

Relative Energy Deficiency in Sport: The Tip of an Iceberg

Margo L. Mountjoy

McMaster University and IOC Medical Commission Games Group

Louise M. Burke

Australian Institute of Sport and Mary MacKillop Institute for Health Research

Trent Stellingwerff

Canadian Sport Institute Pacific

Jorunn Sundgot-Borgen

Norwegian School of Sport Sciences

“I solved the problem. All they have to do is put on the side of the helmet, ‘The Surgeon General has determined that playing football is hazardous to your health’” stated Dr. Bennet Omalu, played by Will Smith, in the movie (*Concussion* 2015). Sport-related concussions receive much attention from the scientific and sports communities; and rightly so, given the impact on athlete health. But what about the issue of relative energy deficiency in sport (RED-S)? Does RED-S also need a dramatic event or a Hollywood ambassador to draw attention to the hidden danger it poses to an athlete’s health and performance? A recent survey of the summer Olympic International Sports Federations (IFs) showed that, although athlete health is an important priority for IFs, only two out of 27 IFs reported having activities (e.g., programs, guidelines, research) related to RED-S (Mountjoy et al., 2018a). This finding is in stark contrast to the recognition that 44% ($n = 12/27$) of the same IFs have sport-specific return-to-play concussion guidelines (Mountjoy et al., 2018a). The problems associated with RED-S resemble an iceberg: its true magnitude is largely hidden, and its devastating impact is likely underestimated. What will be the “Titanic” that illustrates the true submerged and underestimated danger of RED-S? Much more needs to be done to increase awareness of the importance of RED-S for health and performance of both female and male athletes and to catalyze the implementation of prevention and treatment programs from IFs all the way down to grassroots sports.

The term “RED-S” was coined by the International Olympic Committee in 2014 (Mountjoy et al., 2014), expanding the female athlete triad model to recognize that low energy availability (LEA), which underpins both the triad and RED-S, affects (a) both female

and male athletes, (b) individuals who do not identify as athletes, such as performing artists, and (c) numerous health and performance parameters in addition to the bone health and menstrual dysfunction depicted in the triad model (Mountjoy et al., 2014, 2015). The authors have reconvened to provide an updated consensus of RED-S, which features in this edition. This article outlines the interim scientific evidence on the illness/injury and performance impacts of LEA (Mountjoy et al., 2018b).

Since the publication of the original International Olympic Committee consensus paper, we have learned much more about the far-reaching prevalence and the health and performance implications of LEA in both male and female athletes. Ackerman et al. (2018b) recently outlined the prevalence of RED-S in a cohort of 1,000 athletes attending a sports medicine clinic. This descriptive clinical- and questionnaire-based study identified associations between surrogates of LEA and the health and performance factors depicted in the RED-S models. The health parameters significantly associated with LEA included poor bone health, metabolic abnormalities, menstrual dysfunction, hematological detriments, gastrointestinal dysfunction, and cardiovascular deficits. The psychobiological and performance factors significantly correlated with LEA included impairments to judgment, mood, concentration, coordination, training response, and endurance performance and an increase in irritability (Ackerman et al., 2018a). To date, there have been no publications investigating the prevalence of RED-S in team sports. Could it be that RED-S will eventually be found to affect a greater number and range of athletes than concussion?

Health and Performance Impacts of RED-S

This edition features a number of papers that highlight the health and performance concerns associated with RED-S. For example, a study of elite distance athletes by Heikura et al. (2018) shows that markers of LEA are associated with a 4.5× greater rate of bone injuries. Elliott-Sale et al. (2018) review the endocrine hormone markers of RED-S, which will serve as a useful reference for sport clinicians. To provide a clinical application of the science, Robertson and Mountjoy (2018) have prepared a review paper on RED-S in artistic (synchronized) swimming.

Mountjoy is with the Dept. of Family Medicine, Michael G. DeGroot School of Medicine, McMaster University, Hamilton, ON, Canada; and IOC Medical Commission—Games Group, Lausanne, Switzerland. Burke is with Sports Nutrition, Australian Institute of Sport, Belconnen, Australia; and Centre for Exercise and Nutrition, Mary MacKillop Institute for Health Research, Melbourne, Australia. Stellingwerff is with the Canadian Sport Institute Pacific, Victoria, British Columbia, Canada. Sundgot-Borgen is with the Dept. of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway. Address author correspondence to Margo L. Mountjoy at mmsportdoc@mcmaster.ca.

Male Athletes

Since the science underpinning RED-S has been developed from the pivotal work on females by Prof. Barbara Drinkwater (1972) and Prof. Anne Loucks (2004), the breadth and depth of information around RED-S in male athletes is understandably less robust, given the relatively shorter time of research attention. Nonetheless, in recent years, there has been an increase in interest in studying LEA in the male athlete. In this edition, Burke et al. (2018b) have contributed a review outlining current knowledge of the hormonal changes and issues around RED-S in male athletes and an interesting insight from examining the factors underpinning the causes and outcomes of LEA in several different populations of male athletes: that we must recognize new and unique risk factors across different sports, cultures, and subpopulations of male athletes. In addition, there is original research on RED-S in male jockeys (Wilson et al., 2018; Poon et al., 2018) and bodybuilders (Fagerberg et al., 2018). Torstveit et al. (2018) also show that poor within-day energy balance can have deleterious outcomes on health variables in male endurance athletes.

A Peek at the Future

Despite this progress, there is still much work to be done. First and foremost, there is significant challenge in the inability to directly measure energy availability (EA = energy intake [EI] – exercise energy expenditure [EEE]) given that an acute assessment might not accurately represent a chronic state, and that there are considerable errors of reliability and validity in the measurement of the components of the equation. Correspondingly, Burke et al. (2018a) have published a review paper in this edition outlining the pitfalls of measuring LEA, showing that a multifactorial and multimarker approach is currently required. Could it be that a depressed measured resting metabolic rate compared with predicted will be a practical surrogate for energy deficiency? Staal et al. (2018) explore resting metabolic rate as a predictor of dancers at risk for energy deficiency.

There also remains a challenge of safely manipulating the elite athlete body composition (if needed) to balance the dichotomy between ideal performance and the short- and long-term health outcomes of LEA. A case report by Stellingwerff (2018) demonstrates the detail and nuance of managing this delicate balance in an Olympian endurance runner. There is a need to develop guidelines to assist sports scientists and sports medicine personnel in the effective and safe manipulation of body composition.

The Olympic Movement Medical Code (2016) encourages all stakeholders to “take measures . . . to ensure that sport is practiced to minimize harm to the health of the athletes.” Currently, the RED-S iceberg is largely uncharted by most sports policy makers, IFs, National Olympic Committees, coaches, and athletes. Education is needed to ultimately protect athletes from the health and performance impacts of LEA. Like the development of much greater concussion awareness, RED-S is ready for an even greater spotlight to feature its impactful story. We hope this special edition focused on RED-S goes a long way in continuing to showcase preventative, diagnostic, and treatment solutions and expose much more than just the tip of the iceberg.

Acknowledgments

The authors sincerely thank the many scientists, authors, coaches, and clinicians who are active in the field of relative energy deficiency in

sport (RED-S) through research, publications, prevention, and athlete health care. The authors have no conflicts of interest to disclose. There was no funding obtained for this manuscript. M. Mountjoy made substantial contributions to conception and design, coordination of the paper, drafting and revision of the manuscript, and approval of the final version for publication. L. Burke, T. Stellingwerff, and J. Sundgot-Borgen made substantial contributions to conception and design, revision of the manuscript, and approval of the final version for publication.

References

- Ackerman, K., Cooper, K., Flynn, E., Bruinvels, G., Tenforde, A., Popp, K., . . . Parziale, A. (2018a). The prevalence of RED-S in a clinic population. *British Journal of Sports Medicine*.
- Ackerman, K.E., Holtzman, B., Cooper, K.M., Flynn, E.F., Bruinvels, G., Tenforde, A.S., . . . Parziale, A.L. (2018b). Low energy availability surrogates correlate with health and performance consequences of relative energy deficiency in sport. *British Journal of Sports Medicine*. doi:10.1136/bjsports-2017-098958
- Burke, L.M., Lundy, B.L., Fahrenholtz, I., & Melin, A. (2018a). Pitfalls of conducting and interpreting estimates of energy availability in free-living athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, 28(4). doi:10.1123/ijnsnem.2018-0142
- Burke, L.M., Close, G.L., Lundy, B., Mooses, M., Morton, J.P., & Tenforde, A.S. (2018b). 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). doi:10.1123/ijnsnem.2018-0182.
- Concussion. (2015). Retrieved from <http://www.imdb.com/title/tt3322364/quotes>. Directed by Peter Landesman.
- Drinkwater, B.L. (1972). Physical exercise and bone health. *Journal of American Medical Women's Association*, 45(3), 91–97.
- Elliott-Sale, K.J., Tenforde, A.S., Parziale, A.L., Holtzman, B., & Ackerman, K.E. (2018). Endocrine effects of relative energy deficiency in sport. *International Journal of Sport Nutrition and Exercise Metabolism*, 28(4). doi:10.1123/ijnsnem.2018-0127
- Fagerberg, P. (2018). Negative consequences of low energy availability in natural male bodybuilding: A review. *International Journal of Sport Nutrition and Exercise Metabolism* 28(4). doi:10.1123/ijnsnem.2016-0332
- Heikura, I., Uusitalo, A., Stellingwerff, T., Bergland, D., Mero, A., & Burke, L. (2018). Low energy availability is difficult to assess but outcomes have large impact on bone injury rates in elite distance athletes. *International Journal of Sport Nutrition and Exercise Metabolism* 28(4). doi:10.1123/ijnsnem.2017-0313
- Loucks, A.B. (2004). Energy balance and body composition in sports and exercise. *Journal of Sports Sciences*, 22(1), 1–14. PubMed ID: 14974441 doi:10.1080/0264041031000140518
- Mountjoy, M., Costa, A., Budgett, R., Dvorak, J., Engebretsen, L., Miller, S., . . . Carr, J. (2018a). Health promotion through sport: International sport federations' priorities, actions and opportunities. *British Journal of Sports Medicine*, 52(1), 54–60. doi:10.1136/bjsports-2017-097900
- Mountjoy, M., Sundgot-Borgen, J., Burke, L., Carter, S., Constantini, N., Lebrun, C., . . . Ljungqvist, A. (2014). The IOC consensus statement: Beyond the female athlete triad—Relative Energy Deficiency in Sport (RED-S). *British Journal of Sports Medicine*, 48(7), 491–497. PubMed ID: 24620037 doi:10.1136/bjsports-2014-093502
- Mountjoy, M., Sundgot-Borgen, J., Burke, L., Carter, S., Constantini, N., Lebrun, C., . . . Ljungqvist, A. (2015). Authors' 2015 additions to the IOC consensus statement: Relative Energy Deficiency in Sport (RED-S).