Langan-Evans, C, Reale, R, Sullivan, J and Martin, D

Nutritional Considerations for Female Athletes in Weight Category Sports

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Langan-Evans, C, Reale, R, Sullivan, J and Martin, D (2021) Nutritional Considerations for Female Athletes in Weight Category Sports. European Journal of Sport Science, 22 (5). pp. 720-732. ISSN 1746-1391

European Journal of Sport Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tejs20

Nutritional Considerations for Female Athletes in Weight Category Sports

Carl Langan-Evans, Reid Reale, Jordan Sullivan & Daniel Martin

To cite this article: Carl Langan-Evans, Reid Reale, Jordan Sullivan & Daniel Martin (2021): Nutritional Considerations for Female Athletes in Weight Category Sports, European Journal of Sport Science, DOI: 10.1080/17461391.2021.1936655

To link to this article: https://doi.org/10.1080/17461391.2021.1936655

Published online: 17 Jun 2021.

EUROPEAN JOURNAL OF SPORT SCIENCE
https://doi.org/10.1080/17461391.2021.1936655

ORIGINAL INVESTIGATION

OPEN ACCESS

Nutritional Considerations for Female Athletes in Weight Category Sports

Carl Langan-Evans[a], Reid Reale[b], Jordan Sullivan[c] and Daniel Martin[a]

[a]Research Institute for Sport and Exercise Sciences (RISES), Liverpool John Moores University, England, UK; [b]Ultimate Fighting Championship Performance Institute (UFCPI), Shanghai, People's Republic of China; [c]The Fight Dietician Pty Ltd., Brisbane, Australia

ABSTRACT

Weight making can be described as the process of reducing body mass in events where aesthetics, propulsion or the requirement to meet a specific weight category limit, are considered to be of competitive importance. Cross sectional research specifically focussed on weight category sports, has highlighted behaviours and practices that are similar in athletes of both sexes. Regardless of this and despite parallel participation in weight category sporting events, females are drastically underrepresented in studies examining body mass loss interventions across both chronic and acute timeframes. However, it has been well characterised that these types of body mass loss strategies can be causative of low energy availability, leading to consequences of female athlete triad and relative energy deficiency in sports. Furthermore, female-specific body composition and physiological systems modulated by the anterior pituitary and ovarian hormones within the menstrual cycle or use of hormonal contraception, can lead to potential outcomes which need to be considered carefully, particularly when employing acute weight loss strategies that are often utilised by weight making athletes. Therefore, the aim of this article serves to review the aforementioned issues, whilst offering practical recommendations via initial assessment, chronic/acute interventions and refeeding/recovery plans to help support the implementation of body mass loss strategies in the context of weight making specifically with female athletes.

KEYWORDS

Weight making; body mass loss; Acute Weight Loss; low energy availability; Female Athlete Triad; Relative Energy Deficiency in sports

Introduction

Weight making is an umbrella term used to describe the process of reducing body mass (BM) in events where aesthetics, propulsion or the requirement to meet a specific *weight category* limit, are considered to be of competitive importance (Ackland et al., 2012). This process can be broadly classified into either chronic (CWL – months and weeks leading into an event) and acute (AWL – days and hours leading into an event) phases of weight loss (Burke, Slater, Matthews, Langan-Evans, & Horswill, 2021). Given the breadth of research and practical considerations across the differing types of weight making classifications, this article will specifically focus on sporting events mediated by weight categories. Professional and amateur combat sports, horseracing, lightweight rowing, powerlifting and Olympic weightlifting are disciplines where the premise of categorising athletes is to promote competition between competitors of equal proportion (Sundgot-Borgen et al., 2013). A selection of these sports are amongst some of the most popular in the world, with boxing and mixed martial arts (MMA) holding all sport pay-per-view records (Isidore, 2015) and horseracing within the Grand National and Melbourne Cup, viewed by large global audiences (SportingLife, 2019). Within weight category events, athletes of both sexes are required to *make weight*, with thresholds existing to create an even playing field and so as not to have unfair or even dangerous anatomical advantages between competitors (Reale, 2017a). However, the very premise of categorisation within these sports has created unique cultures of weight making behaviours and practices, whereby individual athletes often aim to achieve the lowest category limit possible, in order to gain psycho-physiological advantages over opponents (Pettersson, Pipping Ekstrom, & Berg, 2012). Contrary to these beliefs, it should be noted that an emerging research base is now beginning to outline that the effect of these behaviours and practices, particularly in the context of rapid weight loss and gain, may not convey any overall performance benefits for weight making athletes (Kirk, Langan-Evans, & Morton, 2020).

CONTACT Carl Langan-Evans c.langanevans@ljmu.ac.uk Research Institute for Sport and Exercise Sciences (RISES), High Performance Unit, Primrose Hill Sport & Exercise Science Building, 5 Primrose Hill, Liverpool, Merseyside, England, L3 2AT, UK
This article has been republished with minor changes. These changes do not impact the academic content of the article.

Table 1. Differences in acute and chronic weight loss prevalence, magnitudes, practices and behaviours, between males and females across differing weight category events.

Reference	Weight making event	Number of participants (% ratio)	Findings
(Reale, Slater, & Burke, 2018a) *AWL*	Multi Combat Sport (Boxing, Judo, Taekwondo, Wrestling)	*n* = 260; M = 169; F = 91 (65/35)	No differences in RWLS based on sex between disciplines.
(Artioli et al., 2010a) *AWL*	Judo	*n* = 822; M = 607; F = 215 (74/26)	No differences in RWLS, prevalence (M = 85.8 vs. F = 85.9%) or specific behaviours and practices between the sexes.
(da Silva Santos, Takito, Artioli, & Franchini, 2016) *AWL*	Taekwondo	*n* = 116; M = 72; F = 44 (62/38)	Higher prevalence of weight making in females compared to males (M = 79 vs. F = 91%). No differences in specific behaviours or practices between the sexes.
(Kim & Park, 2020) *AWL*	Wrestling	*n* = 340; M = 240; F = 100 (71/29)	No differences in absolute BM loss amounts (M = 6.12 ± 1.32 vs. F = 4.69 ± 0.90 kg), specific behaviours or practices between the sexes.
(Hillier et al., 2019) *AWL*	MMA	*n* = 314; M = 287; F = 27 (91/9)	No difference in prevalence (M = 97.2 vs. F = 100.0%), magnitude of relative BM loss (M = 9.0 ± 3.9 vs. F = 7.7 ± 3.3%) or specific behaviours and practices between sexes.
(Slater et al., 2005) *CWL*	Lightweight Rowing	*n* = 100; M = 58; F = 42 (58/42)	No difference in prevalence (M = 92.3 vs. F = 94.1%), magnitude of BM loss or specific behaviours and practices between sexes. Females indicated as significantly more likely to restrict CHO as a method of body mass reduction.
(Nolan, Lynch, & Egan, 2020) *AWL*	Powerlifting	*n* = 233; M = 141; F = 92 (61/39)	Higher prevalence of weight making in females compared to males (83.0 vs. 90.2%). No difference in magnitude of relative BM loss (M = 3.0 ± 1.8 vs. F = 3.1 ± 2.1%), RWLS or specific behaviours and practices between sexes.

M: Male; F: Female; RWLS: Rapid Weight Loss Score (see Artioli et al. (2010c) this indicates the aggressiveness of weight management methods); BM: body mass; AWL: Acute Weight Loss; CWL: Chronic Weight Loss (abbreviation denotes focus of weight making phase in each investigation).

Table 1 highlights a select sample of previous cross sectional investigations examining the AWL and CWL practices of male and female athletes within differing weight category events. Typically, these types of studies present a larger proportion of data in males, yet those which include female participants highlight that the BM loss prevalence, magnitudes and specific behaviours/practices of weight making between the sexes are generally similar. To that end and despite parallel female participation in all the aforementioned sporting disciplines, previous exercise science research in weight making sports has persisted to predominantly focus on male athletes. In a study investigating rapid weight gain from official weigh in to immediately prior to bouts within five professional MMA events, the magnitude of BM increase was as high and in some instances higher, when females were compared to male competitors (Kirk et al., 2020). This is also similar to findings from a systematic review exploring rapid weight loss and gain in combat sport athletes, where females comprised only 3.5% of the 4432 collective participants, however, still highlighting similar results between the sexes (Matthews, Stanhope, Godwin, Holmes, & Artioli, 2019). Weight making research in horseracing has included female participants, yet again, with a focus predominantly centred around eating behaviours and preferred weight management practices (Dolan et al., 2011; Martin, Wilson, Morton, Close, & Murphy, 2017). In regards to CWL, one study has documented a six-week dietary intervention to support BM loss in a group of thirteen male and one female jockey athletes, but unfortunately the data was not reported individually to highlight any distinct female considerations (Wilson et al., 2015). However, despite a paucity of specific investigations within weight making *per se*, it has been well characterised that potential disordered eating/eating disorders are highly prevalent during CWL in female weight restricted demographics (Sundgot-Borgen et al., 2013). Furthermore, the effects of low energy availability (LEA) leading to consequences Female Athlete Triad (TRIAD) and Relative Energy Deficiency in Sports (RED-S) (Mountjoy et al., 2018; Nattiv et al., 2007) have also proven to be ubiquitous in female weight making events (Sundgot-Borgen et al., 2013). To date, these effects have predominantly been showcased in female weight category athletes within lightweight rowing, where a limited number of studies have highlighted that cyclic periods of BM manipulation across consecutive racing seasons, can lead to significant reductions in fat free mass (FFM) and is causative of suppression to ovarian hormone function (Slater, Rice, Jenkins, & Hahn, 2014).

Collectively, the existing body of research in weight category athletes is dominated by male participants and lacks consideration of female-specific physiology in research design. As such, there is a dearth of guidance and applied recommendations available when engaging specifically with female weight making athletes. This is particularly concerning given sex-related differences are noted in several physiological systems relevant to making weight, inclusive of body composition, substrate utilisation, fat oxidation, fluid balance and thermoregulation as highlighted in the subsequent sections. Therefore, the aim of this article is to review and provide potential recommendations for initial assessment, chronic/acute interventions and refeeding/recovery plans to help support implementation of BM loss strategies in females. Crucially this manuscript will also draw upon the applied experiences of the four authors, whilst reviewing the existing literature to provide some focussed guidance within this area of sport nutrition.

Key assessments for weight making interventions

Prior to any nutritional or training intervention, a structured assessment of the potential to achieve a targeted BM should be conducted. As a minimum, these assessments should be inclusive of measuring and/or predicting both body composition and resting metabolic rate (RMR), whilst establishing activity based energy expenditure (AEE) from both non-exercise (NEAT) and exercise (EEE) components (Langan-Evans, Close, & Morton, 2011). Additionally, it is also important to examine either the use of contraception or menstrual cycle status, in tandem with the potential for any underlying health issues when working with female athletes. Whilst an in-depth review of these factors are beyond the scope of this article, understanding contraception type and awareness of menstrual cycle time phases are of key relevance when formulating any BM loss intervention. To that regard, the research design recommendations of Elliott-Sale et al. (2021) can also provide relevant further context to be considered when supporting female athletes within a practical field-based setting. The remainder of this section alongside specific detail and considerations in Table 2, aims to provide an overview of assessments which could be considered when utilised with female weight making athletes in applied practice.

Initially, an accurate and reliable measurement of body composition, to evaluate how body tissues and/or water can be modulated in both chronic and acute timeframes is essential. To establish this, it is advisable to use reference methods such as dual x-ray absorptiometry (DXA) and/or bioelectrical impedance analysis (BIA), with appropriate pre assessment standardisation (Dehghan & Merchant, 2008; Nana et al., 2016). However where this isn't feasible, field based measures such as sum of skinfolds and requisite fat mass (FM) % equations can be considered, but only when following criterion protocols and relevant population-based estimations [see (Kasper et al., 2021) for further guidance and alternate body composition assessment methods]. RMR measurement is a crucial component of assessment, given this is not only important to establish the energy intake and macronutrient composition for intervention, but can also be used to define instances of potential energy deficiency (Strock, Koltun, Southmayd, Williams, & De Souza, 2020). As with body composition, the establishment of this value by utilising criterion equipment such indirect calorimetry and again following reference standardisation procedures (Bone & Burke, 2018) is key. If access to indirect calorimetry also isn't available, there are a range of female population-based equations that can be implemented, based on inputting values of FFM or more accessible measures of age, stature and BM as highlighted by Strock et al. (2020). As described earlier, identifying any potential disordered eating/eating disorders and considering the effect this may have on outcome data prior to these assessments is also of relevance. In tandem with the estimation of energy intake (EI – discussed in the following paragraph), the measurement of AEE in the forms of NEAT and EEE can be regarded as the most difficult to assess, given the challenges of establishing valid and reliable data utilising methods available for free-living conditions in athletic populations (Burke, Lundy, Fahrenholtz, & Melin, 2018b). When field based measures are used, where possible the utilisation of systems which integrate both heart rate (HR) and accelerometry are encouraged, given these show a higher degree of agreement with criterion measures (O'Driscoll et al., 2018). Furthermore, when establishing EEE, consideration should also be given to appropriate calculation, whereby the other components of total energy expenditure (i.e. RMR and NEAT) are omitted during the time period of exercise [for a detailed description see Langan-Evans et al. (2020)].

The calculation of energy availability using data from some aforementioned measurement assessments (EI-EEE/FFM) may also prove pertinent, given the nutritional strategies employed with weight making athletes across CWL may result in a purported threshold for LEA (<30 kcal·kgFFM·day^{-1}), as has been highlighted in males (Burke et al., 2018a). To that end, the addition of any further measurements which may aid in identifying potential consequences of LEA, therefore resulting in symptoms of both TRIAD and RED-S could be considered useful, particularly considering some research has elucidated that females may be more susceptible to these effects than males (Areta, Taylor, & Koehler, 2020); Heikura et al. 2021 this special edition). However, caution must be noted when interpreting any assessed outcomes, given the current research in this area is equivocal (Williams, Koltun, Strock, & De Souza, 2019). A case report by Langan-Evans et al. (2020), has

Table 2. Considerations for use of assessment methods during chronic and acute weight making strategies in female athletes.

Assessment	Primary method	Secondary method	Considerations
Menstrual Cycle/ Contraceptive Use Tracking	Urine and/or blood based markers to establish endocrine changes across each distinct menstrual or contraceptive cycle phase (can be mapped against calendar based assessment).	Calendar based assessment to establish time period between menses and record or estimate menstrual cycle phase (can be used in conjunction with urine, blood and/or core temperature measurement).	Primary method is reference standard to accurately establish each cycle phase. However, may not be feasible in applied settings, given requirement for trained phlebotomist and/or cost implications of equipment/consumables. Secondary method can only be used as an approximate estimation of menstrual cycle phase and may be of limited use in female athletes with high intra cycle variability or for those using contraception. Use of both methods advised, or secondary as a minimum.
Body Composition (Tissues)	Dual X-Ray Absorptiometry (DXA) assessment of whole body and regional distribution of fat mass, fat free mass and bone mineral content/density.	Sum of skinfolds and appropriate equations to estimate whole body distribution of fat mass and fat free mass.	Primary method allows for accurate establishment of whole body and regional tissue composition. However, considerable pre assessment standardisation procedures are required to control biological and technical error, alongside delivery of a low radiation dose, which limits frequency of use and potential limited accessibility and/or high cost implications. There can be high degrees of variability between differing equipment manufacturers. Secondary method can only estimate whole body distribution of tissues and may have limited accuracy and reliability, dependent on operator procedure and calculation using relevant equations. However, method is relatively low cost, easily accessible and can be measured more frequently than primary method. Use of both methods advised, or secondary as a minimum.
Body Composition (Total Body Water)	Bioelectrical Impedance Analysis (BIA) assessment of intra/extra cellular and total body water.	Total body mass change recorded in tandem with daily fluid intake, urine output and menstrual cycle tracking.	Primary method allows accurate assessment of total body water, which is sensitive to acute and chronic change and could also be used for body composition assessment. However, also requires considerable pre standardisation which if not considered can lead to reduced accuracy and reliability. There can be high degrees of variability between differing equipment manufacturers and more accurate systems may result in higher cost implications. Secondary method can only be established after a period of assessments using standardised procedures i.e. morning, post urination, nude and against previous daily fluid intake and urine/sweat output measurements, given chronic modulations across a training camp and menstrual cycle phase can influence change. Method is very low cost, but requires calibrated scales and recording of data may be impractical in the applied setting. Can lead to large errors in accuracy and reliability if data is not collected correctly and doesn't provide an objective value of total body water. Use of primary method advised. Secondary method only advised when primary is not feasible.
Resting Metabolism	Indirect calorimetry assessment of resting metabolic rate and substrate utilisation.	Specific equations using estimations of fat free mass (via body composition assessment) or measures of age, stature and body mass.	Primary method can establish an objective assessment of resting energy requirements, which can be used to estimate dietary macronutrient composition. However, considerable pre assessment standardisation procedures are required to control biological and technical error. This method may have limited accessibility and/or potential high cost implications. Secondary method can only be used as an estimation of resting energy requirements, which may differ considerably dependent on equation/s selected. There are few female athletic specific references and this may lead to considerable error in the calculation of dietary energy and macronutrient intakes. However, method is zero cost and can be used in tandem with primary method to assess instances of potential energy deficiency. Use of both methods advised, or secondary as a minimum (n.b. when using secondary method, equations utilising estimations of fat free mass often provide closer estimations to primary method).
Substrate Utilisation & Exercise Capacity	Indirect calorimetry assessment of exercise based substrate utilisation and capacity.	Multi stage fitness tests in conjunction with appropriate equations to estimate exercise capacity.	Primary method can offer considerable information in relation to objective metabolic changes, substrate utilisation and exercise capacity across a training camp, which can be mapped against other metrics such as selected exercise intensities or HR. However, considerable pre assessment standardisation procedures are required to control biological and technical error. This method can also have limited accessibility and/or potential high cost implications. Secondary method can highlight limited detail in regards to exercise capacity, whereby final stage of completion can be used to estimate VO_{2max} and this information can also be mapped against specific metrics as above. However, given

(*Continued*)

Table 2. Continued.

Assessment	Primary method	Secondary method	Considerations
			limitations of method, estimations may result in low accuracy and reliability of predictions. Use of primary method advised. Secondary method only advised when primary is not feasible.
Sweat Rate & Sodium Concentration	Localised filter paper, absorbent patch or Parafilm-M® pouch technologies for assessment of sweat rate and specific electrolyte composition.	Total body mass change recorded in tandem with fluid intake, urine output and menstrual cycle tracking.	Primary method has become more widely available, with commercially viable and easy to use systems, helping to inform chronic changes and aid acute strategies in the post weigh in recovery period. However, when compared to whole body laboratory criterion assessments, localised methods may considerably overestimate both sweat rates and sodium concentrations if timing, duration, site position/cleaning and storage/handling of samples are not standardised. Secondary method can only be established after a period of assessments using standardised procedure i.e. nude pre/post body mass and against fluid intake and urine output within a specified time period i.e. pre post active or passive heating. Method is very low cost, but requires calibrated scales and recording of data may be impractical in the applied setting. Can lead to large errors in accuracy and reliability if data is not collected correctly and doesn't provide an objective value of sodium concentration. Use of primary method advised, or secondary as a minimum.
Core Temperature	Rectal thermometry for assessment of menstrual cycle phase and/or during AWL active and passive heating strategies.	N/A	Primary method considered reference standard, which is practically feasible within the field and can be easily self-administered. Measurement to indicate menstrual cycle phase should be repeated at consistent time points to establish levels of accuracy and reliability. However, can result in some individual discomfort and whilst relatively cheap, more accurate thermometers can result in higher cost implications. Use of peripheral thermometry i.e. oral, aural, tympanic, skin, axillary or temporal is not advised, given these methods may underestimate core temperature by 1-2°C, therefore not adequately identifying menstrual cycle phase and/or acute changes during active and/or passive heating.
Heart Rate/Blood Pressure	Blood pressure monitor unit for assessment of systolic/diastolic pressure and HR.	HR monitor unit or radial/carotid pulse measurement.	Primary method can be used on a daily basis to assess physical fitness/readiness and blood pressure can be considered with other metrics such as resting metabolism, to identify instances of potential energy deficiency i.e. when lowered (hypotension) during chronic weight loss phase. Both HR and blood pressure can also be included during acute weight loss phase to examine stress response to active and/or passive heating i.e. when increased and/or lowered. Method is relatively easy to use and low cost, although more accurate monitors may result in higher cost implications. Secondary method allows a simple and low to zero cost assessment of HR for considerations identified above, in the absence of additional blood pressure measurement. However, subjective nature alongside potential biofeedback during pulse measurement may result in lower accuracy and reliability vs. primary method. Use of primary method advised, or secondary as a minimum.

VO_{2max}: Maximal oxygen uptake; HR: heart rate.

described a number of additional measures that can be conducted in the context of examining factors related to the effects of LEA on both TRIAD and RED-S during weight making, albeit in a male athlete. However, the same assessment methods have been employed by the authors with elite-level female combat sport and jockey athletes, so could also be considered relevant. Indeed, other key measures such as the assessment of blood profiles for markers of female athlete health, TRIAD and RED-S, substrate utilisation, peak fat oxidation, exercise capacity, sweat/sodium concentrations, core temperature and HR/blood pressure (see Table 2), would all prove useful in informing and directing the CWL and AWL strategies, now discussed in the subsequent sections and summarised in Table 3.

Chronic Weight Loss (CWL) strategies

The goal of the chronic phase of BM mass reduction, is to modulate body tissues as identified in the compositional assessment. This stage is crucial in establishing whether an individual can feasibly and reasonably achieve a prescribed BM through dietary and training intervention, without compromising either health and/or performance. However, in instances where a female athlete would need to lose large quantities of BM (beyond those considered acceptable utilising AWL strategies – as discussed in the following section), interventions to reduce FM should be of key focus (Langan-Evans et al., 2011). Taking this into consideration, it would never be advisable to attempt a reduction in FM lower than a relative value of 12% body fat with female athletes, due to the potential to induce subsequent health-related issues particularly associated with symptoms of TRIAD (Nattiv et al., 2007). However, previous research has also highlighted that a range of female health complications can occur independently of reductions beyond the recommended lower limit of FM and/or through periods of LEA (Lieberman, D, Wagstaff, & Williams, & I, 2018; Sanborn, Albrecht, & Wagner, 1987). These findings are consistent with the experiences of the authors, who have observed TRIAD and RED-S consequences that may occur in female athletes across relative FM values ranging from 12 to 22% body fat. Therefore, any negative outcomes are not necessarily always attributed to the modulation of EI and/or EEE, which may lead to specific time periods of LEA during training. Further to this, a case report by Stellingwerff (2018), has elucidated that the potential to periodise body composition in female athletes across competitive timeframes, may be the optimal approach to reduce FM during phases of weight management. However, it must be noted that this study was conducted in a propulsion-based athlete, who was weight stable and in a state of optimal EA, therefore more work is needed to extrapolate this concept to female weight making athletes.

For CWL strategies in females, dietary interventions based on specific energy intake and macro/micronutrient distributions and totals should be considered of the same relevance as in males. Typically daily energy intake should aim to meet at least the equivalent of RMR, which is why an established baseline and consistently repeated measurement of this assessment is crucial (Langan-Evans et al., 2011). Specific studies have highlighted relative macronutrient compositions of 3 g·kgBM^{-1} carbohydrate (CHO), 2 g·kgBM^{-1} protein and 1 g·kgBM^{-1} fat (Langan-Evans et al., 2020; Wilson et al., 2015), resulting in effective BM loss outcomes in weight making athletes. Furthermore, where criterion measures of body composition have been utilised, these values can also be relativised in relation FFM. Whilst these macronutrient compositions aren't definitive and should be considered in the context of each individual case, they serve as a means to reduce BM gradually, ranging from losses of 0.5 to 1.0 kg·wk^{-1} and to protect FFM when combined with resistance training (Sundgot-Borgen et al., 2013). In situations where it is desirable to reduce FFM, then consideration should be given to the gradual reduction of CHO and protein intake across the BM loss intervention period (Morton, Robertson, Sutton, & MacLaren, 2010), however, CHO should always be periodised around targeted training sessions serving to *fuel for the work required* (Impey et al., 2016). Finally, given the sex-related differences in substrate utilisation and the potential for females to have a marginally higher rates of fat oxidation during varying exercise intensities and across 24 h (Melanson et al., 2002), this could be considered as a specific strategy in tandem with periodised meal timings to deliberately target increased reductions in endogenous FM stores over a prolonged training period, which is pertinent given this doesn't appear to be significantly affected over time by either hormonal contraception use or menstrual cycle phases (Isacco, Duché, & Boisseau, 2012); Nathalie Boisseau & Laurie Isacco (2021) this special edition.

Acute Weight Loss (AWL) strategies

The predominant goal of the acute phase of BM mass reduction is to modulate the body fluids as identified in the compositional assessment. There are a number of strategies that can be employed with weight making athletes during the AWL phase, inclusive of reductions in endogenous glycogen content, low residue/fibre/sodium diets and active/passive means of

Table 3. Weight making strategies, nutritional guidelines and female-specific considerations during phases of BM loss and refeeding/recovery.

Phase	Weight making strategy	Nutritional guidelines	Female-specific considerations
General Training	Not Applicable	EI: Periodised and specific to the daily demands of training PRO: 1.5–2.0g·kgBM^{-1} CHO: 5.0–7.0g·kgBM^{-1} (*"Fuel for the work required"* and periodise accordingly to training demands) FAT: 1.0–2.0g·kgBM^{-1} Fibre: >30g·day^{-1} Fluid: Follow planned strategy to ingest adequate fluids matching daily losses Na^+: >2000–2500mg·day^{-1} ideally matched to fluid losses	Investigate use of hormonal contraception type or track and establish phases of menstrual cycle. If possible monitor changes in anterior pituitary/ovarian sex hormones i.e. venous bloods, ovulation kits etc. to confirm tracked phases. Consider any menstrual cycle disturbances i.e. secondary amenorrhea, oligomenorrhea etc. Establish any changes in BM loss/gain, TBW retention, core temperature and monitor symptoms to be prepared in planning for appropriate CWL and AWL body mass loss strategies.
CWL	Reductions in FM and/or FFM as appropriate, based on applicable assessment measures. Do not reduce FM <12%. Focus on 0.5-1.0 kg·wk^{-1} BM loss based on timescale to event. Consider use of heat acclimatisation for strategies, which may be considered in the AWL phase.	EI: Periodised and meeting a minimum daily intake of measured or predicted RMR PRO: 2.0 g·kgBM^{-1}(can be lowered when FFM loss is required) CHO: 3.0–3.5 g·kgBM^{-1} (*"Fuel for the work required"* and periodise accordingly to daily training demands) FAT: <1.0 g·kgBM^{-1}(do not go low or zero fat) Fibre: >30 g·day^{-1} Fluid: Follow planned strategy to ingest adequate fluids matching daily losses Na^+: >2000–2500 mg·day^{-1} ideally matched to fluid losses	Continue to assess same factors as in General Training section. Establish energy balance and/or availability status if possible and consider potential for TRIAD and/or RED-S consequences. Continually monitor BM, composition, RMR, wellbeing and mood status throughout and readjust nutritional intervention accordingly based on subjective/objective feedback.
AWL	Acute reductions in TBW, GI tract and muscle glycogen content as appropriate. Glycogen depletion can be achieved via maintenance of CHO intake and increase in exercise or vice versa. No recommended AWL target, yet 5–10% BM loss may be feasible with an acceptably small impact on health and performance. However, this is context specific and must be based on individual assessment.	EI: In some instances may be reduced below RMR, but consider consequences PRO: 2.0 g·kgBM^{-1} CHO: 3.0–3.5 g·kgBM^{-1} *OR* <50 g·day^{-1} during glycogen depletion FAT: >1.0 g·kgBM^{-1} (can go high to still meet available energy needs) Fibre: <10 g·day^{-1} to reduce GI tract content Fluid: 100 ml·kgBM·day^{-1} if water loading *AND/OR* graded reductions leading to the weigh in to induce TBW losses Na^+: Consistent with CWL phase *OR* <500 mg·day^{-1} to induce TBW losses	Consider changes in BM loss/gain, TBW retention, core temperature as established in General Training and CWL sections. Consider caution if employing water loading strategy during periods of low sodium intake and high TBW retention, given this may lead to hypotonic euvolemic hyponatremia if fluid volumes are not well controlled Consider caution in use of active and/or passive means of inducing sweating (particularly in heated environments), when core temperature may be higher i.e. luteal phase. Continually monitor BM, HR/blood pressure, wellbeing and mood status throughout AWL process and readjust accordingly based on subjective/objective feedback.

(*Continued*)

Table 3. Continued.

Phase	Weight making strategy	Nutritional guidelines	Female-specific considerations
Refeed/ Recovery	Replenish losses of TBW and glycogen reductions induced during AWL phase.	EI: High to replenish post AWL in line with GI comfort	Always consider refeed and recovery strategy in the context of individual circumstances
		PRO: 1.5–2.0 g·kgBM^{-1} (from lean & low fat sources)	.
		CHO Short term recovery (i.e. <4 h): <5 g·kgBM·day^{-1}	Consider use of high CHO content refeeding strategy >1.2 g·kgBM·hr^{-1} during reduced recovery periods and using multiple sources for enhanced glycogen replenishment
		Long term recovery (i.e. >4 h): 7–10 g·kgBM·day^{-1}	
		FAT: <1.0 g·kgBM^{-1}(do not go low or zero fat)	
		Fluid: Consume initial 600–900 ml bolus followed by boluses throughout allotted recovery period to account for 150% of TBW losses.	Subjectively assess GI distress continually leading up to event.
.		Na^+: 1150 mg per litre of fluid	Advise athlete not to gorge and consider a well-controlled and measured nutritional intervention at this phase.

EI: Energy Intake; PRO: Protein; CHO: Carbohydrate; Na^+: Sodium; BM: Body Mass; kg: Kilogram; g: Gram; mg: Milligram; CWL: Chronic Weight loss; FM: Fat Mass; FFM: Fat Free Mass; wk: Week; AWL: Acute Weight Loss; RMR: Resting Metabolic Rate; TRIAD: Female Athlete Triad; RED-S: Relative Energy Deficiency in Sports; TBW: Total Body Water; HR: Heart Rate; HR: Hour; GI: Gastrointestinal.

dehydration through restrictions in exogenous fluid, increases in the capacity to perspire and endogenous fluid balance manipulation. Readers are encouraged to see the following publication by Reale et al. (2017a), for a more detailed review and contextual guidance on these specific techniques and methodologies in practice. However, it is during this phase of BM manipulation that an increased awareness and understanding of sex-specific body composition and physiology should be considered when planning the implementation of particular AWL strategies.

As highlighted earlier, given females have overall higher endogenous FM storage than males, this often occurs in tandem with less total FFM, therefore resulting in a lower total body water (TBW) pool of up to 10% (Keys & Brozek, 1953). Additionally, this is generally coupled with reductions in overall body size/surface area, causative of decreases in metabolic rates and sweat production when compared to males (Gagnon & Kenny, 2012). Whilst a thoroughly descriptive review of sex-specific fluid balance is beyond the scope of this article, it is important to understand when working with female weight making athletes, that there are nuanced processes which regulate TBW across the menstrual cycle, due to the interplay of fluctuations between the ovarian sex hormones oestrogen and progesterone. Time periods of high oestrogen [during the late follicular (ovulation) leading into the luteal phases] have been shown to increase TBW interstitial fluid by up to 2 litres and this is coupled by a reduction in sodium excretion due to increased levels of arginine vasopressin (Sawka et al., 2007; Stachenfeld, 2008). Paradoxically, higher levels of progesterone have been highlighted to have a reverse effect on fluid balance and sodium regulation within the luteal phase (Rodriguez-Giustiniani & Galloway, 2019). Additionally, it is well described that thermoregulatory responses to heat stress in females differ from males, due to reduced sudomotor function. This is also in parallel to high levels of progesterone during the luteal phase, being causative of increases in core temperature by a range of 0.3–0.7°C when compared to the follicular phase (Gagnon & Kenny, 2012). Finally, these mechanisms have also been linked to a reduction in sweating capacity in females when compared to males, during both active and passive modalities and within heated environments (Sawka et al., 2007). Research studies examining the fluid balance and thermoregulatory responses of hormonal contraceptives using differing types of exogenous oestrogen and/or progesterone is currently limited and often equivocal, yet highlight similar outcomes to the fluctuations in anterior pituitary and ovarian sex hormones across the menstrual cycle. To that regard, readers are directed to recent reviews by Giersch, Charkoudian, Stearns, and Casa (2020) and Baker, Siboza, and Fuller (2020) for a more broad overview of fluid balance and temperature regulation in females, when considering the impact on weight making strategies for AWL.

Due to the aforementioned compositional and physiological changes that can modulate both fluid balance and thermoregulation in females during the menstrual cycle or through the use of hormonal contraceptives, caution must be considered in the types of AWL techniques that may be utilised in female weight making populations. Water loading is a popular technique amongst combat sports athletes, which involves ingesting large volumes of fluid to induce subsequent dehydration through potential modulation of vasopressin regulated changes in aquaporin channels (Reale, Slater, Cox, Dunican, & Burke, 2018b). However, given the aforementioned fluid balance fluctuations regulated by oestrogen and progesterone during the luteal phase and via use of specific types of hormonal contraceptives, this technique should be employed carefully during periods of reduced sodium intake and higher TBW, given the potential to induce hypotonic euvolemic hyponatremia (Stachenfeld & Taylor, 2009). However, the evidence base for this concern within the context of water loading doesn't currently exist within the literature and more research is needed to explore if there is an increased risk for this condition in female athletes during applied practice (Giersch et al., 2020). Additionally, it is critical that techniques utilised to induce sweating through active and passive modalities may be less effective in female athletes based on the information provided earlier within this review. As is often the case in practice, if these methods are employed in tandem with uncontrolled restrictions in fluid intake and repeated heating cycles, this may have the predisposition to cause hyperthermia in shorter time periods when compared to males, resulting from increased baseline core body temperature during the luteal phase or when using hormonal contraception high in progesterone as previously described (Inoue et al., 2005; Kuwahara, Inoue, Abe, Sato, & Kondo, 2005). This highlights why the assessment of core temperature during the use of active and/or passive heating, may be of key relevance in identifying any potential for increased instances of hyperthermia (see Pivarnik, Marichal, Spillman, and Morrow (1992) and Table 2). However it must also be noted, that given the limited, ambiguous and often conflicting nature of research in female populations, these considerations should be made on a case by case basis. Indeed, the authors of this article have experienced high degrees of variability in the sweat and renal water modulation of female weight making athletes during their practice and can report some individuals having similar profiles that are equal to their male counterparts with no apparent adverse health effects. Sweat rates and composition are also known to be highly variable between individuals and are likely determined by genetic factors rather than specific sex differences when physically matched for proportion (Barnes et al., 2019). Furthermore, the potential to increase sweating capacity via heat acclimation is a strategy that has been utilised by the authors in female weight making athletes and could also be considered in practice (Baker, 2019). To that end, the sex-specific differences between the approaches which play on endogenous fluid balance and thermoregulatory responses may be minimal and not of consequence (Sawka et al., 2007), however, awareness of these factors in practical scenarios and more consistent research in this field is urgently needed.

Refeed and recovery strategies post weigh in

Recovery strategies will vary across a spectrum of weight making events and will depend on *a.* the extent and methods of BM loss performed and *b.* the time between weigh in and competition. For example, a professional MMA athlete who has engaged in up to 10% AWL, will have the objective of gaining as much BM as possible in the period prior to an event, stemming from the desire to be heavier than their opponent and therefore resulting in the potential for a physical competitive advantage. Conversely, a jockey athlete who may have undertaken a 3% AWL, needs to be mindful of regaining too much BM post event, given repeated competitive weight restrictions required across successive race days. Common to all contexts, this phase of nutrition support should centre around rehydration and endogenous glycogen content restoration, whilst also considering the potential for gastrointestinal distress. Given a thoroughly detailed examination of this area is beyond the scope of this article, readers are again encouraged to see Reale, Slater, and Burke (2017b) and Burke et al. (2021) for an in-depth overview, which provides practical considerations pertinent to refeeding and recovery in weight making athletes of both sexes.

Rehydration protocols depend on the amounts of endogenous water and electrolyte content lost during AWL, alongside the methods used to facilitate the process. Initial focus should seek to restore fluid losses to <2% of pre AWL levels, given the detrimental effects on strength, endurance capacity and cognitive performance associated with >2% dehydration (Wilson et al., 2013). In order for consumed fluids to enter and contribute to the TBW pool, there is a reliance on efficient gastric emptying and absorption via the small intestine into the circulatory system (Maughan & Shirreffs, 1997). Given gastric emptying rates can be variable, an initial ~600–900 ml bolus is considered optimal with further ingestions at regular intervals until a total of 150% of lost BM is achieved and this doesn't appear to be influenced by either menstrual cycle phase or hormonal contraceptive use (Maughan, McArthur, & Shirreffs, 1996; Rodriguez-Giustiniani & Galloway, 2019). Consuming sodium during this recovery period will help to retain fluids and restore potential reductions in electrolytes, with failure to do so preventing a return to euhydration and likely stimulating unwanted and excessive urine losses (Sawka et al., 2007). Knowledge of sweat rate and composition may be advantageous in developing a more bespoke rehydration recovery strategy, particularly given the menstrual cycle and hormonal contraceptive effects on fluid balance highlighted earlier, which can result in altered plasma sodium concentrations (Stachenfeld, 2008). However, this is likely not significant in influencing specific performance outcomes and in the absence of knowing sweat sodium concentrations, commercially available isotonic sports drinks and products containing ~30–90 mmol·L^{-1} of sodium, alongside the consumption of sodium-containing foods can support electrolyte replenishment following AWL, given sweat sodium concentration is typically 20–80 mmol·L^{-1} (Sawka et al., 2007). Finally, we would encourage readers to see the following publication by Rodriguez-Giustiniani, Rodriguez-Sanchez & Galloway, 2021 in this special edition, for a more detailed overview of this area specifically in female athletes.

High intensity exercise alongside a concomitant reduction in CHO intake during AWL, will result in lower stored endogenous glycogen and bound TBW, therefore a priority during the recovery phase should also be focused on increasing CHO intake to restore both muscle and liver reserves (Reale et al., 2017b). Given the comparative rates of CHO utilisation during exercise and relative substrate storage capacity between males and females, macronutrient intakes during recovery shouldn't differ significantly between sexes, nor does this appear different between contraceptive and non-contraceptive users (Flynn, Rosales, Hailes, & Ruby, 2020). A range of 5–10 g·kgBM·day^{-1} CHO is recommended to accommodate the needs of most weight making athlete scenarios (Reale et al., 2017b). Lower intakes of <5 g·kgBM·day^{-1} may be pertinent for those weight making sports who require necessary fuel to perform across shorter durations, but are restricted in the amount of BM gain given the necessity to weigh in more frequently across events (i.e. amateur boxing/MMA, horseracing etc.). Higher intakes of 7–10 g·kgBM·day^{-1} may best suit weight making events where glycogen supercompensation can provide a competitive advantage, as well as the fuel to perform more prolonged high intensity activity (i.e. professional boxing, MMA etc.). Well established recommendations of >1.2 g·kgBM·hr^{-1} CHO can optimise rates of glycogen restoration and where this may be inadequate (<1.0 g·kgBM·hr^{-1}), can be further supported when co-ingested with 0.3–0.4 g·kgBM^{-1}of protein (Burke, van Loon, & Hawley, 2017). However, consideration should be given to the time period between making weight and the requirement to perform, particularly given glycogen restoration is dependent on the level of initial depletion and may take several hours to replete to baseline levels utilising the aforementioned feeding strategies (Burke et al., 2017). To that end, a period of up to 4 h has been shown to be effective in rescuing combat sport performance post AWL of 5% BM (Artioli et al., 2010b). To support intestinal absorption and reduce the likelihood of gastrointestinal distress, athletes may benefit from selecting mixed CHO sources (i.e. glucose and fructose) therefore taking advantage of multiple gut transport mechanisms (Gonzalez, Fuchs, Betts, & van Loon, 2017). Additionally, limiting fibre rich foods is advised, given this may slow absorption of nutrients and cause gastrointestinal discomfort ahead of competition (Reale et al., 2017b). For further and more in-depth recommendations on CHO for recovery post AWL, please see the publication by Morton, 2021 in this special edition.

Conclusions and future considerations

The previous sections within this article have served to deliver scientifically informed, yet practically driven strategies, which can be considered across both chronic and acute time frames in female weight making athletes. Despite the cross sectional research base highlighting that behaviours and practices are similar between the sexes, limited specific investigations providing methods and techniques which can be utilised for BM loss interventions have predominantly been conducted in males. Furthermore, as highlighted throughout the article, there are sex-specific considerations in terms of both body composition and physiological systems, which may present challenges when considering certain strategies across phases of the menstrual cycle or during specific hormonal contraceptive use. On this basis, there is an urgent need to conduct studies examining whether or not sex-specific interventions may actually result in implications for both health and/or performance outcomes in female weight making athletes. Indeed, this is a proposition which should be encouraged across all disciplines of the sport sciences, to further inform practical guidelines for female athletes more broadly. One facet of sport nutrition which this article has not addressed, is the use of dietary ergogenic supplements for sport performance during weight making in female athletes. This has been deliberate given the research base for these nutritional aids is limited within both weight making sports universally and specifically in females. However, there are certainly positive associations in regards to performance enhancement across a range of dietary ergogenic supplements and readers are encouraged to read the other articles on this topic within this special edition. Finally, the authors would like to reinforce that weight making strategies in female athletes should be considered on a case by case basis and individuality should take precedent at all times. Whilst there is some evidence to suggest female body compositional and physiological paradigms may warrant specific interventions vs. males *per se*, this should not be at the detriment of general nutritional guidelines which are pertinent and applicable across athletes of both sexes.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Ackland, T. R., Lohman, T. G., Sundgot-Borgen, J., Maughan, R. J., Meyer, N. L., Stewart, A. D., & Muller, W. (2012). Current status of body composition assessment in sport: Review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. Medical commission. *Sports Medicine*, *42*(3), 227–249. doi:10.2165/11597140-000000000-00000

Areta, J. L., Taylor, H. L., & Koehler, K. (2020). Low energy availability: History, definition and evidence of its endocrine, metabolic and physiological effects in prospective studies in females and males. *European Journal of Applied Physiology*. doi:10.1007/s00421-020-04516-0

Artioli, G. G., Gualano, B., Franchini, E., Scagliusi, F. B., Takesian, M., Fuchs, M., & Lancha, A. H. Jr (2010a). Prevalence, magnitude, and methods of rapid weight loss among judo competitors. *Medicine and Science in Sports and Exercise*, *42*(3), 436–442. doi:10.1249/MSS.0b013e3181ba8055

Artioli, G. G., Iglesias, R. T., Franchini, E., Gualano, B., Kashiwagura, D. B., Solis, M. Y., … Lancha Junior, A. H. (2010b). Rapid weight loss followed by recovery time does not affect judo-related performance. *Journal of Sports Sciences*, *28*(1), 21–32. doi:10.1080/02640410903428574

Artioli, G. G., Scagliusi, F., Kashiwagura, D., Franchini, E., Gualano, B., & Junior, A. L. (2010c). Development, validity and reliability of a questionnaire designed to evaluate rapid weight loss patterns in judo players. *Scandinavian Journal of Medicine and Science in Sports*, *20*(1), e177–e187. doi:10.1111/j.1600-0838.2009.00940.x

Baker, L. B. (2019). Physiology of sweat gland function: The roles of sweating and sweat composition in human health. *Temperature*, *6*(3), 211–259. doi:10.1080/23328940.2019.1632145

Baker, F. C., Siboza, F., & Fuller, A. (2020). Temperature regulation in women: Effects of the menstrual cycle. *Temperature*, *7*(3), 226–262. doi:10.1080/23328940.2020.1735927

Barnes, K. A., Anderson, M. L., Stofan, J. R., Dalrymple, K. J., Reimel, A. J., Roberts, T. J., … Baker, L. B. (2019). Normative data for sweating rate, sweat sodium concentration, and sweat sodium loss in athletes: An update and analysis by sport. *Journal of Sports Sciences*, *37*(20), 2356–2366. doi:10.1080/02640414.2019.1633159

Bone, J. L., & Burke, L. M. (2018). No difference in young adult athletes' resting energy expenditure when measured under inpatient or outpatient conditions. *International Journal of Sport Nutrition and Exercise Metabolism*, *28*(5), 464–467. doi:10.1123/ijsnem.2016-0315

Burke, L. M., Close, G. L., Lundy, B., Mooses, M., Morton, J. P., & Tenforde, A. S. (2018a). Relative Energy Deficiency in Sport in male athletes: A commentary on its presentation among selected groups of male athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *28*(4), 364–374. doi:10.1123/ijsnem.2018-0182

Burke, L. M., Lundy, B., Fahrenholtz, I. L., & Melin, A. K. (2018b). Pitfalls of conducting and interpreting estimates of energy availability in free-living athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *28*(4), 350–363. doi:10.1123/ijsnem.2018-0142

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. doi:10.1249/jsr.0000000000000831

Burke, L. M., van Loon, L. J. C., & Hawley, J. A. (2017). Postexercise muscle glycogen resynthesis in humans. *Journal of Applied Physiology (1985)*, *122*(5), 1055–1067. doi:10.1152/japplphysiol.00860.2016

da Silva Santos, J. F., Takito, M. Y., Artioli, G. G., & Franchini, E. (2016). Weight loss practices in Taekwondo athletes of different competitive levels. *Journal of Exercise Rehabilitation*, *12*(3), 202–208.

Dehghan, M., & Merchant, A. T. (2008). Is bioelectrical impedance accurate for use in large epidemiological studies? *Nutrition Journal*, *7*, 26–26. doi:10.1186/1475-2891-7-26

Dolan, E., O'Connor, H., McGoldrick, A., O'Loughlin, G., Lyons, D., & Warrington, G. (2011). Nutritional, lifestyle, and weight control practices of professional jockeys. *Journal of Sports Sciences*, *29*(8), 791–799. doi:10.1080/02640414.2011.560173

Elliott-Sale, K. J., Minahan, C. L., de Jonge, X., Ackerman, K. E., Sipilä, S., Constantini, N. W., … Hackney, A. C. (2021). Methodological considerations for studies in Sport and Exercise Science with Women as participants: A working guide for standards of practice for research on Women. *SportS Medicine*, doi:10.1007/s40279-021-01435-8

Flynn, S., Rosales, A., Hailes, W., & Ruby, B. (2020). Males and females exhibit similar muscle glycogen recovery with varied recovery food sources. *European Journal of Applied Physiology*, *120*(5), 1131–1142. doi:10.1007/s00421-020-04352-2

Gagnon, D., & Kenny, G. P. (2012). Does sex have an independent effect on thermoeffector responses during exercise in the heat? *Journal of Physiology*, *590*(23), 5963–5973. doi:10.1113/jphysiol.2012.240739

Giersch, G. E. W., Charkoudian, N., Stearns, R. L., & Casa, D. J. (2020). Fluid balance and hydration considerations for women: Review and future directions. *Sports Medicine*, *50*(2), 253–261. doi:10.1007/s40279-019-01206-6

Gonzalez, J. T., Fuchs, C. J., Betts, J. A., & van Loon, L. J. (2017). Glucose plus fructose ingestion for post-exercise recovery-greater than the Sum of Its parts? *Nutrients*, *9*(4), doi:10.3390/nu9040344

Heikura, I. A., Stellingwerff, T., & Areta, J. L. (2021). Low energy availability in female athletes: From the lab to the field. *European Journal of Sport Science*, 1–11.

Hillier, M., Sutton, L., James, L., Mojtahedi, D., Keay, N., & Hind, K. (2019). High prevalence and magnitude of rapid weight loss in mixed martial arts athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *29*(5), 512–517. doi:10.1123/ijsnem.2018-0393

Impey, S. G., Hammond, K. M., Shepherd, S. O., Sharples, A. P., Stewart, C., Limb, M., … Morton, J. P. (2016). Fuel for the work required: A practical approach to amalgamating train-low paradigms for endurance athletes. *Physiological Reports*, *4*(10), e12803. doi:10.14814/phy2.12803

Inoue, Y., Tanaka, Y., Omori, K., Kuwahara, T., Ogura, Y., & Ueda, H. (2005). Sex- and menstrual cycle-related differences in sweating and cutaneous blood flow in response to passive heat exposure. *European Journal of Applied Physiology*, *94*(3), 323–332. doi:10.1007/s00421-004-1303-2

Isacco, L., Duché, P., & Boisseau, N. (2012). Influence of hormonal status on substrate utilization at rest and during exercise in the female population. *Sports Medicine*, *42*(4), 327–342. doi:10.2165/11598900-000000000-00000

Isidore, C. (2015). *Mayweather-Pacquiao rakes in a record $500 million*. Retrieved from https://money.cnn.com/2015/05/12/news/companies/mayweather-pacquiao-revenue/index.html.

Kasper, A. M., Langan-Evans, C., Hudson, J. F., Brownlee, T. E., Harper, L. D., Naughton, R. J., … Close, G. L. (2021). Come back skinfolds, all is forgiven: A narrative review of the efficacy of Common body composition methods in applied Sports practice. *Nutrients*, *13*(4), doi:10.3390/nu13041075

Keys, A., & Brozek, J. (1953). Body fat in adult man. *Physiological Reviews*, *33*(3), 245–325. doi:10.1152/physrev.1953.33.3.245

Kim, J. C., & Park, K. J. (2020). Injuries and rapid weight loss in elite Korean wrestlers: An epidemiological study. *Physician and Sportsmedicine*, 1–8. doi:10.1080/00913847.2020.1824536

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*, 1–5. doi:10.1123/ijsnem.2019-0347

Kuwahara, T., Inoue, Y., Abe, M., Sato, Y., & Kondo, N. (2005). Effects of menstrual cycle and physical training on heat loss responses during dynamic exercise at moderate intensity in a temperate environment. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology*, *288*(5), R1347–R1353. doi:10.1152/ajpregu.00547.2004

Langan-Evans, C., Close, G. L., & Morton, J. P. (2011). Making weight in combat sports. *Strength & Conditioning Journal*, *33*(6), 25–39. doi:10.1519/SSC.0b013e318231bb64

Langan-Evans, C., Germaine, M., Artukovic, M., Oxborough, D. L., Areta, J. L., Close, G. L., & Morton, J. P. (2020). The psychological and physiological consequences of low energy availability in a male combat Sport athlete. *Medicine and Science in Sports and Exercise*, doi:10.1249/mss.0000000000002519

Lieberman, J. L., D, M. J., Wagstaff, E. S., & Williams, D. A., & I, N. (2018). Menstrual disruption with exercise is not linked to an energy availability threshold. *Medicine and Science in Sports and Exercise*, *50*(3), 551–561. doi:10.1249/mss.0000000000001451

Martin, D., Wilson, G., Morton, J., Close, G., & Murphy, R. (2017). The horseracing industry's perception of nutritional and weight-making practices of professional jockeys. *Qualitative Research in Sport, Exercise and Health*, *9*(5), 568–582.

Matthews, J. J., Stanhope, E. N., Godwin, M. S., Holmes, M. E. J., & Artioli, G. G. (2019). The magnitude of Rapid weight loss and Rapid Weight Gain in Combat Sport Athletes preparing for competition: A systematic review. *International Journal of Sport Nutrition and Exercise Metabolism*, *29*(4), 441–452. doi:10.1123/ijsnem.2018-0165

Maughan, R. J., McArthur, M., & Shirreffs, S. M. (1996). Influence of menstrual status on fluid replacement after exercise induced dehydration in healthy young women. *British Journal of Sports Medicine*, *30*(1), 41–47. doi:10.1136/bjsm.30.1.41

Maughan, R. J., & Shirreffs, S. M. (1997). Recovery from prolonged exercise: Restoration of water and electrolyte balance. *Journal of Sports Sciences*, *15*(3), 297–303. doi:10.1080/026404197367308

Melanson, E. L., Sharp, T. A., Seagle, H. M., Horton, T. J., Donahoo, W. T., Grunwald, G. K., … Hill, J. O. (2002). Effect of exercise intensity on 24-h energy expenditure and nutrient oxidation. *Journal of Applied Physiology (1985)*, *92*(3), 1045–1052. doi:10.1152/japplphysiol.00706.2001

Moore, D. R., Sygo, J., & Morton, J. P. (2021). Fuelling the female athlete: Carbohydrate and protein recommendations. *European Journal of Sport Science*, 1–13.

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

Mountjoy, M., Sundgot-Borgen, J. K., Burke, L. M., Ackerman, K. E., Blauwet, C., Constantini, N., … Budgett, R. (2018). IOC consensus statement on relative energy deficiency in sport (RED-S): 2018 update. *British Journal of Sports Medicine*, *52*(11), 687–697. doi:10.1136/bjsports-2018-099193

Nana, A., Slater, G. J., Hopkins, W. G., Halson, S. L., Martin, D. T., West, N. P., & Burke, L. M. (2016). Importance of standardized DXA protocol for assessing physique changes in athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *26*(3), 259–267. doi:10.1123/ijsnem.2013-0111

Nattiv, A., Loucks, A. B., Manore, M. M., Sanborn, C. F., Sundgot-Borgen, J., & Warren, M. P. (2007). American College of Sports Medicine position stand. The female athlete triad. *Medicine and Science in Sports and Exercise*, *39*(10), 1867–1882. doi:10.1249/mss.0b013e318149f111

Nathalie Boisseau & Laurie Isacco (2021). Substrate metabolism during exercise: Sexual dimorphism and women's specificities. *European Journal of Sport Science*. doi:10.1080/17461391.2021.1943713

Nolan, D., Lynch, A. E., & Egan, B. (2020). Self-Reported prevalence, magnitude, and methods of Rapid weight loss in male and female competitive powerlifters. *Journal of Strength and Conditioning Research*. doi:10.1519/jsc.0000000000003488

O'Driscoll, R., Turicchi, J., Beaulieu, K., Scott, S., Matu, J., Deighton, K., … Stubbs, J. (2018). How well do activity monitors estimate energy expenditure? A systematic review and meta-analysis of the validity of current technologies. *British Journal of Sports Medicine*. doi:10.1136/bjsports-2018-099643

Pettersson, S., Pipping Ekstrom, M., & Berg, C. M. (2012). The food and weight combat. A problematic fight for the elite combat sports athlete. *Appetite*, *59*(2), 234–242. doi:10.1016/j.appet.2012.05.007

Paola Rodriguez-Giustiniani, Nidia Rodriguez-Sanchez & Stuart D.R. Galloway. (2021). Fluid and electrolyte balance considerations for female athletes. *European Journal of Sport Science*. doi:10.1080/17461391.2021.1939428

Pivarnik, J. M., Marichal, C. J., Spillman, T., & Morrow, J. R., Jr (1992). Menstrual cycle phase affects temperature regulation during endurance exercise. *Journal of Applied Physiology (1985)*, *72*(2), 543–548. doi:10.1152/jappl.1992.72.2.543

Reale, R., Slater, G., & Burke, L. M. (2017a). Acute-Weight-Loss strategies for combat Sports and applications to Olympic success. *International Journal of Sports Physiology and Performance*, *12*(2), 142–151. doi:10.1123/ijspp.2016-0211

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. doi:10.1080/17461391.2017.1297489

Reale, R., Slater, G., & Burke, L. M. (2018a). Weight management practices of Australian Olympic combat Sport athletes. *International Journal of Sports Physiology and Performance*, *13*(4), 459–466. doi:10.1123/ijspp.2016-0553

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*, 1–9. doi:10.1123/ijsnem.2017-0183

Rodriguez-Giustiniani, P., & Galloway, S. D. R. (2019). Influence of peak menstrual cycle hormonal changes on restoration of fluid balance after induced dehydration. *International Journal of Sport Nutrition and Exercise Metabolism*, 1–7. doi:10.1123/ijsnem.2019-0105

Sanborn, C. F., Albrecht, B. H., & Wagner, W. W., Jr (1987). Athletic amenorrhea: Lack of association with body fat. *Medicine and Science in Sports and Exercise*, *19*(3), 207–212.

Sawka, M. N., Burke, L. M., Eichner, E. R., Maughan, R. J., Montain, S. J., & Stachenfeld, N. S. (2007). American College of Sports Medicine position stand. Exercise and fluid replacement. *Medicine and Science in Sports and Exercise*, *39*(2), 377–390. doi:10.1249/mss.0b013e31802ca597

Slater, G., Rice, A., Jenkins, D., & Hahn, A. (2014). Body mass management of lightweight rowers: Nutritional strategies and performance implications. *British Journal of Sports Medicine*, *48*(21), 1529–1533. doi:10.1136/bjsports-2014-093918

Slater, G. J., Rice, A. J., Sharpe, K., Mujika, I., Jenkins, D., & Hahn, A. G. (2005). Body-mass management of Australian lightweight rowers prior to and during competition. *Medicine and Science in Sports and Exercise*, *37*(5), 860–866. doi:10.1249/01.mss.0000162692.09091.7a

SportingLife. (2019). *Huge global audience for Randox Health Grand National*. Retrieved from https://www.sportinglife.com/racing/news/world-awaits-national/164789.

Stachenfeld, N. S. (2008). Sex hormone effects on body fluid regulation. *Exercise and Sport Sciences Reviews*, *36*(3), 152–159. doi:10.1097/JES.0b013e31817be928

Stachenfeld, N. S., & Taylor, H. S. (2009). Sex hormone effects on body fluid and sodium regulation in women with and without exercise-associated hyponatremia. *Journal of Applied Physiology (1985)*, *107*(3), 864–872. doi:10.1152/japplphysiol.91211.2008

Stellingwerff, T. (2018). Case study: Body composition periodization in an Olympic-level female middle-distance runner over a 9-year career. *International Journal of Sport Nutrition and Exercise Metabolism*, *28*(4), 428–433. doi:10.1123/ijsnem.2017-0312

Strock, N. C. A., Koltun, K. J., Southmayd, E. A., Williams, N. I., & De Souza, M. J. (2020). Indices of resting metabolic rate accurately reflect energy deficiency in exercising women. *International Journal of Sport Nutrition and Exercise Metabolism*, 1–11. doi:10.1123/ijsnem.2019-0199

Sundgot-Borgen, J., Meyer, N. L., Lohman, T. G., Ackland, T. R., Maughan, R. J., Stewart, A. D., & Muller, W. (2013). How to minimise the health risks to athletes who compete in weight-sensitive sports review and position statement on behalf of the Ad Hoc research working group on body composition, health and performance, under the auspices of the IOC Medical commission. *British Journal of Sports Medicine*, *47*(16), 1012–1022. doi:10.1136/bjsports-2013-092966

Williams, N. I., Koltun, K. J., Strock, N. C. A., & De Souza, M. J. (2019). Female athlete triad and relative energy deficiency in sport: A focus on scientific rigor. *Exercise and Sport Sciences Reviews*, *47*(4), 197–205. doi:10.1249/jes.0000000000000200

Wilson, G., Fraser, W. D., Sharma, A., Eubank, M., Drust, B., Morton, J. P., & Close, G. L. (2013). Markers of bone health, renal function, liver function, anthropometry and perception of mood: A comparison between flat and national hunt jockeys. *International Journal of Sports Medicine*, *34*(5), 453–459. doi:10.1055/s-0032-1321898

Wilson, G., Pritchard, P. P., Papageorgiou, C., Phillips, S., Kumar, P., Langan-Evans, C., … Close, G. L. (2015). Fasted exercise and increased dietary protein reduces body fat and improves strength in jockeys. *International Journal of Sports Medicine*, *36*(12), 1008–1014. doi:10.1055/s-0035-1549920