

Original Article

New tendencies in the application of altitude training in sport preparation

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Published online: June 30 2011

(Accepted for publication May 28 2011)

Abstract

Competitive athletes frequently use altitude training (AT) to improve sea-level performance. AT became interesting for sport scientists and athletes since Olympic Games in Mexico City in 1968. Exercise at altitude may increase the training stimulus and enlarge the effects of endurance training. The first noted adaptation induced by staying at altitude is an increase in red blood cell mass that improves aerobic power and sea-level performance. Currently, there are several types of AT modalities: traditional 'live high-train high', contemporary 'live high-train low', intermittent hypoxic exposure during rest, live low-train high and intermittent hypoxic exposure during continuous session. Despite several substantial differences between these methods of hypoxic all of them have the same goal: to stimulate an improvement in athletic performance at sea level. A proper distinction must be made between altitude acclimatization during preparation for competitions at altitude and AT and acclimatization for improvement of the sea-level performances. Former scientific researches identified two longer phases of enhanced work capacity after AT. First phase of enhanced work capacity occurring between days 3-7 and 12-13, while the best results are achieved during 18 and 20 days after AT. Second phase of enhanced work capacity is reported between days 36 and 48 after AT. The further development of practical knowledge in area of AT should predominantly include recommendations about application of different AT methods in training periodization in different sports. Improvement of the work capacity and duration of enhanced work capacity at the sea level after AT stimuli are the main questions opened for future scientific researches.

Key words: altitude training, sea-level performance, erythropoiesis.

Introduction

In order to improve sea-level performance, competitive athletes frequently use altitude training (AT) (Dick, 1992). AT became interesting for sport scientists and athletes since Olympic Games in Mexico City, 1968. Numerous reports since the 1940s have suggested that endurance athletes may achieve some benefit from altitude training for sea-level performance (Levine & Stray-Gundersen, 1997). Despite many articles about AT, the net benefits of training at altitude for sea-level performance are still controversial (Drust & Waterhouse, 2010).

Altitude exercise may increase the training stimulus and enlarge the effects of endurance training (Levine & Stray-Gundersen, 1997) but conversely hypoxia at altitude limits training intensity (Levine & Stray-Gundersen, 1992), which is detrimental to performance in elite athletes.

Besides training on altitude, another widely used conception is living on altitude. While living at low to moderate altitude, several structural changes can occur in skeletal muscle: increased capillary density, density and their mitochondrial division within the muscle cell and myoglobin content (Hoppeler & Vogt, 2001). However, numerous confounding factors such as incomplete reports of athletic performance, lack of appropriate control groups, small subject numbers and different training modalities make difficult the practical application of previous researches about AT. Therefore, the purpose of this study was to discuss current modalities of AT application and novel research data about AT.

Discussion

Characteristics of altitude and physiological adaptation to AT

Effects of AT are combined results of acclimatization on altitude and training in hypoxia. Atmospheric pressure declines as a function of increasing altitude (Chapman et al. 2009). One of the primary effects of a reduction in atmospheric pressure is a proportional reduction in the partial pressure of inspired oxygen (pO_2). Air temperature and humidity are also smaller with increase in altitude and at the same time density of the atmospheric air is smaller. Concurrently with reduction in pO_2 levels of erythropoietin (EPO) and serum erythropoietin (sEPO) are significantly increased (Chapman et al. 1998; Levine et al. 1991; Stray-Gundersen et al. 1997; Rusko et al. 1999; Phiel-Aulin et al. 1998). Increased EPO and sEPO result in significant increase in total hemoglobin (Hb) mass (Chapman et al. 1998; Saunders et al. 2009). Training *per se* in hypoxia increases

mitochondrial and capillary density, capillary-to-fiber ratio, fiber cross-section area, myoglobin content and oxidative enzyme activity (Millet et al. 2010).

Scientific researches about AT started about fifty years ago. Probably the first noted adaptation induced by staying at altitude is an increase in red blood cell mass (Weil et al. 1968). Previous studies showed that this adaptation throughout increase in the oxygen carrying capacity of the blood improves aerobic power and sea-level performance (Levine & Stray-Gundersen, 1997). Although this is the fundamental factor, it might not be the main or the only one employed in performance improvement. Other important factors are central (ventilator, hemodynamic or neural adaptation) or peripheral factors such as muscle buffering capacity (Gore et al. 2001; Gore et al. 2007) or economy which also play an important role in post-altitude performance improvement (Millet et al. 2010).

The combined effects of the following factors will affect exercise performance at altitude (Chapman & Levine, 2000):

- (1) Lower pO_2 and the resulting effect on oxygen delivery to the working skeletal muscles. This will affect both acute exercise efforts and recovery between short-duration high intensity efforts.
- (2) The density of the atmospheric air and the resulting effect of air resistance.
- (3) The process of acclimatization to altitude, which can affect oxygen transport and acid-base balance. Additionally, this will affect motor skill proficiency in events that involve high speeds of the body through the air or high-speed projectiles.

Lower performing speeds in endurance events as a direct response to signals of muscle fatigue, are other characteristic of exercise at altitude (Levine & Stray-Gundersen, 1997; Brosnan et al. 2000). Altitude may have important effects even for short, high-intensity efforts that depend little on oxidative sources of ATP production, throughout increased oxygen debt with repetitive activities. Opposite to these physiological difficulties, density of the atmospheric air at altitude is smaller and the resistance of the air to the moving body is also smaller. Smaller air resistance allows athletes from track and field sprint disciplines, speed skating or speed cycling to achieve better results on the altitude.

The maximal aerobic power (VO_2 max) is reduced by about 15% at an altitude of 2.3km, and it is estimated that VO_2 max declines by 6-7% per 1000m (Gore et al. 1997; Wehrin & Hallen, 2006) or about 1-2% for every 100m above 1.5km (Drust & Waterhouse, 2010). This is manifested in significantly greater extent in trained subjects (Fulco et al. 1998). As a result, exercise at altitude at any level represents a greater 'training intensity' when compared with sea level. Consequently, the proportion of required VO_2 max at any altitude will be greater as the altitude increases (Martin et al. 2009).

Key questions in training for endurance competitions at altitude are: (1) at what altitude should the athlete live; and (2) how many days at altitude prior to the competition are necessary for adequate acclimatization (Chapman et al. 2009)? Considering the training practice, another two points should be added to these doubts: (3) how long should athletes train/live on high altitude; (4) when after altitude preparation positive fitness effects on competitive performance might occur and how long will they last? At present, sport science and practice produced several AT modalities in order to provide answers on those questions.

Effects of different AT modalities on sea-level performance

Currently, several types of AT and/or hypoxic exposure exist: traditional 'live high-train high' (LHTH), contemporary 'live high-train low' (LHTL), intermittent hypoxic exposure during rest (IHE) and live low-train high (LLTH) or intermittent hypoxic exposure during continuous session (IHT) (Miller et al. 2010). Despite several substantial differences between these methods of hypoxic all of them have the same goal: to stimulate an improvement in athletic performance at sea level. Figure 1 presents basic methods of AT used in nowadays sport practice.

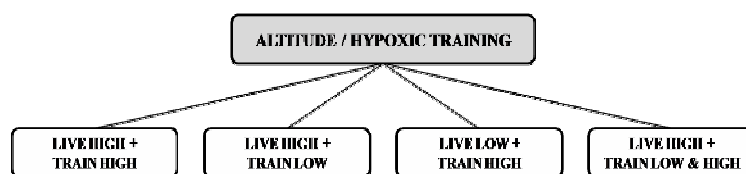


Figure 1. Basic methods of altitude (hypoxic) training (modified from Millet et al. 2010)

Traditional LHTH strategy, through living at altitude and AT, proved to be the most effective in producing hematological changes. The most common mentioned changes are increase in red blood cell mass (Weil et al. 1968), increase in the oxygen carrying capacity (Levine & Stray-Gundersen, 1997), increased levels of EPO and sEPO (Levine et al. 1991; Stray-Gundersen et al. 1997; Rusko et al. 1999; Phiel-Aulin et al. 1998) and increase in total Hb mass (Saunders et al. 2009). Svedenhag et al. (1991) reported that anaerobic capacity

that include alterations in lactate dehydrogenase and in muscle buffer capacity may be positively affected by short stays at altitude. Despite many positive effects, prolonged living at altitude might induce negative effects such as decrease in fat-free mass, muscle fatigue and deteriorated aerobic performance (Mollard et al. 2007). Although this is the basic strategy in training practice, beside physiological improvements, we could not find scientific papers that directly report performance improvements by this training strategy.

Strategy LHTL has been demonstrated to be an effective form of altitude training to improve sea-level endurance performance in endurance sports (Levine & Stray-Gundersen, 1997; Stray-Gundersen et al. 2001). Millet et al. (2010) summarized several AT studies and stated that overall reported performance improvement by strategy LHTL has been 1.0–1.5% for events lasting between 45 seconds and 17 minutes. The efficiency of this strategy on aerobic performance improvement was 1.1% (Levine et al. 1991), 1.2% (Chapman et al. 1998) and 4% (Mattila & Rusko, 1996). Levine and Stray-Gundersen (1997) show improved sea-level running performance, increase in red cell mass and VO_2 max in highly trained runners. Additionally, Chapman et al. (1998) reported significant improvement in VO_2 max and race time on 5000m after AT camp. The same strategy also showed to be effective in improvement of anaerobic performances. Although there is small number of anaerobic AT studies, Nummela and Rusko (2000) reported 1% race time improvement in 400m. They also stated that the race time improvement might be result of improved muscle buffering capacity. Using the same strategy, Gore et al. (2001) also found 18% increase in capacity of muscle buffers.

The efficiency of live low-train high (LLTH) or IHT strategy in scientific studies are still controversial (Truijens et al. 2003). This strategy showed to be not efficient in stimulating increase in EPO, erythropoiesis or other hematological changes (Emonson et al. 1997; Neya et al. 2007; Truijens et al. 2003; Valler et al. 1996). Contrary, other studies reported improvement in running economy in long and middle distance runners (Neya et al. 2007). However, the results of these studies didn't show significant effects on aerobic performance parameters, such as VO_2 max (Meeuwsen et al. 2001; Terrados et al. 1988; Vallier et al. 1996). This short-lasting stimulus is insufficient for hematologic performance improvement. Although, LLTH might be beneficial strategy in order to induce additional training stimulus for sea-level training. High intensity training in hypoxia might be the way to favor oxygen transport and utilization under hypoxic conditions (Vogt et al. 2001).

Millet et al. (2010) reported that LHTL strategy produce larger increase in endurance performance along with an improvement in mechanical efficiency and running economy in comparison to sea-level training. This strategy is proven to be effective in middle-distance athletes. However, the same authors suggested new strategy: mixed pattern by alternating nights at high altitude and nights at low altitude (five/six nights at high altitude and one/two night at sea level). There is clear evidence that intense exercise at high altitude stimulates the muscle adaptations for both aerobic and anaerobic exercise and limits the decrease in power. The authors suggested that it is still unknown if coupling LHTL and IHT strategy is the optimal combination. However, a training pattern associating five nights at 3000m and two nights at sea level with training at sea level, and sessions of supra-threshold training might be very efficient, especially in intermittent sports (such as football, tennis and squash).

Acclimatization to altitude and AT loads

Chapman et al. (2009) reported that it is important to distinguish between: 1) altitude acclimatization during preparation for competitions at altitude, and 2) AT and acclimatization for improvement of the sea-level performances. Proper altitude acclimatization is critical for performance outcomes in endurance events.

Phase of acclimatization starts immediately on arrival to altitude. The main purpose of this phase is to acclimatize the athletes to the reduced partial oxygen pressure at altitude (Miller et al. 2010). In order to facilitate acclimatization to altitude, athletes should be exposed to as much open air, low intensive aerobic activity as possible. Therefore, high-intensity exercise, especially lactic anaerobic workouts are not recommended in this phase. The acclimatization phase usually lasts 7–10 days (Miller et al. 2010). Based on the total duration of the AT camp and previous experience with hypoxic training, length of acclimatization phase might be smaller in experienced athletes (Miller et al. 2010; Issurin, 2007). The optimal duration of AT appears to be 4 weeks for inducing accelerated erythropoiesis (Millet et al. 2010). Threshold height for enhanced erythropoiesis is approximately 2100–2500m (Pottgieser et al. 2004; Rusko et al. 2004)

Periodization and practical application of AT

Training periodization is vital part of sport training theory and practice. Proper application of AT in cycles of sport preparation is difficult task. Screening of the erythropoietic and velocity of training response to acute altitude, in the future might allow us to identify athletes who will appropriately respond to LHTL strategy or traditional LHTH strategy. Moreover, this type of analyze might allow us to determine the athletes who will not respond to AT and those who will make bigger improvements in regular sea-level training (Champan et al. 1998). In the athletes who respond well on the AT stimuli, this type of training showed to produce positive effects on training and competitive performance. Although there are numerous AT studies in nowadays training science, practical training recommendations about delay between descent to the sea level and competitions are

still very few. As already noted by Millet et al. (2010), no study has investigated how to incorporate hypoxic training into the athlete's general training program. Training recommendations are still mainly based on the opinions of elite coaches who have experience with AT in sport practice. The general consensus among top coaches would suggest that endurance performance is optimized after 14 days at sea level after a AT stimulus (Dick, 1992) although there is still no scientific evidence to support this claim (Bailey & Davies, 1997)

One of the rare studies that, based on more 1000 competitive track & field results from middle and long distance runners and repeated VO_2 max tests, identified possible nature of work capacity oscillations following AT camp, was conducted by Suslov (1994). This research identified a decrease in competitive performance in the first two days after returning to sea level. More importantly, he identified two longer phases of enhanced work capacity. First phase of enhanced work capacity occurring between days 3 and 7 is followed by a decrease between days 8 and 10. Another performance improvement was reported between days 12 and 13, while the best results are achieved during 18 and 20 days after AT. Second phase of enhanced work capacity is reported between days 36 and 48 after AT (Figure 2).

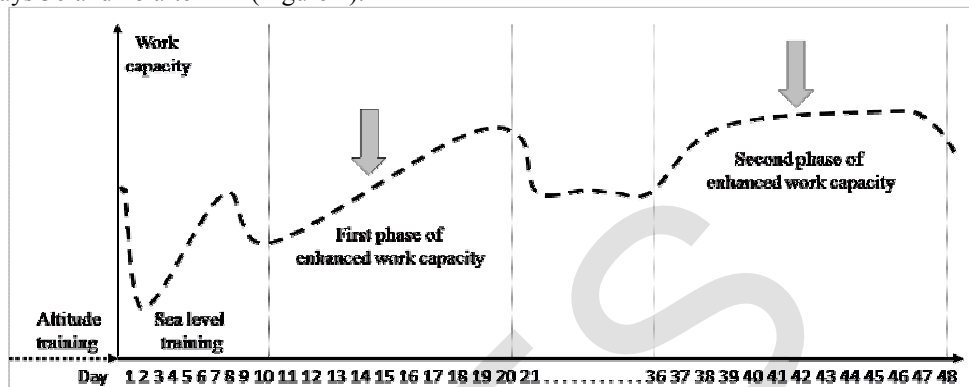


Figure 2. Phases of enhanced work capacity after AT (modified from Suslov, 1994)

Although physiological mechanisms responsible for this oscillations in work capacity were not identified, those training phases showed to be very effective and useful in sport training practice for competitive performance improvement. These two phases should be the main guidelines while planning and programming training for the best competitive performance. Appropriate incorporation of those phases into training and competitive calendar, might induce the best possible fitness on the most important competitions. Therefore, despite numerous novel scientific papers about AT, application of AT in training practice is still mainly based on results from Suslov's study (1994).

Conclusion

Various AT modalities may improve training and competitive performance. Physiological acclimatization to a chronically reduced $p\text{O}_2$ is a vital requirement for achieving optimal physical performance in hypoxic environment. Although numerous, AT researches are still not sufficiently connected with training practice and remain equivocal. It is known that some hypoxic methods are more beneficial than the others are. Despite many different AT modalities, it is still unknown which modality will be the best for improvement of different physiological or competitive parameters. The further development of practical knowledge in area of AT should predominantly include recommendations about application of different AT methods in training periodization of various sports. Improvement of the work capacity and duration of enhanced work capacity at the sea level after AT stimuli are problems for future scientific researches.

References

- Bailey DM, Davies B. (1997). Physiological implications of altitude training for endurance performance at sea level: a review. *Br J Sports Med*, 31:183-190.
- Brosnan MJ, Martin DT, Hahn AG, et al. (2000). Impaired interval exercise responses in elite female cyclists at moderate simulated altitude. *J Appl Physiol*, 89:1819–1824.
- Chapman RF, Levine BD (2000). The effects of hypo and hyperbaria on sport performance. In *Exercise and Sports Science*, ed. Garrett WE & Kirkendall JT, pp. 447–458. Lippincott, Williams & Wilkins, Philadelphia.
- Chapman RF, Stray-Gundersen J, Levine BD. (1998). Individual variation in response to altitude training. *J Appl Physiol*, 85(4):1448-1456.
- Chapman RF, Stickford JL, Levine BD. (2009) Altitude training considerations for winter sport athlete. *Exp Physiol*, 95(3):411–421.
- Dick FW. Training at altitude in practice. (1992). *Int J Sports Med*, 13, Suppl. 1:S203–206.
- Drust B, Waterhouse J. (2010). Exercise at Altitude. *Scott Med J*, 55(2):31-34.
- Emonson DL, Aminuddin AH, Wight RL, et al. (1997). Training induced increases in sea level VO_2 max and endurance are not enhanced by acute hypobaric exposure. *Eur J Appl Physiol Occup Physiol*, 76 (1):8-12.

- Fulco CS, Rock PB, Cymerman A. (1998). Maximal and submaximal exercise performance at altitude. *Aviat Space Environ Med*, 69:793–801.
- Gore CJ, Clark SA, Saunders PU. (2007). Non-hematological mechanisms of improved sea-level performance after hypoxic exposure. *Med Sci Sports Exerc*, 39(9):1600-1609.
- [Gore CJ](#), [Hahn AG](#), [Aughey RJ](#), et al. (2001). Live high: train low increases muscle buffer capacity and submaximal cycling efficiency. *Acta Physiol Scand*, 173(3): 275-286.
- Gore CJ, Little SC, Hahn AG, et al. (1997). Reduced performance of male and female athletes at 580 m altitude. *Eur J Appl Physiol Occup Physiol*, 75:136–143.
- Hoppeler H, Vogt M. (2001) Muscle tissue adaptations to hypoxia. *J Exp Biol*, 204:3133–3139.
- Issurin V. (2007). Altitude training: an up-to-date approach and implementation in practice. *Sporto Mokslas*, 1(47):12-19.
- Levine BD, Stray-Gundersen JS. (1992). A practical approach to altitude training: where to live and train for optimal performance enhancement. *Int J Sports Med*, 13, Suppl 1:S209–S212.
- Levine BD, Stray-Gundersen J, Duhaime G, et al. (1991). “Living high-training low”: the effect of altitude acclimatization/normoxic training in trained runners [abstract]. *Med Sci Sports Exerc*, 23:S25.
- Levine BD, Stray-Gundersen J. (1997) “Living high-training low”: effect of moderate-altitude acclimatization with low-altitude training on performance. *J Appl Physiol*, 83(1):102–112.
- Martin DS, Levett DZ, Grocott MP, et al. (2009). Variation in human performance in the hypoxic mountain environment. *Exp Physiol*, 95(3):463–470.
- Mattila V, Rusko HK. (1996). Effect of living high and training low on sea level performance in cyclists [abstract]. *Med Sci Sports*, 28 Suppl. 5:S157.
- Meeuwssen T, Hendriksen IJM, Holewijn M. (2001) Training induced increases in sea-level performance are enhanced by acute intermittent hypobaric hypoxia. *Eur J Appl Physiol*, 84:283–290.
- Millet GP, Roels B, Schmitt L, et al. (2010). Combining Hypoxic Methods for Peak Performance. *Sports Med*, 40(1):1-25.
- [Mollard P](#), [Woorons X](#), [Letournel M](#), et al. (2007) Determinants of maximal oxygen uptake in moderate acute hypoxia in endurance athletes. *Eur J Appl Physiol*, 100(6):663-673.
- Neya M, Enoki T, Kumai Y, et al. (2007). The effects of nightly normobaric hypoxia and high intensity training under intermittent normobaric hypoxia on running economy and hemoglobin mass. *J Appl Physiol*, 103:828–834.
- Nummela A, Rusko H. (2000). Acclimatization to altitude and normoxic training improve 400-m running performance at sea level. *J Sports Sci*, 18(6):411-419.
- Phiel-Aulin K, Svedenhag J, Wide L. (1998). Short-term intermittent normobaric hypoxia: haematological, physiological and mental effects. *Scand J Med Sci Sports*, 8:132-137.
- Pottgiesser T, Ahlgrim C, Ruthardt S, et al. (2009). Hemoglobin mass after 21 days of conventional altitude training at 1816m. *J Sci Med Sport*, 12:673–675.
- Rusko HK, Tikkanen H, Paavolainen L. (1999) Effect of living in hypoxia and training in normoxia on sea level VO₂ max and red cell mass [abstract]. *Med Sci Sports*, 31 Suppl. 5:S86.
- Rusko HK, Tikkanen HO, Peltonen JE. (2004) Altitude and endurance training. *J Sports Sci*, 22(10):928–944.
- [Saunders PU](#), [Telford RD](#), [Pyne DB](#), et al. (2009) Improved running economy and increased hemoglobin mass in elite runners after extended moderate altitude exposure. *J Sci Med Sport*. 12(1):67-72.
- Stray-Gundersen J, Chapman RF, Levine BD. (2001) “Living high-training low” altitude training improves sea level performance in male and female elite runners. *J Appl Physiol*, 91:1113–1120.
- Suslov FP. (1994). Basic principles of training at high altitude. In: *New studies in athletics, The IAAF Quarterly Magazine for NSA*, 2:45-49.
- Svedenhag J, Saltin B, Johansson C, et al. (1991). Aerobic and anaerobic exercise capacities of elite middle-distance runners after two weeks of training at moderate altitude. *Scand J Med Sci Sports*, 1(4):205- 214.
- Terrados N, Melichna J, Sylven C. (1988). Effects of training at simulated altitude on performance and muscle metabolic capacity in competitive road cyclists. *Eur J Appl Physiol*, 57:203–209.
- Truijens MJ, Toussaint HM, Dow J, et al. (2003). Effect of high-intensity hypoxic training on sea-level swimming performances. *J Appl Physiol*, 94(2):733–743.
- Vallier JM, Chateau P, Guezennec CY. (1996). Effects of physical training in a hypobaric chamber on the physical performance of competitive triathletes. *Eur J Appl Physiol*, 73(5):471-478.
- Vogt M, Puntschart A, Geiser J, et al. (2001). Molecular adaptations in human skeletal muscle to endurance training under simulated hypoxic conditions. *J Appl Physiol*, 91 (1):173-182.
- Wehrlin JP, Hallen J. (2006). Linear decrease in VO₂ max and performance with increasing altitude in endurance athletes. *Eur J Appl Physiol*, 96:404–412.
- Weil JV, Jamieson G, Brown DW, et al. (1968). The red cell mass-arterial oxygen relationship in normal man. *J Clin Invest*, 47:1627–163