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Timing of Arrival and Pre-acclimatization Strategies for the Endurance Athlete Competing at Moderate to High Altitudes

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Abstract

Chapman, Robert F., Abigail S. Laymon, and Benjamin D. Levine. Timing of arrival and pre-acclimatization strategies for the endurance athlete competing at moderate to high altitudes. *High Alt Med Biol* 14:319–324, 2013.—With the wide array of endurance sport competition offerings at moderate and high altitudes, clinicians are frequently asked about best practice recommendations regarding arrival times prior to the event and acclimatization guidelines. This brief review will offer data and current advice on when to arrive at altitude and various potential sea level-based pre-acclimatization strategies in an effort to maximize performance and minimize the risk of altitude sickness.

Clinicians and physiologists regularly receive questions from endurance athletes about the best practices surrounding preparation, travel, and competition at moderate (2000—3000 m) and high (3000—5500 m) altitudes (Bartsch et al., 2008). Common are questions regarding the timing of arrival at altitude—for example, how long prior to the race should the athlete try to arrive at altitude, or is there anything the athlete can do to prepare, if they can only arrive at altitude the night before the race? Answers to these questions are of high importance to the athlete, as the training and financial investment to compete in these events, many being ultra-endurance competitions taking 24 hours or more to complete (Table 1), are quite substantial.

Our task in this review for the Clinician's Corner is to touch briefly on the unique aspect of acclimatization prior to endurance competitions at moderate and high altitudes and offer advice for the clinician and athlete on optimal preparation strategy.

Timing of Arrival at Altitude for Endurance Competition

Normally, endurance athletes who are competing at altitude have personal logistics whereby they can either arrive: a) well in advance of the competition, with no restrictions, or b) within a short period of time prior to the competition, usually 12–36 hours, due to restrictions on travel, work, school, etc. In the case where athletes have the freedom and resources to arrive well in advance of the competition, the two primary variables of interest are how high and how long—meaning to what altitude should the individual choose to acclimatize, and how long is the ideal acclimatization period. For the

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Table 1. Listing of Select Ultra-Endurance Competitions Taking Place at Moderate and High Altitudes

Event	*Altitude*
Running events	
Western States 100 mi Sierra Nevada Mountains, California, USA	1890–2667 m
Leadville 100 mi Rocky Mountains, Colorado, USA	2804–3840 m
Wasatch Front 100 mi Wasatch Mountains, Utah, USA	1433–3188 m
Mountain Ultra, 220 km Rocky Mountains, Colorado, USA	2743–3962 m
Badwater Ultramarathon, 135 mi California, USA	86–2548 m
Ultra-Trail du Mont Blanc, 166 km Alps, Switzerland / France	975–2500 m
Hardrock 100 mi Colorado, USA	Average 3353 m
Ultra Race of Champions 100 k Breckenridge, CO, USA	2743–3568 m
Himalayan 100 mi Stage Race & Mt Everest Challenge Marathon	1830–3658 m
Biking events	
Vapor Trail 125 mi Colorado, USA	2134–3658 m
Leadville Trail 100 mi Colorado, USA	3094–3787 m
Triathlon events	
Ironman Lake Tahoe California/Nevada, USA	All above 1890 m
Cross country skiing events	
Equinox Ski Challenge, 24 hours West Yellowstone, Montana, USA	2134 m
Yellowstone Rendezvous Race, up to 50 km West Yellowstone, Montana, USA	2134 m

athlete who cannot arrive until just prior to the event, is there anything they can do to pre-acclimatize while at sea level? While the evidence we will present suggests that arrival a day or two prior is not as ideal as more prolonged acclimatization time, we will discuss data from prolonged, intermediate, and short arrival times to altitude, as well as data regarding the effectiveness of intermittent hypoxic exposure (IHE) and intermittent hypoxic training (IHT) as pre-acclimatization strategies. With each timeline or strategy, there are both positives and negatives in terms of the physiological and logistical factors affecting travel and performance at altitude and risk of development of altitude sickness (Table 2).

Two Weeks or Longer of Acclimatization Prior to the Event

Upon arrival at altitude, there are a number of physiological acclimatization responses that will take place in an attempt to maintain oxygen delivery to the periphery. Some of these responses occur almost immediately, such as a peripheral chemoreceptor-mediated increase in ventilation, while others will take several days, weeks, or longer. In general, most recommendations for an ideal arrival time to acclimatize prior to an endurance event at altitude are for 14 days (Chapman and Levine 1999; Gore et al., 2008; Levine et al., 2008; Maher et al., 1974; Schuler et al., 2007). Conceptually, this time frame is within a window where the majority of the short term acclimatization effects are nearing completion. This 14-day time frame is also short enough to avoid the reduction in training effect (i.e., reduced oxygen flux and slower training velocities) that occurs with chronic altitude residence (Levine and Stray-Gundersen 1997; McConell et al., 1993). Of course, most endurance athletes will be tapering during the last 2 weeks prior to competition, so training concerns during this recommended acclimatization period may be less important. Excellent data on this topic come from the work of Schuler et al. (2007), where 8 elite cyclists were studied at sea level before and during altitude residence at 2340 m. Primary dependent measures were $\dot{V}O_{2max}$ and time to exhaustion at 80% of $\dot{V}O_{2max}$ (which took these elite cyclists, on average 43 minutes to complete at sea level). On the first day of arrival at altitude, $\dot{V}O_{2max}$ declined by 12.8% and time to exhaustion declined by 25.8% compared to sea level values. Over the next 14 days at 2340 m, these measures significantly improved—by approximately 4% per week for $\dot{V}O_{2max}$ and 6% per week for time to exhaustion. However, from day 14 to day 21 at altitude, improvements in $\dot{V}O_{2max}$ (0.7% from day 14) and time to exhaustion (1.4% from day 14) did not significantly increase. In total, these data would suggest that: a) 14 days is the best practice recommendation, having near-maximal performance benefits with the minimum time investment, b) if 14 days are not available, shorter periods of time (i.e., 7 days) will still allow for positive (but not complete) adaptations relative to performance, and c) altitude residence longer than 14 days does not appear to add appreciable performance improvement over that seen at 14 days.

Despite no performance change from day 14 to 21 at altitude in the Schuler et al. study of elite cyclists (Schuler et al., 2007), there may be performance benefits at altitude from longer term (>3 month) chronic altitude residence. Within permanent residents of moderate altitude (2200 m for 5–46 months; median 20 months), time trial performance decrement with acute exposure to high altitude (4300 m) is half as large as in an equally fit sea level cohort (22% vs. 46% performance decrement) (Fulco et al., 2007). Similarly, the moderate altitude residents displayed significantly higher SaO_2 values and lower acute mountain sickness (AMS) prevalence and severity over the first 72 hours at 4300 m, versus unacclimatized sea level residents (Muza et al., 2006). Ultimately, there are two important caveats with altitude acclimatization prior to competitions at altitude. First, even with the improvements in oxygen uptake and performance that athletes will experience with acclimatization, these measures still will not reach sea level values no matter how much time is spent at altitude. Second, within an athletic population, performance decrements in aerobic activities are normally going to occur at altitude compared to sea level; however, the magnitude of the decrement will depend in part on the elevation of the athlete's permanent residence.

Does Erythropoiesis/Augmented Hemoglobin Mass Affect Performance at Altitude?

With chronic exposure to altitude, erythropoiesis is a key acclimatization response that increases the oxygen-carrying capacity of the blood. The amount of erythropoiesis is strongly dependent on the hypoxic dose, with the length of altitude residence a primary factor (Levine and Stray-

Table 2. Summary List of Positive and Negative Effects of Various Altitude Arrival Timings and Pre-acclimatization Strategies on Performance and Risk of Altitude Sickness

Timing of arrival at altitude	*Positives with this timing*	*Negatives with this timing*
Hours before competition	–Typically lowest financial cost and easiest logistically with work, family, school obligations	–Misses out on acclimatization responses which minimize performance decline.
	–May minimize plasma volume loss	–First day at altitude is commonly the worst for performance
	–May avoid AMS symptoms (initially)	
2–7 days	–Performance decrement at altitude appears to decline with each day of altitude residence (up to ~14 days)	–Additional days at altitude increase financial and logistical cost.
	–May allow for some ventilatory acclimatization response; AMS symptoms (if present) may decline over this time.	–While better than day-of arrival, not as ideal as 14 days
14 days (or longer)	–Near maximal performance improvement vs. acute exposure	–Significant cost and logistics associated with relocation for 14 days (or more) prior to the competition.
	–Allows time to stage ascent to minimize AMS	–Loss of training quality, but usually athlete is tapering for competition in this timeframe.
Permanent moderate altitude relocation (>3 mo.)	–Smaller performance reduction with ascent to higher altitudes	–Effect on chronic training response?
Pre-acclimatization strategy	*Positives with this strategy*	*Negatives with this strategy*
Intermittent hypoxic exposure (IHE)	–Allows the athlete to live and train at home. Short daily time investment. –Likely ventilatory acclimatization	–Equivocal effects on performance and AMS incidence
Intermittent hypoxic training (IHT)	–Improvements in maximal oxygen uptake and peak power output in hypoxia	–Cost and logistics associated with hypoxic gas generation and delivery
Increased hemoglobin mass (erythrocyte infusion, rhEPO administration)	–Mitigates VO_2max decline with acute exposure to altitudes up to 3500 m.	–No change in VO_2max decline with acute exposure to altitudes from 4100–4300 m. –Against competition rules of most sport governing bodies.

Gundersen, 2006). Interestingly, the best practice recommendation of 14 days of chronic altitude exposure is not likely to involve significant erythropoiesis (Levine and Stray-Gundersen, 2006). Even with direct injection of recombinant human erythropoietin (rhEPO) in individuals at sea level, there is barely a detectable increase in hemoglobin or hematocrit after 2 weeks (Birkeland et al., 2000), again suggesting that the primary acclimatization benefits for endurance exercise performance during the first 14 days at altitude are mediated by a mechanism other than erythropoiesis. Increased red cell mass clearly benefits endurance exercise performance at sea level, but its effect on exercise performance with acute exposure to altitude is less clear. On one hand, neither rhEPO injections weekly for 4 weeks in untrained subjects (Lundby and Damsgaard 2006), nor 700 mL autologous blood transfusions in a military cohort (Young et al., 1996) had an effect on the Vo_{2max} decrement with acute exposure to high altitude (4100—4300 m). However, the effect of any method of increased red cell mass on Vo_{2max} decline with acute hypoxic exposure appears to be dependent on the severity of altitude/arterial hypoxemia (Robach et al., 2008; Robertson et al., 1982). After 5 weeks of rhEPO administration in eight active men at sea level, the Vo_{2max} decrement with acute exposure to altitude was less at 1500 m, 2500 m, and 3500 m, but not at 4500 m (Robach et al., 2008). Why increased total hemoglobin mass and arterial oxygen content would increase Vo_{2max} at sea level and moderate altitudes but not at high altitudes is unclear, but is likely related to a very low diffusion gradient in the muscle capillary at the most extreme altitude. The authors also speculate that at altitudes <3500 m, fatigue was primarily peripherally mediated, while at 4500 m central fatigue becomes a larger influence (Amann et al., 2007); however, this hypothesis remains speculative and is in fact countered by recent data (Subudhi et al, 2011). Ultimately, while artificially increasing hemoglobin mass without acclimatization may improve performance with acute exposure to moderate altitude, there are certainly legal and ethical issues that should be considered with this approach.

Living Altitude Selection and Shorter Term Staging at Intermediate Altitudes

When selecting a living altitude for acclimatization prior to an endurance competition at altitude, data suggest the best choice would be to live at an altitude equal to the that of the competition, but not higher. In a cohort of sea level native collegiate distance runners who completed an altitude training camp by living at one of four altitudes (1780 m, 2085 m, 2454 m, 2800 m), time trial performance at 1800 m was significantly influenced by living altitude (Levine and Stray-Gundersen, unpublished data). Specifically, performance decrements in a 3000 m track time trial at 1800 m on day 5 after arrival at altitude was worse with ascending living altitude, with the smallest decrement (4.5%) occurring in the cohort living at 1780 m, increasing within each altitude cohort to the largest decrement (8.2%) being displayed by the 2800 m group. Perhaps not surprisingly, the rate of improvement in time trial performance while at altitude was fastest within the highest living cohorts (e.g., 1.4% per week in the 2800 m cohort vs. 0.4% per week in the 1780 m cohort), with no difference between altitude living groups in time trial performance at 1800 m on day 26 at altitude. It is believed that the more severe acclimatization effects of just 5 days of living at higher altitudes resulted in greater impaired performance at a lower altitude. However, for exercise performance at high altitudes, staging at a lower, moderate altitude for a short period of time appears to enhance performance compared to acute exposure to high altitude. Work by U.S. Army researchers has demonstrated that 6 days of staging at 2200 m, followed immediately by exposure to 4300 m (at Pikes Peak) resulted in improved ventilatory acclimatization, decreased AMS prevalence and severity, and improved (44%) time trial performance, compared to acute hypobaric chamber responses to 4300 m (Beidleman et al., 2009a; Fulco et al., 2009). Therefore, at least for events at high altitude, even if 14 days of acclimatization are not available before the event and access to the full altitude of competition is not available or not preferred (perhaps due to increased likelihood of AMS), short term exposure to moderate altitude does appear to be better than no acclimatization period at all.

Intermittent Altitude Exposure as a Pre-acclimatization Strategy

Because of the logistics and costs associated with travel to altitude for prolonged periods of time, a number of athletes are now using normobaric hypoxic exposure, in an effort to induce some effects of altitude acclimatization while residing at sea level. A number of commercially available products allow for a small enclosed hypoxic environment usually contained within the athlete's own home. Athletes hope to gain the beneficial effects associated with altitude acclimatization through a process of intermittent hypoxic exposure, either with (IHT) or without (IHE) exercise training. Typically, IHE is accomplished either through sleeping 8–12 h per day in a nitrogen tent, or by breathing at rest periodically through a hypoxic mask (generally using an on/off protocol such as alternating 5 min of exposure to $\sim$10%–12% O_2 with 5 min of normoxia for 70–90 min). In theory, pre-acclimatization to simulated altitude could help to mitigate both the loss of performance and prevalence and severity of AMS (Burtscher et al., 2008). While it has been purported that IHE and/or IHT may enhance exercise performance through increasing circulating EPO levels and hemoglobin mass (Knaupp et al., 1992; Powell and Garcia 2000) or even upregulation of hypoxia-inducible factor 1α (HIF-1α), causing structural changes within the muscle fiber (Vogt et al., 2001), the collective evidence from >40 studies of these adaptations is unremarkable (Wilber, 2007). The one clear adaptation with IHE appears to be ventilatory in nature.

Most studies using protocols of relatively short periods of hypoxic exposure has been shown to increase ventilatory acclimatization significantly, for at least some period of time after return to sea level. For example, 20 nights of 8–10 h per night in normobaric hypoxia (equivalent to 2650 m) resulted in a significant increase in the isocapnic hypoxic ventilatory response (HVR) at rest, as well as a significant decrease in resting end-tidal P_{CO_2} concentrations (Townsend et al., 2002). Even intermittent exposures of 4×5–7 min per day to $\sim$10% O_2 for 14 days resulted in a reported increase in the HVR (Bernardi et al., 2001), although durations of 1–3 h/day for at least 1 week appears to be necessary for effective ventilatory pre-acclimatization (Burtscher et al., 2008). As AMS and HAPE susceptible individuals typically demonstrate low HVRs (Burtscher et al., 2004; Hohenhaus et al., 1995), increasing the HVR and improving arterial oxygenation appears to be the most beneficial aspect of pre-acclimatization. In the limited number of studies that have examined IHE and AMS prevention at high altitude, most have shown beneficial effects (Beidleman et al., 2004; Burtscher et al., 2008;), but this finding is not universal (Fulco et al., 2011) and may depend on whether the intermittent hypoxic exposure is normobaric or hypobaric. As a general rule, pre-acclimatization strategies that utilize hypobaric hypoxia have been shown to be more effective than those that utilize normobaric hypoxia (for a review, see Fulco et al., 2013). Why this is the case is not exactly clear, and the topic of outcome differences between hypoxic delivery modes remains a strongly debated topic among physiologists (Millet et al., 2012; Mounier and Brugnaiux, 2012).

Whether the resulting ventilatory acclimatization from IHE helps competitive performance at altitude is equivocal. While exercise performance in mountaineers at high altitude has been positively related to baseline HVR values (Schoene et al., 1984), exercise performance at a moderate altitude (2100 m) in elite distance runners showed no relation to HVR (Laymon et al., 2011). In multiple studies completed on soldiers, IHE in normobaric hypoxia for 7 days did not improve cycle exercise performance at 4300 m (Beidleman et al., 2009b). However, divergent results are seen when hypobaric hypoxia exposure is used for pre-acclimatization. Interestingly, intermittent hypobaric hypoxia exposure to 4300 m for either 7 or 15 days did result in a 16%–21% improvement in time trial performance compared to acute exposure to 4300 m (Beidleman et al., 2003; 2008). This intermittent hypobaric hypoxic exposure also essentially eliminated the incidence of AMS (Beidleman et al., 2004). However in practicality, most sea level based athletes will not have daily access to hypobaric hypoxia, whether terrestrial or chamber based.

While the pre-acclimatization effects of IHE on exercise performance at altitude are less clear, there is evidence that IHT may hold the potential to assist athletes in preparation for competition at altitude. Sea level-based cyclists who completed 3 weeks of 5 $d\cdot wk^{-1}$ of 60–90 $min\cdot d^{-1}$ of training in hypoxia (simulated 3000 m) significantly improved peak power output in hypoxia, while a sea level-trained control group did not (Roels et al., 2007). Similarly, well trained distance runners who completed 6 weeks of 2 $d\cdot wk^{-1}$ of 24–40 $min\cdot d^{-1}$ of hypoxic training (14.5% O_2) improved $V_{O_{2max}}$ and maximal running velocity at $V_{O_{2max}}$ at a simulated altitude equal to 3000 m, while a sea level trained control group did not (Dufour et al., 2006). It is important to note that IHT did not result in a significant difference in performance in normoxia over the sea level control group; still, for the athletes looking to pre-acclimatize at sea level prior to a competition at altitude competition, an IHT protocol appears to hold promise.

Arrival Just Prior to the Competition

For most competitive athletes, the logistics involved with travel to altitude (work, school, family obligation, financial cost) usually do not allow for 14 days of acclimatization. Many will be forced to arrive at altitude a day or two prior to the competition, with many arriving just the evening prior. In this case, two contrasting strategies have been traditionally recommended and practiced concerning short-term arrival time at altitude. One recommendation is to arrive as soon as logistically possible, as even a few added hours of acclimatization time may be beneficial for exercise performance at altitude (Weston et al., 2001). Alternatively, it has been proposed that arrival at altitude should be as close as logistically possible to the event start time to minimize some of the acute negative effects of altitude exposure, such as sleep disruptions, the small reduction in plasma volume, and the compensatory reduction in plasma bicarbonate (Chapman and Levine 1999; Chapman et al., 2010). This latter strategy, termed "fly in, fly out," is commonly utilized by professional and national soccer teams who will arrive just hours before matches held at altitudes between 2100 m and 3600 m in Latin American cities such as Mexico City, Bogota, Toluca, Quito, and La Paz (Gore et al., 2008). While this strategy may potentially help to minimize (but not eliminate) some of the negative initial effects of acute altitude exposure, it has not been rigorously tested, and it may in fact be more beneficial to obtain whatever ventilatory acclimatization would occur with overnight residence at the competition altitude. This "fly in, fly out" strategy also misses out on skill component adaptations due to changes in air resistance with the reduced air density at altitude, which could substantially affect technical performance in sports such as soccer (Levine et al., 2008). Ultimately, any strategy in regards to a short available arrival time at altitude needs to be tempered with other negatives that are harder to factor into firm recommendations, such as jet lag, housing availability, and travel demands.

Conclusions

For the athlete preparing to compete at altitude, the advantages of properly timed terrestrial acclimatization versus acute exposure are clear. However, for many athletes, the cost, demands, and time investment of travel away from home make the best practice of this strategy unfeasible or impossible. Sea level-based pre-acclimatization strategies may serve as a beneficial compromise, but these various strategies hold their own disadvantages of equivocal findings or difficult logistics. Ultimately, recommendations for arrival into altitude prior to a competitive event will need to be individualized for each athlete or team, based on the best-practice physiological evidence versus the logistical demands of travel and training.

Author Disclosure Statement

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