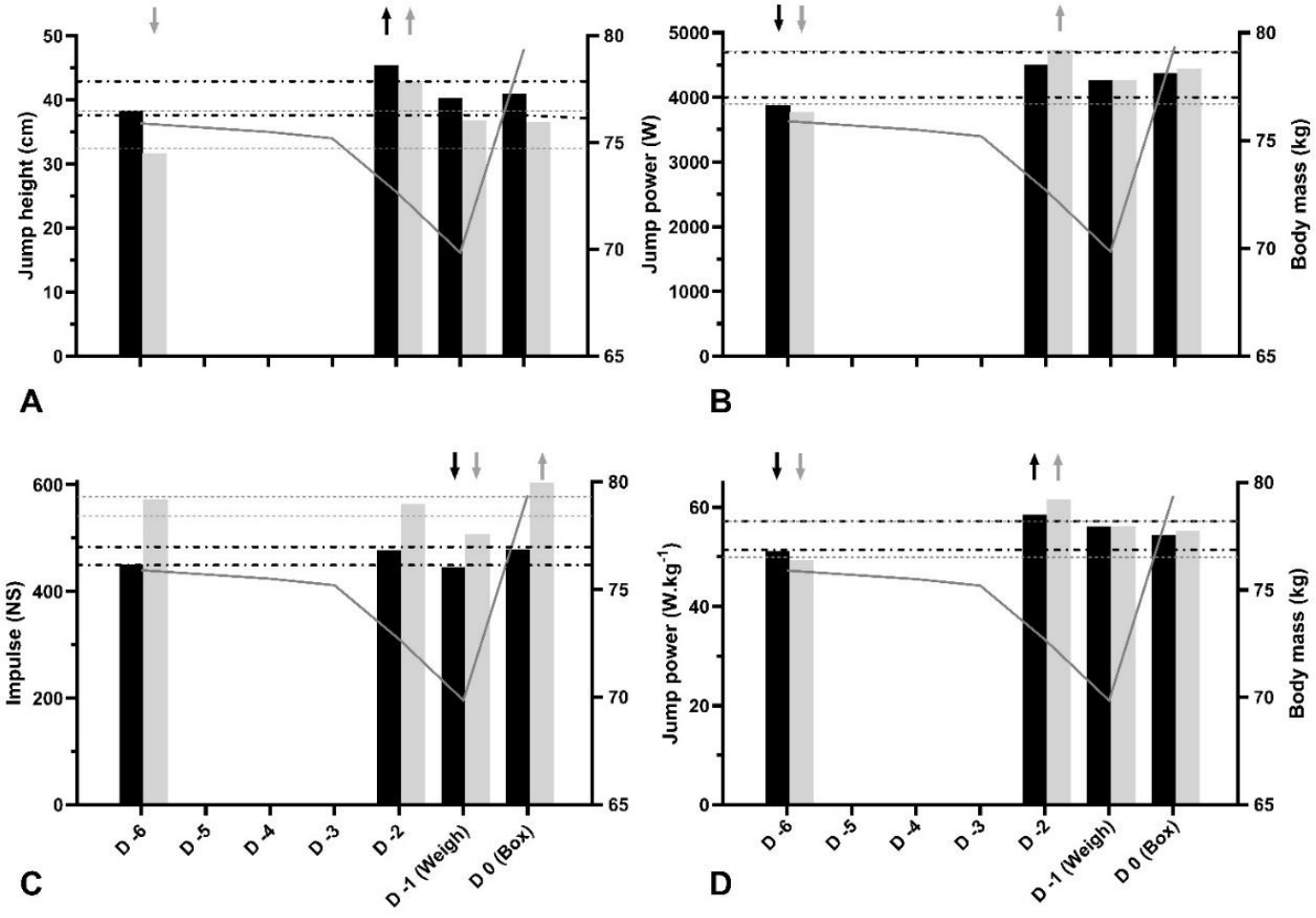

Figure 2: Countermovement and squat jump performance throughout rapid weight-loss, alongside changes in body mass. *Note:* A = Jump height; B = Peak propulsive power; C = Propulsive impulse; D = Normalised peak propulsive power; Days numbered as D-6 to D0, with D0 (Box) indicating competition day; Weigh = weigh-in; Black solid bars = Countermovement jumps; Grey solid bars = Squat jumps; Black and grey dashed lines represent upper and lower 95% confidence limits for squat jump and countermovement jump metrics, respectively, with arrows representing significant elevations above, or declines below confidence limits.

Table 2: Daily nutritional intakes, body mass and hormonal changes throughout RWL

Day	D-6	D-5	D-4	D-3	D-2	D-1 (Weigh-in)	D 0 (Box)*
Body mass	75.9	75.7	75.5	75.2	74.5	69.9	79.4
EI (Kcal)	1129	1247	698	829	466	5905	2575
Pro (g)	125	162	81	88	67	162	48
CHO (g)	120	77	24	6	2	725	367
Fat (g)	22	33	31	51	21	262	101
Na (mg)	592	1532	865	384	699	17517	4722
Urine mOsm·kg^{-1}	540	460			560	1020	970
Urine SG	1.015	1.013			1.016	1.027	1.026
sIgA (ug·ml^{-1})*	189.8	502.9			338	677.2	378.7
Cortisol (ng·ml^{-1})**	4.5	7.1			5.2	4	7.1

Note: EI = Energy intake; Pro = protein; CHO = carbohydrates; Na = sodium; Weigh = weigh-in; Box = Competition day; Urine mOsm·kg^{-1} = Urine osmolarity; Urine SG = Urine specific gravity; sIgA = Salivary immunoglobulin-A concentration; *Nutrition on fight-day was only recorded up to competition, and excludes post-fight nutrition; *Baseline sIgA concentration before training camp recorded as 21.5 ug·ml^{-1}; **Baseline cortisol concentrations before training camp recorded as 4.5 ng·ml^{-1}.

4. Discussion

This is the first study to report the effects of RWL and subsequent regain on pre-competition performance in an elite boxer. Importantly, our findings suggest that this boxer was able to re-establish lower-body neuromuscular performance when RWL of 7.9% body mass over the final week before weigh-in (6.2% body mass in the preceding 24 h) was followed by a 36 h rehydration and refeeding strategy. These findings are made all the more significant considering the level of the participant. As punch performance depends upon force generation in the lower-body (Lenetsky et al., 2020; Loturco et al., 2016; Stanley et al., 2018), these findings have important implications for elite boxers undertaking RWL.

Despite weighing-in at the competition limit of 154 lb (69.9 kg), the boxer averaged 78.2 kg over camp, entered the ring at 79.4 kg, and displayed normalised performance scores exceeding those from the limited data on high-performance boxers. The boxer's absolute IMTP performance appears at least equal to that of an elite Australian super-middleweight (competition limit of 168 lb or 76.2 kg), reported previously (Halperin et al., 2016), who recorded values of ~3170, or 40 N·kg^{-1} (mean of the best two attempts), seven weeks pre-competition (when 80 kg). These values fall within the 95% CI calculated in the present study and are comparable to our boxer's baseline scores of 3186 ± 66 (3116 to 3247 N, or 39 to 41 N·kg^{-1}) five weeks before competition, despite him competing two weight-classes below. Similarly, his normalised scores greatly exceed those recorded in national/international-level amateurs (34 ± 4 kg^{-1}) (Dunn, Humberstone, Franchini, Iredale, & Blazevich, 2022). Regarding the boxer's lower-body power, his mean (40.2 ± 2.2 cm) and best (43.5 ± 2.2 cm at four weeks, ranging from 41–45.1 cm over three attempts) CMJ performance throughout camp also compare favourably with those from Halperin's case study (~40 cm), as well as the Brazilian national amateur squad (Loturco et al., 2016). Loturco and colleagues reported descriptively lower CMJ values of 37 ± 5 cm, although they reported peak (rather than average) jump heights, which were calculated from flight time—a method known to provide a significant overestimate (Wade, Lichtwark, & Farris, 2020). Whilst strong and powerful for his weight, the RWL phase allowed the boxer to compete in an even lower category to maximise his physiological advantages.

Despite demonstrating impressive levels of strength and power, neuromuscular performance appeared to decline at the end of the initial training block. Most jump metrics and absolute peak IMPT force declined below the 95% CI by week 6 (Table 1). Taken alongside the fact that descriptive declines (40 to 38 N·kg^{-1}, or -4.3%) in normalised IMTP performance were maintained within the 95% CI (38–42 N·kg^{-1}) it is likely that observed performance changes reflect the effects of weight-making, and the cumulative physiological stress associated with training with insufficient energy availability (Garthe, Raastad, Refsnes, Koivisto, & Sundgot-Borgen, 2011).

The current findings support previous research reporting inconsistent effects from hypohydration on maximal strength and power (Judelson et al., 2007; Montain et al., 1998; Pallarés et al., 2016; Savoie, Kenefick, Ely, Cheuvront, & Goulet, 2015; Schoffstall, Branch, Leutholtz, & Swain, 2001). Lower body isometric strength and jump performance can withstand as much as 4.8 ± 0.4% body mass reduction (Judelson et al., 2007), while combat athletes classified as moderately hypohydrated at weigh-in (urine osmolarity 701–1080 mOsm·kg^{-1}) showed no improvement in any metric of strength or power in bench press, CMJ or grip-strength tests following rehydration of 1.2 ± 0.2%

body mass (Pallarés et al., 2016). Furthermore, it is likely boxers familiar with RWL have a high tolerance for hypohydration, with even club-level amateurs being observed to withstand fluid losses of 4% body mass without affecting punch force during simulated bouts (Smith et al., 2001; Smith, Dyson, Hale, Harrison, & McManus, 2000). Whilst the boxer in the current study suffered greater acute fluid losses (6.2% body mass), he then regained almost twice the weight lost before competing, suggesting a meaningful improvement in hydration status (Figure 2). However, it must be acknowledged that body mass variation represents an indirect and imprecise measure of hydration (Barley, Chapman, & Abbiss, 2020), likely influenced by sizeable contributions from glycogen replenishment and gut weight (Reale et al., 2017a, 2018a). Importantly, however, it is well established that hypohydration is more detrimental to endurance compared to neuromuscular performance (Kasper et al., 2019; Montain et al., 1998), while the studies of Smith et al. focused on amateurs competing over 11 min, as opposed to the 39 min undertaken by the boxer in the current study. Future research is required to assess the effects of large magnitudes of RWL and rehydration on endurance and boxing-specific performance.

The current findings may serve to highlight appropriate indices for monitoring performance throughout RWL. For example, whilst measures of force and impulse remained stable mid-way through the boxer's hypohydration protocol (D-2, following the loss of 2.5 kg fluids, or 3.3% body-mass), significant improvements were observed (somewhat counterintuitively) for CMJ and SJ jump heights, as well as for measures of peak velocity and power (Figure 2). Personal bests (PBs) were recorded for the heights and peak velocities of both jumps, as well as for both absolute and normalised peak CMJ power, and normalised SJ power (Table 1; Figure 2). These outcomes were maintained even on the morning of the weigh-in, with only absolute CMJ and SJ impulse values deteriorating below the 95% CI (Figure 2). Before competition, impulse values for CMJ and SJ then recovered and exceeded established 95% CIs, respectively. Such findings are likely explained by considering the technical and load-bearing nature of jumping. Body mass reductions from RWL will have reduced the work the boxer was required to perform against gravity, explaining observed improvements in velocity-based metrics (Savoie et al., 2015). This phenomenon is more commonly observed in well trained athletes, who may be better able to tolerate the negative impacts of hypohydration (Savoie et al., 2015). It is also possible that utilizing jump height as a discrete performance outcome may be insensitive to subtle changes in neuromuscular function, with athletes potentially able to preserve performance via compensatory technical changes (Kennedy & Drake, 2017; Spencer et al., 2023).

In contrast to jump heights and power metrics, impulse was sensitive to RWL and recovery (Figure 2). This measure is particularly important, with impulse being mathematically equivalent to a change in momentum and therefore a commonly used measure of performance in punching (Lenetsky, Nates, Brughelli, & Schoustra, 2016; Stanley et al., 2018), and explosive movements such as throwing (Bartonietz, 1996; Lenetsky et al., 2020; Zaras et al., 2014). Impairments may have been related to neuromuscular deficits from hypohydration, which originate from electrolyte losses disrupting electrochemical gradients, subsequently impairing membrane conductivity, calcium metabolism and motor-unit recruitment (Uddin, Tallent, & Patterson, 2022a). However, it is likely that reductions in CMJ/SJ impulse were predominantly mediated by changes in total mass, with net impulse unaffected in either jump (Table 1). Similarly, no reductions in either total, or net propulsive forces were observed throughout in response to RWL. It would therefore appear that RWL had little effect on neuromuscular indices of jump performance, although monitoring impulse may provide a measure of absolute force application, which is sensitive to RWL.

Observed changes in hormonal markers do not immediately suggest any utility for monitoring the effects of RWL (Table 2). In contrast to previous observations that declines in sIgA indicate physiological stress and a potential impairment of immune function (Turner et al., 2021; Uchino et al., 2024), the boxer's salivary levels descriptively increased from baseline over RWL, peaking before weigh-in. It is likely that the extreme levels of hypohydration observed reduced saliva flow-rates to increase relative concentrations of this marker (Fortes, Diment, Di Felice, & Walsh, 2012). Furthermore, whilst the observation that peak cortisol concentrations were recorded immediately before competition supports observations of this marker being sensitive to pre-competition arousal (Filaire, Sagnol, Ferrand, Maso, & Lac, 2001; van Paridon, Timmis, Nevison, & Bristow, 2017) this measure was not sensitive to the stresses imposed by RWL (Table 2).

The current study is unique in reporting the performance impacts of RWL in situ, before elite, international competition and can inform practitioners and researchers in formulating and monitoring RWL strategies. However, findings must be contextualised alongside several important limitations; not least of which is the lack of generalisability of a study on a single participant. No measures of punch performance, or endurance were taken, while the urinary measures of hydration analysed may be unreliable in the face of large, acute changes in fluid intake (Maughan & Shirreffs, 2010). For example, despite the 13.6% increase in body mass over 36 h recovery and rehydration, urine osmolarity and specific gravity did not decline to levels typical of adequate hydration—commonly taken as osmolarity 500–700 mOsm/kg, or specific gravity < 1.02 (Maughan & Shirreffs, 2010; Table 2). Furthermore, whilst energy and macronutrient intake throughout RWL were closely monitored in person, the accuracy of dietary monitoring throughout camp is uncertain, considering the propensity of athletes with weight-loss targets to underreport (Ferraris et al., 2019). Accordingly, this study focused on the principal research question of the effect of RWL on physiological parameters over the final week's build-up to competition. Perhaps most importantly for the boxer's safety, no evidence was obtained on the boxer's reaction time or cognitive function following RWL (Uddin, Waldron, Patterson, Winter, & Tallent, 2022b), which likely influence boxers' abilities to defend themselves (Clark & Sirois, 2020; Teramoto, Cross, Cushman, & Willick, 2018; Uddin et al., 2022b). The effects of RWL and subsequent recovery on endurance performance, punch performance and cognitive function remain to be explored. Finally, since no training load data was collected, it is plausible that training volume and intensity influenced the reported outcomes. The initial reductions in jump performance during the weight cut could have been a result of overreaching following 6 weeks of intense training with limited energy availability (Garthe, Raastad, Refsnes, Koivisto, & Sundgot-Borgen, 2011), with the subsequent recovery in these variables likely reflecting a reduction in training volume and the compensatory phase of recovery.

Conclusion

The current evidence indicates that 36 h was sufficient time to restore lower-body muscle function when RWL was followed with a dietary strategy comprising of a high carbohydrate diet and rehydration with high sodium solutions. Future research assessing endurance and boxing specific performance is required.

Conflict of Interest

The authors declare no conflict of interests.

Acknowledgment

We owe a debt of thanks to the coach and boxer involved in this study, along with Dr. Jason Talis for technical guidance, and Chef Mouhssine Benhamacht ("Moose") from the Loews Hotel, Arlington, Texas for liaising over the boxer's dietary needs.

References

Aragon, A. A., Schoenfeld, B. J., Wildman, R., Kleiner, S., VanDusseldorp, T., Taylor, L., Earnest, C. P., Arciero, P. J., Wilborn, C., & Kalman, D. S. (2017). International society of sports nutrition position stand: Diets and body composition. *Journal of the International Society of Sports Nutrition, 14*(1), 1–19.

Association of Boxing Commissions. (2005). Regulatory guidelines. Retrieved from https://www.abcboxing.com/abc-regulatory-guidelines/

Baribeau, V., Kirk, C., Le, D. Q., Bose, A., Mueller, A., French, D., Sarge, T., Langan-Evans, C., Reale, R., & Murugappan, K. R. (2023). Rapid weight gain and weight differential predict competitive success in 2100 professional combat-sport athletes. *International Journal of Sports Physiology and Performance, 18*(1), 85–94.

Barley, O. R., Chapman, D. W., & Abbiss, C. R. (2018). Weight Loss Strategies in Combat Sports and Concerning Habits in Mixed Martial Arts. *The International Journal of Sports Physiology and Performance, 13*(7), 933–939.

Barley, O. R., Chapman, D. W., & Abbiss, C. R. (2019). The current state of weight-cutting in combat sports. *Sports, 7*(5), 123–133.

Barley, O. R., Chapman, D. W., & Abbiss, C. R. (2020). Reviewing the current methods of assessing hydration in athletes. *Journal of the International Society of Sports Nutrition, 17*(1), 52–64.

Bartonietz, K. (1996). Biomechanical aspects of the performance structure in throwing events. *Modern Athlete and Coach, 34*, 7–11.

Betts, J. A., Richardson, J. D., Chowdhury, E. A., Holman, G. D., Tsintzas, K., & Thompson, D. (2014). The causal role of breakfast in energy balance and health: A randomized controlled trial in lean adults. *The American Journal of Clinical Nutrition, 100*(2), 539–547.

Bishop, C., Turner, A., Jordan, M., Harry, J., Loturco, I., Lake, J., & Comfort, P. (2022). A framework to guide practitioners for selecting metrics during the countermovement and drop jump tests. *Strength and Conditioning Journal, 44*(4), 95–103.

Burke, L. M., Slater, G. J., Matthews, J. J., Langan-Evans, C., & Horswill, C. A. (2021). ACSM expert consensus statement on weight loss in weight-category sports. *Current Sports Medicine Reports, 20*(4), 199–217.

Castor-Praga, C., Sanchez-Lopez, J., Lopez-Walle, J. M., Enríquez-Reyna, M. C., Garrido-Esquivel, A., & Medina-Corrales, M. (2023). Effect of rapid weight loss in combat sports: Systematic review. *Archives of Budo Science of Martial Arts, 19*, 83–94.

Chaabène, H., Tabben, M., Mkaouer, B., Franchini, E., Negra, Y., Hammami, M., Amara, S., Chaabène, R. B., & Hachana, Y. (2015). Amateur boxing: Physical and physiological attributes. *Sports Medicine, 45*(3), 337–352.

Clark, J. E., & Sirois, E. (2020). The possible role of hydration in concussions and long-term symptoms of concussion for athletes. A review of the evidence. *Journal of Concussion, 4*, 1–15.

Coad, S., Mclellan, C., Whitehouse, T., & Gray, B. (2015). Validity and reliability of a novel salivary immunoassay for individual profiling in applied sports science. *Research in Sports Medicine, 23*(2), 140–150.

Control, C. f. D., & Prevention. (1998). Hyperthermia and dehydration-related deaths associated with intentional rapid weight loss in three collegiate wrestlers--North Carolina, Wisconsin, and Michigan, November-December 1997. *MMWR. Morbidity and Mortality Weekly Report, 47*(6), 105–108.

Coswig, V. S., Fukuda, D. H., & Del Vecchio, F. B. (2015). Rapid weight loss elicits harmful biochemical and hormonal responses in mixed martial arts athletes. *International Journal of Sport Nutrition Exercise Metabolism, 25*(5), 480–486.

Daniele, G., Weinstein, R. N., Wallace, P. W., Palmieri, V., & Bianco, M. (2016). Rapid weight gain in professional boxing and correlation with fight decisions: Analysis from 71 title fights. *The Physician and Sportsmedicine, 44*(4), 349–354.

Dunbar, J., Hazell, G., Jehanli, A., & Wallingford, U. (2015). *Evaluation of a new point of care quantitative cube reader for salivary analysis in premier league soccer clubs.* Paper presented at the International Sports Science and Sports Medicine Conference.

Dunn, E. C., Humberstone, C. E., Franchini, E., Iredale, K. F., & Blazevich, A. J. (2022). Relationships between punch impact force and upper- and lower-body Muscular strength and power in highly trained amateur boxers. *Journal of Strength and Conditioning Research, 36*(4), 1019–1025.

Dunn, E. C., Humberstone, C. E., Iredale, K. F., Martin, D. T., & Blazevich, A. J. (2017). Human behaviours associated with dominance in elite amateur boxing bouts: A comparison of winners and losers under the Ten Point Must System. *PLoS One, 12*(12), e0188675–e0188686.

Evenepoel, C., Clevers, E., Deroover, L., Van Loo, W., Matthys, C., & Verbeke, K. (2020). Accuracy of nutrient calculations using the consumer-focused online app MyFitnessPal: Validation study. *Journal of Medical Internet Research, 22*(10), e18237–e18245.

Ferraris, C., Guglielmetti, M., Trentani, C., & Tagliabue, A. (2019). Assessment of dietary under-reporting in Italian college team sport athletes. *Nutrients, 11*(6), 1391–1402.

Filaire, E., Sagnol, M., Ferrand, C., Maso, F., & Lac, G. (2001). Psychophysiological stress in judo athletes during

competitions. *Journal of Sports Medicine and Physical Fitness, 41*(2), 263–268.

Fortes, M. B., Diment, B. C., Di Felice, U., & Walsh, N. P. (2012). Dehydration decreases saliva antimicrobial proteins important for mucosal immunity. *Applied Physiology, Nutrition, and Metabolism, 37*(5), 850–859.

Garthe, I., Raastad, T., Refsnes, P. E., Koivisto, A., & Sundgot-Borgen, J. (2011). Effect of two different weight-loss rates on body composition and strength and power-related performance in elite athletes. *International Journal of Sport Nutrition and Exercise Metabolism, 21*(2), 97–104.

Gross, M., & Lüthy, F. (2020). Anaerobic power assessment in athletes: Are cycling and vertical jump tests interchangeable? *Sports (Basel), 8*(5), 60–73.

Halperin, I., Hughes, S., & Chapman, D. W. (2016). Physiological profile of a professional boxer preparing for Title Bout: A case study. *Journal of Sports Sciences, 34*(20), 1949–1956.

Harper, D. J., Cohen, D. D., Rhodes, D., Carling, C., & Kiely, J. (2022). Drop jump neuromuscular performance qualities associated with maximal horizontal deceleration ability in team sport athletes. *European Journal of Sport Science, 22*(7), 1005–1016.

Helms, E. R., Zinn, C., Rowlands, D. S., & Brown, S. R. (2014). A systematic review of dietary protein during caloric restriction in resistance trained lean athletes: A case for higher intakes. *International Journal of Sport Nutrition and Exercise Metabolism, 24*(2), 127–138.

Heymsfield, S. B., Thomas, D., Martin, C. K., Redman, L. M., Strauss, B., Bosy-Westphal, A., Müller, M. J., Shen, W., & Nguyen, A. M. (2012). Energy content of weight loss: kinetic features during voluntary caloric restriction. *Metabolism, 61*(7), 937–943.

Ismail, M., WD, W. N., & Zawiah, H. (1997). Energy expenditure studies to predict requirements of selected national athletes. *Malaysian Journal of Nutrition, 3*(1), 71–81.

Judelson, D. A., Maresh, C. M., Farrell, M. J., Yamamoto, L. M., Armstrong, L. E., Kraemer, W. J., Volek, J. S., Spiering, B. A., Casa, D. J., & Anderson, J. M. (2007). Effect of hydration state on strength, power, and resistance exercise performance. *Medicine & Science in Sports & Exercise, 39*(10), 1817–1824.

Kasper, A. M., Crighton, B., Langan-Evans, C., Riley, P., Sharma, A., Close, G. L., & Morton, J. P. (2019). Case study: Extreme weight making causes relative energy deficiency, dehydration, and acute kidney injury in a male mixed martial arts athlete. *International Journal of Sport Nutrition and Exercise Metabolism, 29*(3), 331–338.

Kennedy, R., & Drake, D. (2017). The effect of acute fatigue on countermovement jump performance in rugby union players during preseason. *Journal of Sports Medicine and Physical Fitness, 57*(10), 1261–1266.

Kinugasa, T. (2013). The application of single-case research designs to study elite athletes' conditioning: An update. *Journal of Applied Sport Psychology, 25*(1), 157–166.

Kinugasa, T., Cerin, E., & Hooper, S. (2004). Single-subject research designs and data analyses for assessing elite athletes' conditioning. *Sports Medicine, 34*(15), 1035–1050.

Kirk, C., Langan-Evans, C., & Morton, J. P. (2020). Worth the weight? Post weigh-in rapid weight gain is not related to winning or losing in professional mixed martial arts. *International Journal of Sport Nutrition and Exercise Metabolism, 30*(5), 357–361.

Langan-Evans, C., Close, G. L., & Morton, J. P. (2011). Making weight in combat sports. *Strength & Conditioning Journal, 33*(6), 25–39.

Lebron, M. A., Stout, J. R., & Fukuda, D. H. (2024). Physiological perturbations in combat sports: Weight cycling and metabolic function—a narrative review. *Metabolites, 14*(2), 83–96.

Lee, E. C., Fragala, M. S., Kavouras, S. A., Queen, R. M., Pryor, J. L., & Casa, D. J. (2017). Biomarkers in sports and exercise: Tracking health, performance, and recovery in athletes. *The Journal of Strength & Conditioning Research, 31*(10), 2920–2937.

Lenetsky, S., Brughelli, M., Nates, R. J., Neville, J., Cross, M. R., & Lormier, A. V. (2020). Defining the phases of boxing punches: A mixed-method approach. *The Journal of Strength & Conditioning Research, 34*(4), 1040–1051.

Linden, H. (2021). A cross-sectional performance analysis and projection of the UFC athlete volume two. from UFC Performance Institute

Loturco, I., Nakamura, F. Y., Artioli, G. G., Kobal, R., Kitamura, K., Abad, C. C. C., Cruz, I. F., Romano, F., Pereira, L. A., & Franchini, E. (2016). Strength and power qualities are highly associated with punching impact in elite amateur boxers. *The Journal of Strength & Conditioning Research, 30*(1), 109–116.

Marquet, L.-A., Hausswirth, C., Molle, O., Hawley, J. A., Burke, L. M., Tiollier, E., & Brisswalter, J. (2016). Periodization of carbohydrate intake: Short-term effect on performance. *Nutrients, 8*(12), 755–787.

Matthews, J. J., & Nicholas, C. (2017). Extreme rapid weight loss and rapid weight gain observed in UK mixed martial arts athletes preparing for competition. *International Journal of Sport Nutrition and Exercise Metabolism, 27*(2), 122–129.

Maughan, R., & Shirreffs, S. (2010). Dehydration and rehydration in competative sport. *Scandinavian Journal of Medicine & Science in Sports, 20*, 40–47.

McDermott, B. P., Anderson, S. A., Armstrong, L. E., Casa, D. J., Cheuvront, S. N., Cooper, L., Kenney, W. L., O'Connor, F. G., & Roberts, W. O. (2017). National athletic trainers' association position statement: Fluid replacement for the physically active. *Journal of Athletic Training, 52*(9), 877–895.

McKay, A. K., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., Sheppard, J., & Burke, L. M. (2021). Defining training and performance caliber: A participant classification framework. *International Journal of Sports Physiology and Performance, 17*(2), 317–331.

Merson, S. J., Maughan, R. J., & Shirreffs, S. M. (2008). Rehydration with drinks differing in sodium concentration and recovery from moderate exercise-induced hypohydration in man. *European Journal of Applied Physiology, 103*(5), 585–594.

Montain, S. J., Smith, S. A., Mattot, R. P., Zientara, G. P., Jolesz, F. A., & Sawka, M. N. (1998). Hypohydration effects on skeletal muscle performance and metabolism: A 31P-MRS study. *Journal of Applied Physiology, 84*(6), 1889–1894.

Morton, J. P., Robertson, C., & Sutton, L. (2010). Making the weight: A case study from professional boxing. *International Journal of Sports Nutrition and Exercise Metabolism, 20*(1), 80–85.

Pallarés, J., Martínez-Abellán, A., López-Gullón, J., Morán-Navarro, R., De la Cruz-Sánchez, E., & Mora-Rodríguez, R. (2016). Muscle contraction velocity, strength and power output changes following different degrees of hypohydration in competitive olympic combat sports. *Journal of the International Society of Sports Nutrition, 13*(1), 1–9.

Park, S., Alencar, M., Sassone, J., Madrigal, L., & Ede, A. (2019). Self-reported methods of weight cutting in professional mixed-martial artists: How much are they losing and who is advising them? *Journal of the International Society of Sports Nutrition, 16*(1), 52–59.

Peacock, C. A., French, D., Sanders, G. J., Ricci, A., Stull, C., & Antonio, J. (2022). Weight loss and competition weight in Ultimate Fighting Championship (UFC) athletes. *Journal of Functional Morphology and Kinesiology, 7*(4), 115–120.

Pettersson, S., Ekström, M. P., & Berg, C. M. (2013). Practices of weight regulation among elite athletes in combat sports: a matter of mental advantage? *Journal of Athletic Training, 48*(1), 99–108.

Reale, R., Slater, G., & Burke, L. M. (2017a). Acute-Weight-Loss Strategies for Combat Sports and Applications to Olympic Success. *The International Journal of Sports Physiology and Performance, 12*(2), 142–151.

Reale, R., Slater, G., & Burke, L. M. (2017b). Individualised dietary strategies for Olympic combat sports: Acute weight loss, recovery and competition nutrition. *European Journal of Sport Science, 17*(6), 727–740.

Reale, R., Slater, G., & Burke, L. M. (2018a). Weight Management Practices of Australian Olympic Combat Sport Athletes. *The International Journal of Sports Physiology and Performance, 13*(4), 459–466.

Reale, R., Slater, G., Cox, G. R., Dunican, I. C., & Burke, L. M. (2018b). The effect of water loading on acute weight loss following fluid restriction in combat sports athletes. *International Journal of Sport Nutrition and Exercise Metabolism, 28*(6), 565-573.

Ruddock, A. D., Wilson, D. C., Thompson, S. W., Hembrough, D., & Winter, E. M. (2016). Strength and conditioning for professional boxing: Recommendations for physical preparation. *Strength & Conditioning Journal, 38*(3), 81–90.

Savoie, F.-A., Kenefick, R. W., Ely, B. R., Cheuvront, S. N., & Goulet, E. D. B. (2015). Effect of hypohydration on muscle endurance, strength, anaerobic power and capacity and vertical jumping ability: A meta-analysis. *Sports Medicine, 45*(8), 1207–1227.

Schoffstall, J. E., Branch, J. D., Leutholtz, B. C., & Swain, D. P. (2001). Effects of dehydration and rehydration on the one-repetition maximum bench press of weight-trained males. *The Journal of Strength & Conditioning Research, 15*(1), 102–108.

Smith, M., Dyson, R., Hale, T., Hamilton, M., Kelly, J., & Wellington, P. (2001). The effects of restricted energy and fluid intake on simulated amateur boxing performance. *International Journal of Sport Nutrition and Exercise Metabolism, 11*(2), 238–247.

Smith, M., Dyson, R., Hale, T., Harrison, J., & McManus, P. (2000). The effects in humans of rapid loss of body mass on a boxing-related task. *European Journal of Applied Physiology, 83*(1), 34–39.

Smithson, M. (2003). *Confidence intervals*: Sage.

Spencer, R., Sindall, P., Hammond, K. M., Atkins, S. J., Quinn, M., & McMahon, J. J. (2023). Changes in body mass and movement strategy maintain jump height immediately after soccer match. *Applied Sciences, 13*(12), 7188–7198.

Stanley, E., Thomson, E., Smith, G., & Lamb, K. L. (2018). An analysis of the three-dimensional kinetics and kinematics of maximal effort punches among amateur boxers. *International Journal of Performance Analysis in Sport, 18*(5), 835–854.

Teramoto, M., Cross, C. L., Cushman, D. M., & Willick, S. E. (2018). Boxing fatalities in relation to rule changes in Japan: Secondary data analysis. *The Physician and Sportsmedicine, 46*(3), 349–354.

Turner, S. E. G., Loosemore, M., Shah, A., Kelleher, P., & Hull, J. H. (2021). Salivary IgA as a potential biomarker in the evaluation of respiratory tract infection risk in athletes. *The Journal of Allergy and Clinical Immunology: In Practice, 9*(1), 151–159.

Uchino, T., Uchida, M., Ito, R., Fujie, S., Iemitsu, K., Kojima, C., Nakamura, M., Shimizu, K., Tanimura, Y., Shinohara, Y., Hashimoto, T., Isaka, T., & Iemitsu, M. (2024). Effects of different exercise intensities or durations on salivary IgA secretion. *European Journal of Applied Physiology, 124*(9), 2687–2696.

Uddin, N., Tallent, J., & Patterson, S. D. (2022a). Corticospinal and peripheral responses to heat-induced hypo-hydration: Potential physiological mechanisms and implications for neuromuscular function. *European Journal of Applied Physiology, 122*(8), 1797–1810.

Uddin, N., Waldron, M., Patterson, S. D., Winter, S., & Tallent, J. (2022b). A survey of combat athletes' rapid weight loss practices and evaluation of the relationship with concussion symptom recall. *Clinical Journal of Sport Medicine, 32*(6), 580-587.

van Paridon, K. N., Timmis, M. A., Nevison, C. M., & Bristow, M. (2017). The anticipatory stress response to sport competition; a systematic review with meta-analysis of cortisol reactivity. *BMJ Open Sport & Exercise Medicine, 3*(1), e000261– e000271.

Vivanti, A. P. (2012). Origins for the estimations of water requirements in adults. *European Journal of Clinical Nutrition, 66*(12), 1282–1289.

Wade, L., Lichtwark, G. A., & Farris, D. J. (2020). Comparisons of laboratory-based methods to calculate jump height and improvements to the field-based flight-time method. *Scandinavian Journal of Medicine & Science in Sports, 30*(1), 31–37.

Zaras, N. D., Angeliki-nikoletta, E. S., Krase, A. A., Methenitis, S. K., Karampatsos, G. P., Georgiadis, G. V., Spengos, K. M., & Terzis, G. D. (2014). Effects of tapering with light vs. heavy loads on track and field throwing performance. *The Journal of Strength & Conditioning Research, 28*(12), 3484–3495.

Zhuo, M., Li, J., & William, J. H. (2019). Sauna-induced fatal rhabdomyolysis. *Kidney International Reports, 4*(1), 171–173.