Altitude Training, Performance, and Physiological Responses to Exercise

Quick Summary

Athletes and coaches often include altitude training as part of their seasonal plan because of the beneficial effects it can have on performance. The physiological changes that occur as a result of altitude training can have positive effects on both endurance and sprint performance. However, the extent of these effects may depend on the individual swimmer and how their body reacts to altitude. Most research on altitude training has been performed using the live high/train low method, which allows the athlete to train at sea-level intensities, while still obtaining the potential benefits of living at altitude (2,500-3,000m).

Altitude Training, Performance, and Physiological Responses to Exercise

Athletes and coaches often include altitude training as part of their seasonal plan because of the beneficial effects it can have on performance. In fact, several teams travel to the Olympic Training Center in Colorado Springs, CO every year, in part to take advantage of living and training at an altitude of 6,200ft. Research in this area has focused on four basic manipulations of altitude training: 1) live high/train high, 2) live high/train low, 3) live low/train high, and 4) live low/train low. The majority of research has explored the live high/train low method of altitude training. This form of altitude training can improve sea-level performance if the altitude stimulus is sufficient in length and altitude. The chain of events that may lead to an improvement in athletic performance during/after altitude training includes:

1. Decreased barometric pressure at altitude leads to decreased partial pressure of oxygen and lower amounts of oxygen in the blood. **
2. The kidneys sense the decreased amounts of oxygen and release erythropoietin (EPO).
3. EPO signals the bone marrow to increase production of red blood cells (RBC), which are released into the bloodstream.
4. Each red blood cell contains oxygen-carrying particles called hemoglobin. Increased RBCs allow the blood to carry more oxygen to active muscles and may result in increased maximal oxygen consumption when initially returning to sea level.

** It should be noted that devices such as altitude tents can artificially simulate the altitude environment. Altitude tents function based on a normobaric hypoxic environment. The tent is used at sea level (normal atmospheric pressure), but the oxygen content of the air entering the tent is lower than normal, thus artificially reducing the partial pressure of oxygen in the tent.

In addition, there is a limited amount of research that shows that altitude training may increase the lactate buffering capacity of muscle, thereby improving anaerobic capacity as well as aerobic capacity. Furthermore, altitude training can improve the recovery of an athlete from difficult training sessions, and therefore allow them to train at higher levels. This effect can improve performance in sprint events in swimming.

While many research studies have shown an improvement in endurance performance after altitude training, there still remain many uncertainties in this area of research. Living at moderately high altitude (2,500-3,000m) and training at low altitude (sea level) may improve endurance performance at sea level in well-trained athletes. However, the questions remains as to whether this applies to elite athletes, who may be closer to the functional capacity of their respiratory system and, therefore, unable to benefit as much from altitude training. In addition,
although there is a potential group response to altitude training, there is large variability in the individual response. Living at moderate altitude and training at low altitude may improve endurance performance and increase maximal oxygen uptake, however, this may not be a feasible option for all athletes. It can be expensive and time consuming to live at altitude and commute 2-3 times daily to workout at sea level. One potential alternative may be to live at a moderate altitude and to artificially create training conditions at low altitude by breathing supplemental oxygen. Furthermore, since the majority of swimming events take place in less than five minutes and many in less than one minute and 30 seconds, investigations on the effects of altitude on endurance performance may not be completely relevant. Studies investigating the effects of altitude on sprint or anaerobic performance are more relevant to the sport of swimming. Lastly, most research on altitude training has been conducted in sports other than swimming. In order to more closely examine the relevance of this research to the sport of swimming, studies must be performed on elite swimmers.

The literature on altitude training is extensive and this research review examines a few aspects of altitude training from recently published journals. These articles explore altitude training and its effects on performance and physiological responses to exercise. In addition, some of the issues mentioned above will be addressed in the following journal articles.

1. Elite-level athletes improve endurance performance following altitude exposure.


**Purpose and Methods**

The purpose of this study was to examine whether elite athletes benefit from altitude training (live high/train low) to the same degree as well-trained (non-elite) athletes. Twenty-two elite distance runners (14 men and 8 women) who were competitive at the national level and had previously lived at less than 1,000m, lived at moderate altitude (2,500m) for 27 days. During this time, the athletes completed high-intensity interval training at 1,250m and low-intensity training at 1,250m to 3,000m. All athletes completed a 3,000m time trial at sea-level three days before and three days after altitude exposure. Performance, maximal oxygen consumption, hemoglobin concentration, and plasma erythropoietin were measured during the study protocol.

**Findings**

- Performance during the 3,000m time trial improved significantly after the live high/train low protocol (improved time by 5.8 seconds on average), with 1/3 of the athletes performing personal best times.
- Maximal oxygen consumption increased significantly by 3% after the altitude training protocol.
- Hemoglobin concentration increased significantly during altitude exposure and was significantly elevated compared to initial levels when they returned to sea level.
- Plasma erythropoietin (EPO) concentration almost doubled after one night at moderate altitude. EPO concentration was not significantly different from initial levels after 19 days of living at altitude and EPO levels dropped significantly below initial levels upon return to sea level.

**Implications**

- Living high and training low can result in improved sea-level endurance performance.
The extent and mechanism of the improvement in elite athletes following altitude exposure is similar to that in non-elite athletes (increased hemoglobin concentration, initial EPO levels, and maximal oxygen consumption).

2. Response of athletes to altitude training is very individual.


**Purpose and Methods**

The purpose of this study was to determine the factors that contribute to the individual variability in the response to altitude training. Thirty-nine distance runners (27 men and 12 women) spent 4 weeks at moderate altitude (2,500m). The athletes were divided into three training groups that involved: 1) training at moderate altitude (high-high), 2) training at low altitude (high-low) or 3) low-intensity base training at moderate altitude and high-intensity interval training at low altitude (high-high-low). Before and after the 4-week altitude exposure, laboratory and performance testing were completed. After altitude exposure, the athletes were divided into "responders" and "non-responders" to altitude training based on the change in performance of a 5,000m time trial at sea level before and after altitude training camp. The responders (n=17) came from all three groups (7 high-high, 4 high-high-low, 4 high-low) and the non-responders also came from all three training groups (3 high-high, 6 high-high-low, 8 high-low). Differences in various physiological parameters between the responders and non-responders were examined in order to determine the reasons for individual variability in response to altitude training.

**Findings**

- Erythropoietin (EPO) concentration increased significantly in responders and non-responders after 30 hours at altitude. However, the responders had a significantly larger increase in average EPO compared to the non-responders during this timeframe (6.5 mU/ml vs. 4.7 mU/ml).
- After the 4-week altitude training camp, total red cell volume and maximal oxygen consumption increased significantly in responders but remained comparable to pre-altitude levels in non-responders.
- Even though there was no initial sea level difference, when at altitude non-responders performed their interval training at a significantly slower pace than responders.

**Implications**

- In order to potentially receive the benefits of altitude training, a swimmer may need to live at a sufficiently high altitude to stimulate a large, rapid increase in EPO.
- The altitude needed to bring about these effects may be highly individual.
- Some swimmers may also need to train at an altitude that is relatively close to sea level in order to maintain interval-training paces and oxygen consumption.
- A pre-altitude training camp screening of EPO and interval training responses to acute altitude in swimmers may further aid the appropriate assignment of proper living and training altitudes.

3. Supplemental oxygen during high-intensity training at altitude can improve performance.

**Purpose and Methods**

The purpose of this study was to compare the training effects of doing high-intensity interval training at moderate altitude (1840m) while breathing different mixtures of supplemental oxygen. Fifteen highly trained competitive cyclists completed 3 weeks of living and training at altitude. During this time, the athletes completed 3 days a week of moderate intensity training and 3 days a week of high-intensity training. During the high-intensity training, athletes either breathed a normoxic gas mixture (similar to moderate altitude conditions) or a hyperoxic gas mixture (similar to sea-level conditions). Physiological and performance testing was completed before and after the three weeks of altitude training. The performance test consisted of the time to complete 120 kJ of work on a cycle ergometer while breathing supplemental oxygen simulating a sea-level altitude. In this study, power at maximal steady state was defined as “the highest workload that could be sustained for 9 min without a rise in blood lactate (<1.0 mmol•L⁻¹).”

**Findings**

- The hyperoxic group (sea-level) was able to train at a significantly higher percentage of their power output at lactate threshold than the normoxic group (moderate altitude) (126% vs. 109%).
- The hyperoxic group significantly improved their performance test time by 15 seconds, whereas the normoxic group did not significantly improve their performance time over the altitude training period.
- The hyperoxic group significantly improved power output at maximal steady state by 20 watts, however the normoxic group did not significantly improve power output at maximal steady state.

**Implications**

- While training at altitude, breathing supplemental oxygen allows athletes to train at higher intensities that can result in performance improvements.
- This may be an easy alternative to living at altitude and commuting to lower altitudes on a daily basis to train.

4. **Live high, train low improves anaerobic performance.**


**Purpose and Methods**

The purpose of this study was to examine whether living high and training low has an effect on sea level anaerobic performance. Eighteen well-trained 400-m runners from the Finnish national team were divided into: 1) a “living high and training low” group that lived in an “altitude house” and trained at sea level and 2) a control group that lived and trained at sea level. The altitude house is an apparatus used to simulate altitude conditions in a sea-level environment. In the altitude house, altitude conditions were created by increasing the concentration of nitrogen in inspired air, thus decreasing the fraction of oxygen in the air. The percent of oxygen was equivalent to an altitude of about 2,200m. The altitude house group spent 10 days living in the
houses and training at sea level. All subjects completed performance testing before and within 1 week following the experimental protocol.

Findings

- Altitude house runners significantly improved their 400m or 400m hurdle times. The sea-level group did not significantly improve their performance times.
- The altitude group significantly increased running speed at blood lactate concentrations of 5 and 7 mmol•l⁻¹ after the altitude house compared to pre-altitude house.

Implications

- Living at moderate altitude and training at low altitude may lead to improvements in anaerobic, sprint performance. This is important for swimmers because many swimming events take place in less than 2½ minutes and require all out efforts that largely depend on the use of the anaerobic pathway.
- Improved anaerobic performance may be due to an increased ability to metabolize lactate after altitude training.
- Altitude tents that artificially simulate living at altitude might be used as an easy alternative to an altitude house.

5. Variable response of elite swimmers to altitude training.


Purpose and Methods

The purpose of this study was to examine changes in performance and certain physiological parameters in elite swimmers during two altitude-training camps. The two training camps were conducted over three weeks at moderate altitude (2102) meters in Flagstaff, AZ. Sixteen swimmers took part in Camp 1 (May, 1995) and twenty-two swimmers participated in Camp 2 (March, 1996). The training camps were divided into three phases: acclimatization (days 1-5), volume/intensity (days 6-20), and recovery (days 21-24). Swimmers performed an incremental swimming test consisting of 5 x 200m at least twice during the training camp. Heart rate and blood lactate were measured during the incremental swimming test. Heart rate-swimming velocity and lactate-swimming velocity ratios were computed for the 1st, 3rd, and 5th swims of the incremental swim test.

Findings

- During Camp 1, the time for the 5th 200m swim (maximal effort) significantly improved from day 8 to day 18 (2:20.1 to 2:17.3). During Camp 2, performance time for the 5th 200m swim improved from day 8 to day 18 and from pre-training camp to post-training camp at sea level.
- During Camp 1 but not Camp 2, the heart rate-swimming velocity and lactate-swimming velocity ratios were significantly lower on Day 18 compared to Day 8 for the three swims. In other words, heart rate and lactate levels decreased relative to swimming velocity.
- During Camp 1, levels of creatine kinase (a biochemical indicator of exercise-induced muscle damage) did not significantly increase during the three-week altitude training camp. The elite swimmers were able to adapt to the physiological changes endured when training at altitude.
Implications

- Altitude training can improve altitude and sea level performance of a non-endurance event.
- Some of the benefits of altitude training may depend on initial fitness level. For example, swimmers at Camp 2 (in 1996, an Olympic year) did not improve submaximal fitness, while those at Camp 1 did improve submaximal fitness.

The Final Word

- While altitude training can result in improvements in athletic performance, there are many variables that can alter or modify the effects of altitude training on individual athletes.
- Important points to remember are:
  1. Living at moderate to high altitude and training at low altitude can result in significant improvement in endurance and anaerobic performances at sea-level.
  2. Individual athletes may vary in their response to altitude training. Some athletes may respond very favorably to altitude training, while other athletes may not respond at all. The short-term altitude response of erythropoietin in the blood can be a good indicator of a positive response or no response to altitude training.
  3. There are alternatives such as supplemental oxygen, altitude tents, and nitrogen houses that can be used to simulate the live high/train low philosophy of altitude training.
  4. The effect of altitude training on performance and physiological variables in elite swimmers needs to be examined further.
  5. The athlete should spend a minimum of 2-3 weeks doing altitude training in order to receive the benefits.
  6. In order to receive the potential benefits from altitude training, athletes should maintain sufficient levels of iron, stay healthy and injury-free, hydrate well, and eat properly!

Recommended Reading


