

# Relative Energy Deficiency in Sport in Male Athletes: A Commentary on Its Presentation Among Selected Groups of Male Athletes

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Low energy availability (LEA) is a key element of the Female Athlete Triad. Causes of LEA include failure to match high exercise energy expenditure (unintentional) or pathological behaviors of disordered eating (compulsive) and overzealous weight control programs (misguided but intentional). Recognition of such scenarios in male athletes contributed to the pronouncement of the more inclusive Relative Energy Deficiency in Sport (RED-S) syndrome. This commentary describes the insights and experience of the current group of authors around the apparently heightened risk of LEA in some populations of male athletes: road cyclists, rowers (lightweight and open weight), athletes in combat sports, distance runners, and jockeys. The frequency, duration, and magnitude of the LEA state appear to vary between populations. Common risk factors include cyclical management of challenging body mass and composition targets (including “making weight”) and the high energy cost of some training programs or events that is not easily matched by energy intake. However, additional factors such as food insecurity and lack of finances may also contribute to impaired nutrition in some populations. Collectively, these insights substantiate the concept of RED-S in male athletes and suggest that a specific understanding of a sport, subpopulation, or culture may identify a complex series of factors that can contribute to LEA and the type and severity of its outcomes. This commentary provides a perspective on the range of risk factors that should be addressed in future surveys of RED-S in athletic populations and targeted for specific investigation and modification.

**Keywords:** combat sports, East African distance runners, jockeys, road cyclists, rowers

Recognition of low energy availability (LEA) in male athletes, associated with a range of negative outcomes, played a role in the

framing of the Relative Energy Deficiency in Sport (RED-S) syndrome (Mountjoy et al., 2014). Indeed, a variety of scenarios have been investigated in which male athletes report dietary intakes that are unable to meet the energy costs of maintenance of health and well-being, as well as the expenditure associated with their training/event programs (Lombardi et al., 2012; Morton et al., 2010; Wilson et al., 2014a). The initial response to RED-S included criticism of the elevation of these scenarios to the same level of concern or management as afforded the Female Athlete Triad (De Souza et al., 2014). This was based on considerations of both the relative recentness of the investigations among male athletes and suggestions that physiological/biological differences

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between sexes may alter the type and severity of the sequelae of LEA in male populations (De Souza et al., 2014). It is also noted that females across all ages, cultures, and communities are more concerned than their male counterparts about body image and composition and are more likely to exhibit the major risk factor for LEA: a drive to reduce body mass/body fat (Loucks et al., 2011). More recent reviews, however, have confirmed that although LEA in male athletes may involve different or novel issues to those seen among their female counterparts, there is justification for concern and further investigation of the situation in male athlete cohorts (Tenforde et al., 2016). The current state of knowledge of resulting effects of LEA on endocrine changes and health outcomes in male athletes is provided elsewhere (Ackerman & Tenforde, 2018).

Typically, the factors underpinning LEA are considered to range from failure to meet the high energy costs of some training/competition programs (unintentional), to overzealous but often well-intentioned behaviors to control body mass or competition (misguided), and to disordered eating/eating disorders (compulsive) (Loucks, 2004; Mountjoy et al., 2014). Nevertheless, a suite of factors within the culture, regulation, and performance drivers of a sport/event may predispose an athlete to adopting eating and/or exercise patterns that result in LEA. The aim of this commentary is to summarize the experience and insights of the current group of authors about the unique risk factors and apparent outcomes of LEA in some specific populations of male athletes. It will explore the characteristics that may contribute systematic or predictable stressors resulting in a mismatch between energy intake and the energy cost of training or competition loads. This is not intended to

be a systematic or comprehensive summary of all male athletes who are at risk of LEA or who show symptoms associated with RED-S. Rather, this commentary is an opportunistic account of our lengthy history of sports nutrition research and practice with a specific range of elite male athletes who demonstrate an elevated risk of LEA. Our observations will be integrated with the current literature to summarize the unique issues underpinning LEA as well as the manifestations of RED-S in these populations (see Table 1). This may provoke interest in a more systematic investigation across a larger range of male athletes to identify factors that cause LEA and increase or attenuate its effects on health, function, and performance. A summary of some key areas that should be addressed, at least with the current athlete populations (Table 2), may help to drive these activities and to support a more systematic investigation. Understanding the complexity of the environment in which LEA occurs, both for male and female athletes, may allow strategies to be better targeted for prevention, early detection, and effective management of problems.

## RED-S in Male Road Cyclists

Road cyclists may have LEA resulting from the sustained high energy expenditure combined with the challenges of optimizing physique. Road cycling involves high volume training, long seasons with frequent racing (e.g., 60–80 days/year), and competitive events including single races of up to 6–8 hr and stage races such as the Grand Tours (Tour de France, Vuelta a España, and

**Table 1** What Is Known About LEA and RED-s in Some Specific Populations of Male Athletes

<p>General male athlete populations (Ackerman &amp; Tenforde, 2018; Tenforde et al., 2016)</p> <ul style="list-style-type: none"> <li>• Reduced sex hormone testosterone seen in subset of male athletes, particularly in endurance, lean sports or during periods of LEA.</li> <li>• Impaired skeletal health in male athletes with LEA including running or sports with reduced weight bearing, such as jockeys and cyclists.</li> <li>• Low body weight may be associated with low BMD particularly in adolescent male athletes.</li> <li>• Athletes with bone stress injuries in trabecular-rich site may be at higher risk for low BMD.</li> </ul>
<p>Cyclists (Barry &amp; Korht, 2008; Campion et al., 2010; Filaire et al., 2007; Yates et al., 2003)</p> <ul style="list-style-type: none"> <li>• Combination of high energy demands and impaired energy intake common in longer events, particularly stage races, may result in LEA.</li> <li>• Dietary behaviors contribute to LEA with goal to achieve high power output to low body mass.</li> <li>• LEA and DE/ED may contribute to impairments of mood, performance, and recovery.</li> <li>• Lower BMD particularly noted in lumbar spine of cyclists due to combination of LEA and low weight-bearing activity, including offloading of spine during aerodynamic riding positions.</li> </ul>
<p>Combat sports (Brugh et al., 2001; Dolan et al., 2012; Morton et al., 2010; Reale et al., 2018; Rouveix et al., 2007)</p> <ul style="list-style-type: none"> <li>• Weight classes of sport may result in dietary and weight loss strategies that contribute to LEA.</li> <li>• Short periods of weight cycling, a temporary LEA state, may not result in measurable long-term loss in BMD.</li> <li>• Weight cycling may contribute to cardiovascular disease, endocrine disruptions, and mood disorders.</li> </ul>
<p>Jockeys (Dolan et al., 2011; Wilson et al., 2013a, 2013b, 2014a, 2014b, 2015a)</p> <ul style="list-style-type: none"> <li>• Requirements for weight making are unique and potentially more extreme than in other “weight-restricted” sports, due to the low and changing weight targets and the low energy expenditure of riding.</li> <li>• LEA and DE/ED may contribute to low BMD, impaired mood, compromised strength, and impaired riding performance.</li> </ul>
<p>Rowers (Jurimae et al., 2003; Slater et al., 2005; Vinther et al., 2008; Woods et al., 2017)</p> <ul style="list-style-type: none"> <li>• Lightweight rowers may have greater demands than open weight class to maintain low body weight.</li> <li>• Demands on lightweight rowers to maintain low weight over time promotes long-term strategies of prolonged LEA.</li> <li>• Lightweight rowers may be at higher risk for low BMD, rib fractures, and lower testosterone.</li> <li>• Open weight rowers may experience reduced access to food during prolonged exercise reducing energy intake, high energy expenditure from sport and pressure to optimize power to mass ratio; degree of LEA is likely lower than weight class rowers.</li> </ul>
<p>East African distance runners (Fudge et al., 2006; Mooses et al., 2017; Onywera et al., 2004; Tam et al., 2018)</p> <ul style="list-style-type: none"> <li>• Chronic LEA state is common from combination of low energy intake combined with prolonged endurance running that often starts during youth.</li> <li>• Cultural eating practices (e.g., limited dietary range, focus on high-carbohydrate, vegetable-rich foods and sweet beverages) are ingrained, even when away from home environment, and may contribute to inadequate dietary intake.</li> <li>• Food insecurity, underpinned by lack of finances or sharing of resources with other family members, may also contribute to LEA.</li> <li>• Resulting LEA may contribute to low BMD in a large portion of runners.</li> </ul>

Note. BMD = bone mineral density; LEA = low energy availability; RED-S = Relative Energy Deficiency in Sport; DE/ED = disordered eating/eating disorders.

**Table 2 Areas for Further Research on RED-S in Male Athletes**

Population	Issue of interest
General populations of male athletes	<ul style="list-style-type: none"> <li>• Which endocrine systems are affected by LEA?</li> <li>• Are there individual susceptibilities to LEA?</li> <li>• What is the pattern of reduction in biological systems, which accompanies the reduction in EA; is there a threshold of EA below which most problems occur?</li> <li>• What other dietary factors (e.g., carbohydrate availability, vitamin D status, calcium intake) and nondietary factors (e.g., nonweight-bearing activity) contribute/ exacerbate the effect of LEA on bone health and other outcomes, particularly factors that can be manipulated to reduce the effect?</li> <li>• Can sport-specific guidelines for the threshold and duration of LEA that results in health and performance consequences be identified?</li> <li>• What strategies can be employed to correct LEA in athletes for health and performance?</li> </ul>
Cyclists	<ul style="list-style-type: none"> <li>• How do current elite cyclists periodize their body composition and EA over the season?</li> <li>• What is the acute and chronic effect on endocrine systems, metabolic rate, and other issues involved in RED-S?</li> <li>• What is the effect of a riding season on testosterone concentrations, and what are the consequences of low testosterone levels?</li> <li>• How well do elite cyclists manage EA during Grand Tours?</li> <li>• Are there separate effects of competition in Grand Tours or single-day classics on functional outcomes typically associated with LEA?</li> <li>• What is the true prevalence of low BMD among elite male cyclists? How much does LEA contribute to this?</li> <li>• Is there a pattern of LEA (level of energy mismatch and accumulation of period of exposure) that could be considered a threshold for major problems for balance against the benefits provided by low body mass on cycling economy?</li> </ul>
East African distance runners	<ul style="list-style-type: none"> <li>• What is the prevalence of RED-s components/risk factors in elite-level male East African distance runners?</li> <li>• Are there differences in the level of EA that is associated with negative health/performance effects in male and female distance runners from East Africa compared with White population?</li> <li>• Do cultural dietary practices of East African runners (e.g., energy spread, high intakes of fiber and vegetable food sources) contribute to, or protect against, functional outcomes associated with LEA?</li> <li>• How can EA be managed to optimize body mass/composition for running economy and performance while minimizing health effects?</li> <li>• How does chronic exposure to LEA during early childhood affects distance runners health and performance later in their career?</li> </ul>
Rowers	<ul style="list-style-type: none"> <li>• What is the prevalence of LEA in lightweight and open weight rowers, and how much can be attributed to weight management versus inadequate opportunity to meet very high energy expenditure?</li> <li>• What are the health and performance outcomes (bone density, injury, illness, and testosterone) of LEA in rowers?</li> <li>• Do the functional outcomes of LEA in rowers differ in terms of type or severity between weight classes, depending on the underlying cause?</li> </ul>
Combat athletes	<ul style="list-style-type: none"> <li>• What is the typical energy intake, energy expenditure, and EA in specific combat sports?</li> <li>• What combat sports are especially sensitive to symptoms of RED-S? Are there differences between striking and grappling combat sports?</li> <li>• What is the impact of a single training camp and multiple training camps (i.e., making weight several times per year) on symptoms of RED-S, for example, RMR, endocrine and immune function?</li> <li>• How does LEA during making weight affect combat sport-specific performance indices?</li> <li>• Can carefully scheduled periods (e.g., 4–7 days) of “refeeding” and/or reduced “training load” to restore EA during an 8- to 12-week training camp reduce RED-S symptoms while still allowing the athlete to make weight?</li> <li>• How does LEA affect symptoms of RED-S in adolescent combat athletes who also repeatedly make weight?</li> <li>• Do transient periods of LEA during weight cycling (considering a professional boxer may have 40–50 contests) manifest as negative RED-S consequences in retired combat athletes?</li> </ul>
Jockeys	<ul style="list-style-type: none"> <li>• Are the low BMD scores in jockeys indicative of poor bone health or simply representative of a population with extremely low body mass? Following the collection of bone tissue during routine surgery (common with jockeys post fracture), do jockeys with low DXA BMD also present with clinical signs of osteoporosis?</li> <li>• How much are low BMD values in jockeys a consequence of a lack of weight-bearing exercise (and estrogenic stimulus) during adolescence versus poor nutrition?</li> <li>• How dehydrated are jockeys on race day?</li> <li>• Do jockeys display abnormal hormonal profiles on race days?</li> <li>• Does the daily sweating in saunas result in increased sweat calcium excretion, which may contribute to impaired bone health?</li> <li>• Would increasing the minimum riding weights improve the physical and mental health markers in jockeys?</li> <li>• Would daily load-bearing exercise (i.e., skipping) correct or prevent low BMD?</li> </ul>

*Note.* BMD = bone mineral density; LEA = low energy availability; DXA = dual-energy X-ray absorptiometry; RED-S = Relative Energy Deficiency in Sport; RMR = resting metabolic rate; EA = energy availability.



situations, muscle mass may be lost by accident throughout the training camp period (Morton et al., 2010); however, other athletes may achieve it intentionally due to the belief it will translate to more rapid and explosive actions. A range of health and performance issues are associated with acute weight-making practices in these sports (Reale et al., 2017b).

In contrast to endurance sports that may cause chronic LEA, short periods of LEA may not result in a loss of BMD. Combat athletes practice transient periods of “weight cycling,” two to six times a year, to achieve their perceived “optimal” weight for a specific competition. A case study of a professional boxer assessed daily EA at <5 kcal/kg fat-free mass while he trained three times per day (e.g., fasted morning run, mid-morning boxing-specific session, and an evening track run or strength and condition session). This pattern continued over a 12-week period during which he lost 9.4 kg, which was assessed via dual-energy X-ray absorptiometry to include 3 kg of lean tissue (Morton et al., 2010). However, simultaneous assessment of whole-body bone density showed Z scores >2.5. In addition, one study in amateur boxers found greater BMD in hip and lumbar spine when compared with age-matched recreationally active individuals and a cohort of professional jockeys (Dolan et al., 2012). Bone density within normal range was also reported in a population of elite judoists (Prouteau et al., 2006). One possible explanation is that the negative effects of transient periods of weight cycling (i.e., multiple training camps per year) on bone health may be offset by the high osteogenic stimulus of habitual training activities (e.g., professional boxers may run 5–10 km on 5–6 days/week) and typical pattern of rapid weight gain within 7–10 days of postcontest. RED-S may also likely to be more prevalent among professional athletes who are not as closely monitored by the sport science institutes of national governing bodies that support their amateur athletes in preparation for Olympic events (Morton, unpublished data, July 2018).

Although the effects of weight making on bone health may not be as pronounced as other sports with LEA state, other health consequences may result from shorter bouts of LEA. The magnitude and time course of weight loss experienced by combat athletes are often similar to those reported in military personnel during simulated expeditions (Friedl et al., 2000; Nindl et al., 1997) during which severe reductions in testosterone are observed concomitant with hypercholesterolemia and elevated triglycerides. In unpublished observations on professional boxers and mixed martial arts athletes, we previously observed reductions in resting metabolic rate (RMR, ranging from 200 to 350 kcal/day) during the course of an 8-week training camp where absolute testosterone concentrations decreased to <5 nmol/L in the final 3 days prior to competition (Morton, unpublished data). Such fluctuations in hormonal regulation, resting metabolic rate, and potential periods of hyperphagia and binge eating in the weeks after competition (Dulloo, 1997; Dulloo et al., 2017) may also contribute to the enhanced prevalence of obesity among retired weight-cycling athletes when compared with nonweight-cycling athletes and age-matched nonathletic individuals (Saarni et al., 2006). Studies of combat athletes report a high prevalence of disordered eating and eating disorders associated with their weight-making practices (Brugh et al., 2001; Rouveix et al., 2007). Testimonials from combat athletes who exhibit extreme depression and suicidal thoughts upon retirement also cite excessive weight gain as a contributing factor (Hatton, 2013). When taken together, combat athletes appear at risk for LEA and resulting RED-S including cardiovascular disease, endocrine disruptions, and impaired mental health.

## RED-S in Jockeys in Horse Racing

The weight-making challenges faced by male jockeys are greater than for any other sport and place them at high risk for chronic LEA state (Wilson et al., 2014b). During the horse racing season, which with the advent of all-weather race tracks now lasts for 52 weeks of the year depending on the region, jockeys may ride in 4–8 race meets/week, with 4–10 rides/day. Indeed, some jockeys have ridden in more than 1,200 rides in a calendar, with weight making required for each race. Jockeys are required to weigh-in before every race, with some needing to meet different targets for each race on the day’s program. Unlike other weight-making sports, jockeys are not permitted to fully refuel or rehydrate after the prerace weigh-in, as postrace body mass may be rechecked and must remain within 1 kg of their prerace value (Wilson et al., 2014a). Riding weights are allocated on a handicap basis, with the minimum weight being 49.9–52 kg for flat racing and 57.0–63.5 kg for jump racing (Wilson et al., 2014a). Notably, weight classifications were established hundreds of years ago, without sports science insights, and have not changed significantly over time. As the height of jockeys has continued to increase along with secular trends in the population but weight limits have remained constant, it is now common for jockeys to present on race day with a BMI of <18 kg/m<sup>2</sup> (Wilson et al., 2013b). Management of physique is also made difficult due to the low energy expenditure required for sport. With caloric requirement of race riding being estimated between 50 and 75 kcal/race (Wilson et al., 2012) and a low lean body mass (typically 45 kg), a jockey’s total daily energy expenditure may be as low as 2,000 kcal/day (Wilson et al., 2018).

Prior reports suggest that jockeys have tended to rely on peers to obtain weight-making advice (Dolan et al., 2011; Wilson et al., 2013b) and often resort to practices that may compromise health. Common methods to make weight include food restriction, prolonged sweating, and even forced vomiting, known in the horse-racing industry as “flipping” (Dolan et al., 2011; Wilson et al., 2014b). Jockeys typically consume inadequate diets (Dolan et al., 2011; Poon et al., 2018; Wilson et al., 2012, 2013a, 2013b, 2015a) with daily EA as low as <20 kcal/kg lean mass (Wilson et al., 2014a), making them a particularly high risk for RED-S. Total energy intake derived from 7-day food diaries has been reported at <1,500 kcal/day during a typical race-riding week, substantially less than total energy expenditure (Wilson et al., 2013a), with daily carbohydrate intake <3 g/kg body mass. Further analysis of food diaries has suggested that many jockeys only consume one meal per day with the rest of their energy intake coming from convenience snacks. Jockeys present with particularly low vitamin D concentrations (Close et al., 2013) and inadequate intakes of micronutrients, including calcium (Waldron-Lynch et al., 2010). Although these findings are plausible based on the known environment around weight making in the horse racing industry, our knowledge of the prevalence and degree of LEA in jockeys has been largely based on self-reported food diaries, which are known to contain errors of underreporting (Lundy, 2006; Poslusna et al., 2009). Indeed, one study in Irish apprentice jockeys used cameras to record food intake (O’Loughlin et al., 2013) and found significantly higher energy intakes than documented from self-reported food diaries.

Resulting disordered eating behaviors, combined with LEA, have been shown to contribute to a number of RED-S health consequences in jockeys; these include low BMD (Waldron-Lynch et al., 2010; Wilson et al., 2015a), impaired mood profiles (Wilson et al., 2012, 2013a, 2015b), and compromised strength and

race-riding performance (Wilson et al., 2014b). Skeletal health may be unnecessarily compromised by the avoidance of weight-bearing exercise by many jockeys, due to their fears that it may increase muscle mass (Martin et al., 2017). Low BMD in this population has been documented (Wilson et al., 2015a) alongside elevated markers of bone resorption and bone turnover compared with healthy controls (Waldron-Lynch et al., 2010; Wilson et al., 2013a). Impaired skeletal health is of particular concern, as jockeys fall from a horse, on average, once per 12 rides (two to three times per week); fractures are common given the speed of movement (>33 km/hr). To date, only one study has reported impaired markers of endocrine function in jockeys (Dolan et al., 2012); here, sex hormone-binding globulin and insulin-like growth factor 1 were increased, and bioavailable testosterone was lower in jockeys compared with controls. It is noted, however, that most blood samples were collected on nonriding days when a jockey is not actively making weight, and this may distort results. Despite limited studies describing endocrine function, eating behaviors, low BMD, and other health issues identified in jockeys suggest that this population is at risk for impaired health resulting from RED-S.

### RED-S in Rowers

Lightweight male rowers share challenges and characteristics similar to many weight-category sports that place them at high risk for LEA. A notable difference from other weight division sports is that there are only two weight categories for rowing. In practical terms, this may result in a large number of individuals who are neither big enough to be competitive in open weight events nor small enough to naturally achieve the weight limit for light weight racing. For example, the typical open weight rower (90–95 kg, 190–195 cm; Lundy, unpublished data) has major performance advantages over an 80 kg, 185 cm male rower, due to greater power and strength characteristics, as well as the biomechanical advantages of longer limbs and torso (Kerr et al., 2007; Slater et al., 2005). However, this latter rower is clearly larger than the average weight limit for a lightweight male (70 kg). A large gap is also seen between the typical open weight female rower (75–80 kg, height > 180 cm) and the average weight limit for females of 57 kg (Kerr et al., 2007; Lundy, unpublished data). As there is evidence of a correlation between performance and lean mass among lightweight rowers (Slater et al., 2005), it is understandable that the sport is dominated by athletes who are naturally heavier than their weigh-in target and rely on weight management for competition qualification. Important strategies for managing these athletes include early advice around phenotype suitability to row as a lightweight, as well as ongoing monitoring and support to achieve weight goals in a safe fashion.

Male lightweight rowers have been shown to have lower testosterone (Vinther et al., 2008), lower BMD, and increased risk of rib stress fracture (Vinther et al., 2006) relative to their open weight counterparts, potentially reflecting the imposition of energy restriction associated with weight manipulation strategies. In contrast to the rules and culture of most weight-category sports that promote greater reliance on acute dehydration strategies to temporarily achieve competition weigh-in targets (Reale et al., 2017a), elements of “weight making” in lightweight rowing may favor a more long-term approach to achieving body mass goals through chronic energy restriction. These features include the need to achieve the weigh-in target on each day of competition (up to 5 days in the case of international regattas), which discourages the practice of repetitive dehydration. In addition, some country sports bodies have set up systems of “sliding scale” targets in which

rowers can compete “above weight” in prognostic tests or events in the early part of the season while gradually achieving the real weigh-in target important events and international competition. Such practices may assist with a safer approach to avoid rapid weight manipulation. However, lightweight rowers may accumulate longer periods of LEA spanning a season or sporting career, exposing athletes to health consequences from prolonged LEA.

The potential for RED-S in open weight male rowers has only recently been recognized. Indeed, their physique characteristics of large total (~90 kg) and fat-free (~80–85 kg) mass (Lundy, unpublished data) were initially seen as a protective element against LEA, as it signaled a lack of risk for deliberate weight loss activities or disordered eating. However, the training programs of high-level rowers include ~6 hr/day of high energy cost activity for the majority of the year. This may include two rowing sessions, over a total 35–40 km, and a cross training session, of either strength and conditioning or ergometer training. Whereas endurance athletes who undertake similarly high training volumes (e.g., distance runners or cyclists) almost always have low body mass and lean tissue, the energy cost in rowing is elevated by the combination of training load, body size, and muscularity. In addition, the long training hours (the first daily session starting at sunrise and the final session being completed at sunset) can present a practical challenge to achieving sufficient energy intake.

Opportunities for rowers to consume energy and the preferred food choices are necessarily influenced by the time of the sessions, the duration of the break in between, and the type of session to be completed. Training sessions of high intensity also limit the range and volume of food that may be comfortably consumed. The morning session is usually the longest, and athletes may prioritize sleep over digestion time, which can limit the volume of food it is possible to consume pre-session. Food or drink can be consumed on the water, but only during the short breaks in training, and is further limited in type by the need to avoid contamination with dirt and water in the bottom of the boat. Rowers may manage to meet energy needs in lower training periods but fail to sufficiently increase intake during intensive training blocks with resulting negative metabolic and performance outcomes (Woods et al., 2017). This finding is supported by earlier research suggesting endocrine perturbations in response to intensive training periods (Jurimae et al., 2003; Jurimae, 2003; Vervoorn et al., 1991). Finally, although open weight rowing is not strictly a weight-sensitive sport, many coaches believe that a higher mass within the shell may cause the boat to sit lower in the water and negatively influence the hydrodynamics. Therefore, although it is unlikely to be the most common cause of LEA, a coach’s wish to reduce weight/increase power to weight according to the boat class and seating position in the boat may see some male rowers undertaking energy restriction to reduce weight or body fat.

### East African Distance Runners

Elite-level East African runners have dominated international running events for decades, with their superior running economy and performance often being attributed, based on limited evidence, to specific anthropometric features and body composition (Mooses & Hackney, 2017). Although very low BMI, body mass, and body fat levels may have a positive effect on running economy, these characteristics are associated with an increased risk of RED-S conditions (Mooses & Hackney, 2017); indeed, East African runners are at high risk for LEA due to combination of high exercise energy expenditure and inadequate energy intake.



BMD) are similar to that found in the more established literature on North American White populations, it seems likely that different factors will contribute to these problems (e.g., food insecurity, differences in the hierarchical value placed on Western concepts of sports nutrition and culturally derived patterns of food choice and distribution over the day). Therefore, different solutions to prevention and management of the problem are needed.

Future research should investigate both the factors that contribute to an energy mismatch in male athletes, as well as the effects of LEA on their health and performance. Table 2 provides a summary of key questions that should be addressed in the current populations of male athletes as well as others who may be exposed to individual- and sports-specific risk factors.

## Conclusion

In summary, systematic research addressing the prevalence and causes of LEA, and strategies to improve health outcomes of male athletes suffering from RED-S should be a high priority for the sports medicine community. Although the issues may be different in males to those of their female counterparts, there is mounting evidence that RED-S is prevalent and problematic in a range of sports. The insights gained from this commentary (summarized in Tables 1 and 2) include the importance of understanding the unique and specific factors that occur within sports, events and subpopulations, as well as the need to strategically target information on how the outcomes affect athlete health and performance.

## References

- Ackerman, K., & Tenforde, A. (2018). Endocrine review. *International Journal of Sport Nutrition and Exercise Metabolism*. Manuscript in preparation.
- Alderman, B., Landers, D.M., Carlson, J., & Scott, J.R. (2004). Factors related to rapid weight loss practices among international-style wrestlers. *Medicine & Science in Sports & Exercise*, 36(2), 249–252. PubMed ID: 14767247 doi:10.1249/01.MSS.0000113668.03443.66
- Areta, J.L., Burke, L.M., Camera, D.M., West, D.W., Crawshaw, S., Moore, D.R., . . . Coffey, V.G. (2014). Reduced resting skeletal muscle protein synthesis is rescued by resistance exercise and protein ingestion following short-term energy deficit. *American Journal of Physiology: Endocrinology and Metabolism*, 306(8), E989–E997. PubMed ID: 24595305
- Armstrong, L. (2000). *It's not about the bike: My journey back to life* (p. 224). Sydney, Australia: Allen & Unwin.
- Barrack, M.T., Fredericson, M., Tenforde, A.S., & Nattiv, A. (2017). Evidence of a cumulative effect for risk factors predicting lower bone mass among male adolescent athletes. *British Journal of Sports Medicine*, 51, 200–205. PubMed ID: 29461218 doi:10.1136/bjsports-2016-096698
- Barrack, M.T., Rauh, M.J., & Nichols, J.F. (2008). Prevalence of and traits associated with low BMD among female adolescent runners. *Medicine & Science in Sports & Exercise*, 40(12), 2015–2021. PubMed ID: 18981950 doi:10.1249/MSS.0b013e3181822ea0
- Barry, D.W., & Kohrt, W.M. (2008). BMD decreases over the course of a year in competitive male cyclists. *Journal of Bone and Mineral Research*, 23, 484–491. PubMed ID: 18072875 doi:10.1359/jbmr.071203
- Beis, L.Y., Willkomm, L., Ross, R., Bekele, Z., Wolde, B., Fudge, B., & Pitsiladis, Y.P. (2011). Food and macronutrient intake of elite Ethiopian distance runners. *Journal of the International Society of Sports Nutrition*, 8, 7. PubMed ID: 21595961 doi:10.1186/1550-2783-8-7
- Boardman, C. (2000). *The complete book of cycling* (pp. 45–46). London, UK: Partridge.
- Brugh, D.D., Williford, J.H., Chibucos, T.R., & Shewokis, P.A. (2001). The frequency of eating disorder tendencies among male high school wrestlers, non wrestler athletes, and nonathletes. *Journal of the American Dietetic Association*, 101(9), A86. doi:10.1016/S0002-8223(01)80294-7
- Burke, L.M., Melin, A., Fahrenholtz, I., & Lundy, B. (2018). Pitfalls and problems with measuring energy availability. *International Journal of Sport Nutrition and Exercise Metabolism*. Manuscript in preparation.
- Campion, F., Nevill, A.M., Karlsson, M.K., Lounana, J., Shabani, M., Fardellone, P., & Medelli, J. (2010). Bone status in professional cyclists. *International Journal of Sports Medicine*, 31(7), 511–515. PubMed ID: 20432201 doi:10.1055/s-0029-1243616
- Christensen, D.L., Van Hall, G., & Hambraeus, L. (2002). Food and macronutrient intake of male adolescent Kalenjin runners in Kenya. *The British Journal of Nutrition*, 88(6), 711–717. PubMed ID: 12493093 doi:10.1079/BJN2002728
- Close, G.L., Russell, J., Cobley, J.N., Owens, D.J., Wilson, G., Gregson, W., . . . Morton, J.P. (2013). Assessment of vitamin D concentration in non-supplemented professional athletes and healthy adults during the winter months in the UK: Implications for skeletal muscle function. *Journal of Sports Sciences*, 31(4), 344–353. PubMed ID: 23083379 doi:10.1080/02640414.2012.733822
- Crighton, B., Close, G.L., & Morton, J.P. (2016). Alarming weight cutting behaviours in mixed martial arts: A cause for concern and a call for action. *British Journal of Sports Medicine*, 50(8), 446–447. PubMed ID: 26459278 doi:10.1136/bjsports-2015-094732
- 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. PubMed ID: 27564844 doi:10.1080/00913847.2016.1228421
- 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. PubMed ID: 27419116 doi:10.12965/jer.1632610.305
- De Souza, M.J., Nattiv, A., Joy, E., Misra, M., Williams, N.I., Mallinson, R.J., . . . American Bone Health Alliance. (2014). 2014 Female Athlete Triad Coalition consensus statement on treatment and return to play of the female athlete triad: 1st International Conference held in San Francisco, CA, May 2012, and 2nd International Conference held in Indianapolis, IN, May 2013. *Clinical Journal of Sport Medicine*, 24(2), 96–119. PubMed ID: 24569429 doi:10.1097/JSM.0000000000000085
- De Sousa, M.V., Pereira, R.M., Fukui, R., Caparbo, V.F., & da Silva, M.E. (2014). Carbohydrate beverages attenuate bone resorption markers in elite runners. *Metabolism: Clinical and Experimental*, 63(12), 1536–1541. doi:10.1016/j.metabol.2014.08.011
- Dolan, E., Crabtree, N., McGoldrick, A., Ashley, D.T., McCaffrey, N., & Warrington, G.D. (2012). Weight regulation and bone mass: A comparison between professional jockeys, elite amateur boxers, and age, gender and BMI matched controls. *Journal of Bone and Mineral Metabolism*, 30(2), 164–170. PubMed ID: 21773703 doi:10.1007/s00774-011-0297-1
- 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. PubMed ID: 21506039 doi:10.1080/02640414.2011.560173





- Australian Journal of Science and Medicine in Sport*, 27(2), 29–33. PubMed ID: [8521030](#)
- Olmedillas, H., Gonzalez-Aguero, A., Moreno, L.A., Casajus, J.A., & Vicente-Rodriguez, G. (2012). Cycling and bone health: A systematic review. *BMC Medicine*, 10, 168. PubMed ID: [23256921](#) doi:[10.1186/1741-7015-10-168](#)
- O'Loughlin, G., Cullen, S.J., McGoldrick, A., O'Connor, S., Blain, R., O'Malley, S., & Warrington, G.D. (2013). Using a wearable camera to increase the accuracy of dietary analysis. *American Journal of Preventive Medicine*, 44(3), 297–301. doi:[10.1016/j.amepre.2012.11.007](#)
- Onywera, V.O., Kiplamai, F.K., Boit, M.K., & Pitsiladis, Y.P. (2004). Food and macronutrient intake of elite Kenyan distance runners. *International Journal of Sport Nutrition and Exercise Metabolism*, 14(6), 709–719. PubMed ID: [15657475](#) doi:[10.1123/ijsnem.14.6.709](#)
- Onywera, V.O., Scott, R.A., Boit, M.K., & Pitsiladis, Y.P. (2006). Demographic characteristics of elite Kenyan endurance runners. *Journal of Sports Sciences*, 24(4), 415–422. PubMed ID: [16492605](#) doi:[10.1080/02640410500189033](#)
- Pollock, N., & Hamilton, B. (2008). Osteoporotic fracture in an elite male Kenyan athlete. *British Journal of Sports Medicine*, 42(12), 1000–1001. PubMed ID: [18048427](#) doi:[10.1136/bjism.2007.039818](#)
- Poon, E.T., O'Reilly, J., Sheridan, S., Cai, M.M., & Wong, S.H. (2018). Markers of bone health, bone-specific physical activities, nutritional intake and quality of life of professional jockeys in Hong Kong. *International Journal of Sport Nutrition and Exercise Metabolism*, 28(4). doi:[10.1123/ijsnem.2016-0176](#)
- Poslusna, K., Ruprich, J., de Vries, J.H., Jakubikova, M., & van't Veer, P. (2009). Misreporting of energy and micronutrient intake estimated by food records and 24 hour recalls, control and adjustment methods in practice. *The British Journal of Nutrition*, 101(Suppl. 2), S73–S85. doi:[10.1017/S0007114509990602](#)
- Prouteau, S., Pelle, A., Collomp, K., Benhamou, L., & Courteix, D. (2006). Bone density in elite judoists and effects of weight cycling on bone metabolic balance. *Medicine & Science in Sports & Exercise*, 38(4), 694–700. PubMed ID: [16679985](#) doi:[10.1249/01.mss.0000210207.55941.fb](#)
- Reale, R., Cox, G.R., Slater, G., & Burke, L.M. (2016). Regain in body mass after weigh-in is linked to success in real life judo competition. *International Journal of Sport Nutrition and Exercise Metabolism*, 26(6), 525–530. PubMed ID: [27206272](#) doi:[10.1123/ijsnem.2015-0359](#)
- Reale, R., Cox, G.R., Slater, G., & Burke, L.M. (2017a). Weight regain: No link to success in a real-life multiday boxing tournament. *International Journal of Sports Physiology and Performance*, 12(7), 856–863. doi:[10.1123/ijsp.2016-0311](#)
- 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 Sports Sciences*, 17(6), 727–740. doi:[10.1080/17461391.2017.1297489](#)
- Reale, R., Slater, G., & Burke, L.M. (2018). Weight management practices of Australian Olympic combat sport athletes. *International Journal of Sports Physiology and Performance*, 13(4), 459–466. PubMed ID: [28872383](#) doi:[10.1123/ijsp.2016-0553](#)
- Rector, R.S., Rogers, R., Ruebel, M., & Hinton, P.S. (2008). Participation in road cycling vs running is associated with lower bone mineral density in men. *Metabolism: Clinical and Experimental*, 57(2), 226–232. doi:[10.1016/j.metabol.2007.09.005](#)
- Rouveix, M., Bouget, M., Pannafieux, C., Champely, S., & Filaire, E. (2007). Eating attitudes body esteem, perfectionism and anxiety of judo athletes and nonathletes. *International Journal of Sports Medicine*, 28, 340–345. PubMed ID: [17024652](#) doi:[10.1055/s-2006-924334](#)
- Saarni, S.E., Rissanen, A., Sarna, S., Koskenvuo, M., & Kaprio, J. (2006). Weight cycling of athletes and subsequent weight gain in middleage. *International Journal of Obesity*, 30(11), 1639–1644. PubMed ID: [16568134](#) doi:[10.1038/sj.ijo.0803325](#)
- Saris, W.H., van Erp-Baart, M.A., Brouns, F., Westerterp, K.R., & ten Hoor, F. (1989). Study on food intake and energy expenditure during extreme sustained exercise: The Tour de France. *International Journal of Sports Medicine*, 10(Suppl. 1), S26–S31. doi:[10.1055/s-2007-1024951](#)
- Scott, R.A., Georgiades, E., Wilson, R.H., Goodwin, W.H., Wolde, B., & Pitsiladis, Y.P. (2003). Demographic characteristics of elite Ethiopian endurance runners. *Medicine & Science in Sports & Exercise*, 35(10), 1727–1732. PubMed ID: [14523311](#) doi:[10.1249/01.MSS.0000089335.85254.89](#)
- Slater, G.J., Rice, A.J., Mujika, I., Hahn, A.G., Sharpe, K., & Jenkins, D.G. (2005). Physique traits of lightweight rowers and their relationship to competitive success. *British Journal of Sports Medicine*, 39(10), 736–741. PubMed ID: [16183770](#) doi:[10.1136/bjism.2004.015990](#)
- Stellingwerf, 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). doi:[10.1123/ijsnem.2017-0312](#)
- Tam, N., Santos-Concejero, J., Tucker, R., Lamberts, R.P., & Micklesfield, L.K. (2018). Bone health in elite Kenyan runners. *Journal of Sports Sciences*, 36(4), 456–461. PubMed ID: [28406358](#) doi:[10.1080/02640414.2017.1313998](#)
- Tanser, T. (1997). *Train hard, win easy: The Kenyan way*. Mountain View, CA: Track & Field News.
- Tenforde, A.S., Barrack, M.T., Nattiv, A., & Fredericson, M. (2016). Parallels with the female athlete triad in male athletes. *Sports Medicine*, 46(2), 171–182. PubMed ID: [26497148](#) doi:[10.1007/s40279-015-0411-y](#)
- Tenforde, A.S., Fredericson, M., Sayres, L.C., Cutti, P., & Sainani, K.L. (2015). Identifying sex-specific risk factors for low BMD in adolescent runners. *American Journal of Sports Medicine*, 43, 1494–1504. PubMed ID: [25748470](#) doi:[10.1177/0363546515572142](#)
- Tenforde, A.S., Parziale, A.L., Popp, K.L., & Ackerman, K.E. (2018). Low bone mineral density in male athletes is associated with bone stress injuries at anatomic sites with greater trabecular composition. *The American Journal of Sports Medicine*, 46(1), 30–36. PubMed ID: [28985103](#) doi:[10.1177/0363546517730584](#)
- Tucker, R., Onywera, V.O., & Santos-Concejero, J. (2015). Analysis of the Kenyan distance-running phenomenon. *International Journal of Sports Physiology and Performance*, 10(3), 285–291. PubMed ID: [25115138](#) doi:[10.1123/ijsp.2014-0247](#)
- Vervoorn, C., Quist, A.M., Vermulst, L.J., Erich, W.B., de Vries, W.R., & Thijssen, J.H. (1991). The behaviour of the plasma free testosterone/cortisol ratio during a season of elite rowing training. *International Journal of Sports Medicine*, 12(3), 257–263. PubMed ID: [1889932](#) doi:[10.1055/s-2007-1024677](#)
- Viner, R.T., Harris, M., Berning, J.R., & Meyer, N.L. (2015). Energy availability and dietary patterns of adult male and female competitive cyclists with lower than expected bone mineral density. *International Journal of Sport Nutrition and Exercise Metabolism*, 25(6), 594–602. PubMed ID: [26131616](#) doi:[10.1123/ijsnem.2015-0073](#)
- Vinther, A., Kanstrup, I.L., Christiansen, E., Alkjaer, T., Larsson, B., Magnusson, S.P., . . . Aagaard, P. (2006). Exercise-induced rib stress fractures: Potential risk factors related to thoracic muscle co-contraction and movement pattern. *Scandinavian Journal of*

