



NUTRITION RECOMMENDATIONS FOR ALTITUDE TRAINING

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- Altitude research and associated nutrition reviews have mainly focused on high to extreme altitudes (> 3,000 m). Recent data and associated practical nutrition recommendations are emerging from studies conducted at altitudes where athletes typically train (~1,600–2,400 m).
- Until further research on carbohydrate and fat oxidation and/or protein metabolism during exercise is conducted during the types of training undertaken by athletes at low to moderate altitudes (~1,600–2,400 m), guidelines for altered macronutrient needs remain theoretical and should align with sea-level recommendations.
- It is not clear whether low to moderate altitudes have alternative effects on energy availability (EA) requirements and/or risk for Relative Energy Deficiency in Sport, but there are several recent studies to suggest that EA will play an important role in optimizing hypoxic adaptations.
- The micronutrient iron is especially important at altitude, as hypoxia results in a distinct environment where the erythropoietic drive increases reticulocyte formation and hemoglobin mass gains, which are dependent upon adequate iron availability.
- A common theme that has emerged is that more research in physiology, metabolism and nutrition should focus on low to moderate altitudes that elite athletes use for training.

INTRODUCTION

The implementation of altitude training to optimize elite athlete performance rose to prominence prior to and during the 1968 Mexico City Olympics (held at 2,250 m above sea level). Since this time, there has been an explosion in the utilization of altitude, as well as the supporting science, in the preparation of elite athletes for competition (Mujika et al., 2019). By extension, given the altered hypoxic environment and resultant altered metabolism, there are many unique nutrition-based recommendations required to optimize altitude adaptations. However, most of the research and the associated nutrition reviews have focused on high to extreme altitudes (> 3,000 m) (Bergeron et al., 2012). Therefore, the focus of this Sport Science Exchange (SSE) article will be on the novel data and associated practical nutrition recommendations that are emerging from work at low to moderate altitudes that athletes typically implement into their periodized training (~1,600–2,400 m). For a comprehensive review, see Stellingwerff et al. (2019b).

GENERAL NUTRITION AND HYDRATION RECOMMENDATIONS AT LOW TO MODERATE ALTITUDES

Many elite athletes travel to specific global altitude training locations for 2–4 week training camps, repeated several times per year, rather than reside continually at altitude (Mujika et al., 2019). Therefore, it should be recognized that when most athletes enter any “training camp” situation, regardless of the altitude, they tend to increase training loads. So regardless of the hypoxic stress, the practitioner, along with coaches and athletes, should not neglect the sea-level importance of contemporary sports nutrition guidelines. Although it is commonly accepted that altitude results in increased carbohydrate (CHO) oxidation during exercise, and thus CHO intake requirements, it should be noted

that the study demonstrating this was conducted at 4,300 m (Brooks et al., 1991), and another study in females at the same altitude actually showed decreased CHO utilization (Braun et al., 2000). Therefore, until further metabolism research (CHO vs. fat oxidation, protein metabolism) is conducted during the types of training undertaken by athletes at low to moderate altitudes (~1,600–2,400 m), guidelines to address macronutrient needs remain theoretical, and should align with sea-level recommendations (Burke et al., 2019; Stellingwerff, 2013; Stellingwerff et al., 2019a).

The lower air humidity associated with most altitude environments, along with hypoxia, are also likely to increase fluid losses at rest and during training. Furthermore, there are increased respiratory water losses coupled with hypoxic-induced diuresis that can also result in significant increases in water requirements at altitude to prevent dehydration (Butterfield et al., 1992). Therefore, increased hydration diligence and hydration status monitoring should be implemented. These include monitoring urine characteristics and daily body mass (BM) changes and being proactive with fluid intake during and after training sessions and with meals. Table 1 highlights unique altitude training camp situations that may require enhanced monitoring and/or nutritional interventions for the practitioner to consider with their athletes.

EFFECTS OF ALTITUDE ON ENERGY AVAILABILITY, BODY MASS AND ADAPTATION

Energy availability (EA) is a concept reflecting the amount of energy that is available after exercise for use by other body processes (such as endocrine, immune, skeletal and reproductive systems) and is calculated as energy intake (EI) minus exercise energy expenditure (EEE) relative to fat-free mass. Optimal EA is not only an important

consideration at sea level, but also while at altitude, especially given the increased stress of hypoxia. This concept of low EA has recently been coined Relative Energy Deficiency in Sports (RED-S), and can have important and significant outcomes not only on athlete health but also performance (Mountjoy et al., 2018). However, it is not clear whether low to moderate altitudes have alternative effects on EA requirements and/or increase the risk of RED-S, but there are several recent studies to suggest that EA will play an important role in optimizing hypoxic adaptations.

Practical Monitoring and Nutrition Recommendations for Common Altitude Training Camp Issues	
Potential Issue	Recommended Monitoring and/or Nutrition-Based Solution
Many global altitude training camp locations require significant athlete travel, resulting in travel fatigue and jet lag.	Initiate travel well-fed, hydrated and rested. Bring appropriate snacks, and hydrate well en route (as planes are dry), while being extra diligent with personal hygiene (e.g., handwashing). Upon arrival, ease into training, and if jet-lagged, use meals and coffee (caffeine) to help re-establish time zone (zeitgeber).
Upon arrival to altitude, athletes will have initial hypoxic compensatory mechanisms (over several days) such as hyperventilation and potentially mild altitude sickness (e.g., poor sleep, headaches, mild GI issues).	Ease into the first 3–5 days of training, while monitoring individual athlete fatigue, BM, sleep, general appetite and hydration levels.
Low humidity at most altitude locations and increased respiratory water losses, can predispose athletes to greater dehydration risks.	Continual hydration monitoring, such as morning void USG and BM, along with thirst and urine color, can help athletes recalibrate their hydration requirements in the new location. It is especially important to be proactive with hydration around training and with meals.
Most athletes who enter any training camp situation with a group of other athletes (regardless of altitude) tend to increase training loads (intensities and durations).	Have progressive training load and fatigue monitoring in place to help give feedback to the athlete and coach on training progression. One might also consider morning and exercise heart rates, ratings of perceived exertion and peripheral oxygen saturation monitoring at altitude to give enhanced feedback. Athletes have to be more diligent around recovery nutrition and adequate daily caloric intake to optimize EA and training adaptation during hard training blocks. Contemporary sea-level sports nutrition guidelines should be followed.
A new training location and shared athlete accommodations can result in altered nutrition and hydration practices compared to home.	Ensure each athlete has the nutrition/cooking skills to prepare adequate food while away from home, while at the same time allowing for travel nutrition flexibility. Appreciate that altered social aspect of a training camp (shared accommodations) might also result in altered nutrition practices that may need to be addressed.
Altitude results in enhanced iron requirements.	Each athlete should have baseline blood work, including iron values, measured 4–6 weeks prior to camp and an individually informed iron supplementation protocol while at altitude.

Table 1. BM, body mass; EA, energy availability; GI, gastrointestinal; USG, urine specific gravity.

Energy Availability and Hemoglobin Mass at Altitude

Attenuation of sex hormone concentrations (estrogen, testosterone) due to low EA may impair hematological adaptations to altitude, as low

EA and adverse iron metabolism have been linked (Petkus et al., 2017), and iron is a critical micronutrient to optimize hemoglobin mass (HBmass) gains at altitude (see below). Furthermore, optimization of long-term HBmass appears to be impacted by EA, as amenorrheic elite female runners had an 8% lower baseline HBmass (Figure 1) when compared to their eumenorrheic counterparts prior to an altitude camp (Heikura et al., 2018b). Interestingly, this difference in baseline HBmass was greater than the average female HBmass increase across many altitude camps (Heikura et al., 2018b) (Figure 1).

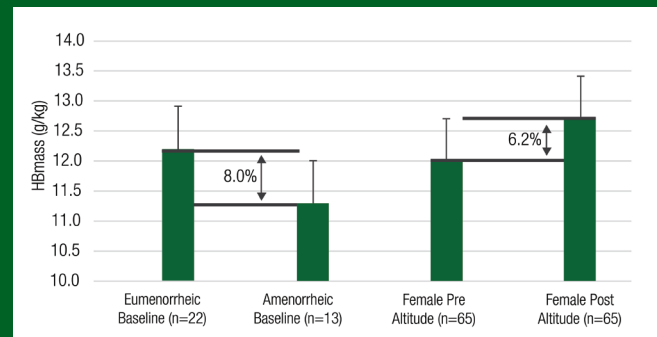


Figure 1. Baseline HBmass (grams/kg) in eumenorrheic females (n=22) versus amenorrheic female athletes (n=13) upon arrival to altitude camp (8% difference; all observation in 2016) vs. a 4-year training camp average, featuring 65 observations, of total pre- (baseline) altitude camp to post-altitude camp HBmass outcomes (+6.2%). Dated adapted from (Heikura et al., 2018b) and unpublished sources.

Human Metabolic Rate and Energy Intake and Expenditure Implications at Altitude

Much of the seminal research on the effects of altitude on human physiology, metabolism and associated nutritional interventions has been conducted at 4,300 m at the United States Army Pikes Peak Research Laboratory. At these high altitudes, there are consistent, and profound, effects on endocrine systems, EI, resting metabolic rate (RMR) and ultimately BM. Indeed, studies have reported 5%–15% reductions in BM, with 60%–70% of the weight loss coming via muscle atrophy at altitudes of 4,300 m (Fulco et al., 2002). The primary mechanisms for these extreme BM losses are appetite suppression resulting in lower EIs coupled with a > 3-fold increase in RMR compared to sea level (Butterfield et al., 1992). Nevertheless, aggressive EI interventions at high altitude also have shown to significantly attenuate BM losses while maintaining optimal EA (Butterfield et al., 1992).

While the effects of high-altitude exposure on EI, RMR and BM are severe, the handful of research findings at low to moderate altitudes, where athletes typically train, are much less consistent and appear to be far less deleterious. For example, a case report in four elite rowers reported loss of appetite and increased fatigue during a training block at 1,800 m (Woods et al., 2017a), while five elite runners reported an increase in appetite, with no measured change in EI, after 4 weeks of training at 2,200 m (Woods et al., 2017b). Further inconsistencies include reports of both negative (Fudge et al., 2006; Onywera et al.,

2004) as well as optimal energy balance (Beis et al., 2011) in elite Kenyan and Ethiopian runners at moderate altitudes. Only two studies have investigated the effects of moderate altitude on RMR in athletes, with one study reporting a 19% increase over 4 weeks at 2,200 m in five elite runners (Woods et al., 2017b) and the second study reporting no change in RMR after 12 days at 1,800 m in four trained rowers (Woods et al., 2017a). However, given the small number of subjects, more research is required to confirm these findings that RMR is increased at low to moderate altitudes, as reported at high altitudes.

Elite Athlete Body Mass Changes at Altitude Training Camps

Given that prolonged sojourns at high altitude (> 4,000 m) can cause significant BM losses (Fulco et al., 2002), it is a commonly accepted notion that elite athletes are also at risk for significant BM losses at the typical low to moderate altitudes (~1,600–2,400 m) implemented in training camps. In terms of changes in BM during altitude training camps (~3 weeks), studies have reported no change (Beis et al., 2011; Fudge et al., 2006; Heikura et al., 2018a; Koivisto et al., 2018; Woods et al., 2017b) or minor BM decreases (Gore et al., 1998; Onywera et al., 2004; Woods et al., 2017a) when exposed to moderate altitudes. Additionally, data from four separate altitude training camps (over 3–4 weeks, with n=114 athletes) showed no relationships with BM changes (only a $0.6 \pm 1.5\%$ BM decrease), HBmass increases and injury/illness outcomes (Stellingwerff et al., 2019b). However, changes in BM alone are a poor indicator of EA status, as prolonged and/or severe reductions in EI may lead to adaptive thermogenesis, which promotes maintenance or gain of BM despite low EA (Trexler et al., 2014). Nevertheless, even though the hypoxic stress of altitudes < 2,400 m is minor in comparison with mountaineering altitudes, the extreme and prolonged training and the fact that athletes may spend as much as 20%–25% of the entire year at altitude needs to be considered (Mujika et al., 2019). Much research remains to better quantify and characterize the BM, energetic (EI, EEE and EA), metabolic and RED-S risk effects at low to moderate altitudes in athletes.

IRON – THE KEY MICRONUTRIENT CONSIDERATION FOR ALTITUDE

The micronutrient iron is especially important at altitude, as hypoxia results in a distinct environment where the erythropoietic drive increases reticulocyte formation and HBmass gains, which are dependent upon adequate iron availability. Optimal iron is especially important for endurance athletes given the importance of HBmass for aerobic power, and the fact that endurance athletes face increased iron losses through sweat, urine, the gastrointestinal tract, hemolysis (foot strike and muscle contraction), and blood loss associated with injury and menses (Sim et al., 2019). With regard to altitude, since no correlation has been observed between pre-altitude ferritin stores and the magnitude of the erythropoietic/HBmass response (Heikura et al., 2018a), it appears that iron availability via supplementation during altitude is more important

for optimal adaptations than pre-altitude iron stores (Garvican-Lewis et al., 2016; Hall et al., 2019). Accordingly, it is paramount to have iron well monitored in athletes coupled with an optimal iron supplementation protocol while at altitude.

It is beyond the scope of this SSE to elucidate the extensive and complex science involving metabolism and athletes at altitude, including the various steps and considerations of iron supplementation at altitude (see the extensive reviews, Sim et al., 2019; Stellingwerff et al., 2019b). Instead, this SSE will highlight the key recommendations/steps for athletes and their staff, regarding iron screening, monitoring and supplementation with respect to altitude camps (Table 2). We also recommend the involvement of a sports medicine physician in this process, as excess iron supplementation and clinically elevated endogenous iron stores can have negative health consequences (Munoz et al., 2018).

Iron monitoring and supplementation considerations at altitude.

- In consultation with a sports medicine physician, and depending on the athlete's historical ferritin values (e.g., low vs. high), history of iron deficiencies/anemias, number of yearly altitude camps and typical dietary iron intake, an individualized yearly iron (and blood work) monitoring program should be implemented to ensure optimal iron stores and blood health.
- Generally, ferritin cutoffs of < 30 ng/mL and < 40 ng/mL have often been used as an athlete "check" to ensure optimal altitude adaptations and/or whether to supplement with iron in females and males, respectively (Bergeron et al., 2012).
- Aim for pre-altitude blood work ~4–6 weeks prior to departure to allow for more precise pre-altitude ferritin assessment, to give time to still supplement and correct prior to altitude if required.
- Current evidence suggests that most athletes will maximize the hypoxia-induced increases in HBmass while consuming ~100–200 mg of elemental iron daily in oral form, with most evidence coming from iron salts (Govus et al., 2015; Hall et al., 2019). However, the level of daily elemental iron intake should be confirmed by a physician and may be dependent upon baseline ferritin values.
- Single daily doses, rather than split daily doses, of iron may help to optimize HBmass gains when supplementation is indicated (Hall et al., 2019; Stoffel et al., 2017).
- Depending on training schedules and typical breakfast, athletes may be best to take their iron supplementation first thing in the morning when hepcidin levels (hormone which blocks iron uptake) are lower (Schaap et al., 2013).
- Athletes may be best to prioritize increased total iron supplementation on rest days or lighter training days when hepcidin is theoretically lower to optimize iron uptake (Peeling et al., 2009).
- Taking a single dose may result in slightly greater gastrointestinal discomfort for the first 1–2 weeks at altitude, but appears to attenuate (adapt) by week 3 (Hall et al., 2019).

Table 2. Practical recommendations and steps for iron monitoring and supplementation for athletes training at low to moderate altitudes (~1,600 m to 2,400 m). For extensive review on this topic see (Sim et al., 2019; Stellingwerff et al., 2019b).

OXIDATIVE STRESS AT ALTITUDE – ARE ANTIOXIDANTS REQUIRED?

There are some emerging data on antioxidant considerations for altitude, as exercise at both extreme and moderate altitudes is

associated with increased production of reactive oxygen species (ROS) with reduced antioxidant capacity, leading to oxidative stress, which may impair cell and immune function, and in some instances, potentially delaying post-exercise recovery (Sies et al., 2017). Both acute and chronic hypoxia increases oxidative stress in athletes, and this may persist for up to 2 weeks post altitude training (Pialoux et al., 2010). By extension, it might be hypothesized that since exogenous antioxidant supplements neutralize ROS, supplementation with antioxidants is needed at altitude. However, most studies have shown minimal to no effects (Subudhi et al., 2004) on ROS, and most studies have not examined the impact that exogenous antioxidants may have on training adaptations. Indeed, contemporary knowledge is that ROS actually initiates positive endurance training adaptations (Powers et al., 2010), and that single high-dose antioxidant supplementation may actually impair and attenuate training adaptation (Gomez-Cabrera et al., 2008). Interestingly, a recent study examined the impact of high and low antioxidant effects from food sources (not supplements) on the adaptive response to altitude training. This study showed that more than doubling the daily intake of antioxidant-rich foods during a 3-week altitude camp (2,320 m) did not interfere with the training responses in elite endurance athletes (measured as HBmass and maximal oxygen uptake) (Koivisto et al., 2018)). Taken together, there is not sufficient evidence to recommend high-dose single antioxidant supplementation at low to moderate altitude to attenuate altitude-induced oxidative stress. However, food-based diets high in antioxidants can be recommended, as this does not seem to attenuate training adaptation and may confer other health benefits.

PRACTICAL APPLICATIONS

Although our understanding of basic physiological and metabolic responses at low to moderate altitudes (1,600–2,400 m) compared to more extreme mountaineering altitudes is still only emerging, several practical nutrition applications can be made to further enhance altitude training adaptations (also see Tables 1, 2).

- Altitude training camps tend to present like any training camp situation with significantly increased training loads. Thus, regardless of the hypoxic stress, the practitioner should implement contemporary sea-level sports nutrition guidelines to maximize training adaptations and optimize recovery.
- Altitude locations tend to have lower air humidity and are likely to increase fluid losses at rest and during training. Therefore, increased fluid intake as well as hydration status monitoring should be implemented (Table 1).
- Although the impact of low to moderate altitude on EI, RMR and BM appear to be far less deleterious compared to extreme altitudes, some emerging indicators suggest RMR and energy requirements may be elevated. Therefore, enhanced monitoring to ensure optimal energy availability is recommended (Table 1).
- Iron is a critical micronutrient to optimize altitude adaptations. Therefore, it is paramount to have iron well monitored in athletes

coupled with an optimal iron supplementation protocol while at altitude (Table 2). Current evidence suggests that most athletes will maximize the hypoxia-induced increases in HBmass while consuming ~100–200 mg of elemental iron daily in oral form, but this should be confirmed by a physician.

CONCLUSIONS

This SSE has focused on key altitude-related nutrition themes with emerging data for novel nutritional considerations at low to moderate altitudes (~1,600–2,400 m), and associated nutrition and altitude-related monitoring tools. A common theme that has emerged is that more research should focus on low to moderate altitudes that elite athletes use for training. However, recent data has shown that general contemporary nutrition guidelines, iron supplementation, and optimal energy availability are nutritional concepts that are vital to optimize altitude training adaptations.

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