The ALTITUDE Project

An international collaborative research project on the impact of different strategies of altitude training on performance, technique and health status in elite swimmers

IMPORTANT NOTE: This document is a privileged copy of the research project draft. Although summarizing its main features at present time, changes, even of relevance, may be implemented after all-party agreements. Requests and further information: thealtitudeproject@gmail.com
The ALTITUDE Project

A summary

In swimming, Olympic medals are often won by fractions of a second. One strategy that is often employed to obtain that advantage is altitude training. Over the past decade, a large amount of altitude training research has led to a new paradigm—the “living high-training low” model. In this approach, athletes live at altitude to gain the advantages of altitude acclimatization, but train at sea level to maximize hard training. Indeed a recent summary of many studies concluded that the potential performance benefit from altitude training for elite athletes could be as high as 1.6% (the difference between a gold medal, and not even making it to the Olympic Games!). However virtually all these studies have been done in land-based athletes with remarkably few studies performed in swimmers. Nevertheless, many sports teams expend precious resources going to altitude without knowing whether they are using the right approach, or even whether they should bother at all. **The key question we need to answer is whether altitude training really works for swimmers, as well as why, how, when, and for whom it works.**

The ALTITUDE Project aims to: 1) determine the effectiveness of altitude training using the Hi-Hi (living and training at moderate altitude), or the Hi-Lo (living high but training at lower altitude) model, in comparison with sea level training; 2) establish the physiological mechanisms involved; 3) ascertain whether altitude training affects swimming technique; 4) uncover any negative impact on athletes’ health and performance; and 5) identify markers of individual response and adaptation to training at altitude that could help clarify which athletes are likely to respond to an altitude training swimming camp.

To answer these cutting-edge questions, in an unprecedented cooperative effort in sports sciences, a high-profile international group of researchers belonging to universities and national swimming organizations of Spain, USA and The Netherlands, the High Altitude Training Center of Sierra Nevada, the USOC, the Australian Institute of Sport—among others—, have developed a major international swimming study called The ALTITUDE Project. About 40 elite swimmers from various countries and their coaches will participate in sea level or altitude training camps at the High Performance Training Centers of Sierra Nevada (2,320 m) and Barcelona (sea level) during January-February, 2011.

The project is open to sports and scientific national organizations from all countries willing to contribute with recruiting and funding athletes, coaches and scientists.

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What is the ALTITUDE Project?

- An international collaborative research project on the impact of different strategies of altitude training on performance, technique and health in elite swimmers
- The project is open to sports and scientific international and national organizations from all countries willing to contribute by recruiting and funding volunteer athletes, coaches or scientists

What are the goals of the project?

- To determine the effectiveness of altitude training for swimmers using the two most commonly used strategies—Hi-Hi (living and training at moderate altitude) vs. Hi-Lo (living at moderate high altitude but training at lower altitude)—in comparison with an excellent training camp at sea level
- To elucidate the physiological mechanisms involved in altitude training, including acclimatization to moderate altitude, training adaptations and how these might work together
- To ascertain whether training at altitude affects swimming technique
- To uncover any negative impact on athletes’ health and performance
- To identify markers of individual response and adaptation to training at altitude

Who is eligible to participate?

- A total of 40 elite swimmers—and their coaches—from various countries will voluntarily participate in the study
- Elite swimmer is defined as a male or female swimming athlete, typically—but not exclusively—older than 17 years of age, who has recently competed or foresees to compete internationally representing his/her country. Swimmers who do not meet this criteria may also be eligible according to their competitive records
- Athletes, coaches, and scientific and medical staff from the countries involved—including the USA, The Netherlands, Australia, Germany, Denmark, Finland, Japan, Italy, France, Estonia, and Spain, among others—will take part in the study based on previous agreements with their respective national swimming federations, clubs, and Olympic committees
- An internationally renowned scientific and medical staff will collaborate in designing, monitoring, and assessing a high-profile scientific research study while a performance-oriented training plan is implemented in agreement with individual or national team coaches

Why should I participate in this study?

For athletes

- To benefit from a well-planned training camp aimed at improving swimming performance and directly implemented by your own personal coaches. Our experience with many studies of this type is that all groups of athletes improve from a well designed training camp experience, regardless of whether it is at altitude or at sea level
- To determine whether altitude training works for you, and whether you should consider incorporating of altitude training in preparation for major competitions leading up to London 2012
- To enjoy the unique experience of training with other top athletes from other countries in the optimal environment of internationally famous high-performance training centers
- To have the opportunity of visiting two of the most beautiful Mediterranean cities—Barcelona and Granada—proud to exhibit a magnificent cultural, artistic and human heritage

For coaches

- To provide a unique athletic and personal experience to your athletes while taking part in serious training
- To share training experiences with high-profile colleagues and scientists from various countries—some among the most successful swimming nations
To gather up-to-date information and experience in testing, assessment, and training procedures, as well as the most effective strategies for altitude training

To get direct access to individual and group results of physiological, medical, and technical assessments and to privileged information about the research outcomes before scientific publication. However, only sample group data will be available, thus protecting individual information, which will be blinded to other nations/squads

To determine whether you should consider altitude training into your preparation for major competitions before 2012, or if your resources are better served training hard at home

Where will the study take place?

- Participation starts at home with one week of lead-in training and finishes also at home with pre-planned time-trial tests
- Preliminary testing, as well as the sea level training camp, will take place in Barcelona, at the High Performance Training Centers CAR Sant Cugat and Club Natació Sabadell (CARPE). Alternatively, some tests could be arranged at Malaga or even at home
- The altitude training camps will be based at the High Altitude Training Center CAR Sierra Nevada (2,230 m) Granada, Spain
- All centers offer high-quality accommodation, nutrition, training facilities —50 m pool and dry-land training sets— and sports medicine and sports science services

When will the study take place and for how long?

- The study abroad is planned for the period October 1 to November 22, 2011
- There will be some staggering between groups during the testing week; thus, the total duration of the study in Spain will typically be 3 or 4 weeks (plus 3 days for testing if in Spain)
- Dates were selected taking into consideration the 2012 season, looking towards qualification and preparation for the London 2012 Olympics, in a preparatory period free of international competitions and thus suitable for a good training camp, whether at altitude or at sea level

Will I be responsible for any of the costs of this study?

- The project has obtained partial funding from the Ministry of Science and the Higher Sports Council of Spain. These funds will cover all experimental and research costs
- Sports organizations from the countries involved are asked to contribute with travel expenses (round trip flights to Barcelona and/or Granada)
- Accommodation for swimmers, coaches and staff can be free of charge and will be available in any case at lowest rates
- The goal of the project ultimately is to achieve a final zero-sum budget. Any financial budget surplus will be deducted from each participant's share and refunded to the participants if we are fortunate enough to exceed the costs of the project
- Countries eligible for IOC Olympic Scholarships for Athletes and Coaches (Olympic Solidarity programs) are encouraged to contact and apply to their NOCs for financial support
- Financial support from participant countries and institutions are most welcome

What will I be asked to do?

- The final study plan will be agreed upon by the scientific and coaching staff and all other participants involved in the project before September 15, 2011
- After initial testing, subjects will be matched according to their gender, level, stroke and physiological profile, and then assigned to one of the training groups:

* Please contact us for special rates at CAR Sierra Nevada
Hi-Hi: living and training at altitude — CAR Sierra Nevada (2,320 m)

Hi-Lo: living at altitude and training at high and lower altitude — these athletes will live at the CAR Sierra Nevada with their Hi-Hi fellows, and conduct most of their training at altitude; at least three times per week—or more if requested by athletes and coaches—, these athletes will be driven down to Granada (690 m, about a 45-minute drive) for high-intensity/quality training

Lo-Lo: living and training at sea level — CAR Sant Cugat, CN Sabadell, Barcelona

- All tests and assessments will comply with high-standard scientific procedures and conducted by fully qualified scientific and medical personnel. Approval of a governmental ethical committee has already been released. Invasive procedures will be limited to conventional venopunctures (blood tests) and ear pricks
- The study protocol will be based on the following scheme:

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<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>Hi-Hi</th>
<th>Hi-Lo</th>
<th>Lo-Lo</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
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</tr>
<tr>
<td>2,230</td>
<td>Hi-Hi</td>
<td>Hi-Lo</td>
<td></td>
</tr>
<tr>
<td>690</td>
<td></td>
<td></td>
<td>Lo-Lo</td>
</tr>
</tbody>
</table>
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**Post Testing**
- Hi-Lo
- Lead-in Training Home

**Testing**
- Home

**Training**
- High Intensity Training

**Performance | Technique**
- TT: time trials (50, 100/200/400 m, PB); KIN: kinematic analysis; ECON: swimming economy (3x200 m submaximal); VO2M: maximal oxygen uptake test (200 m all-out); MAOD: maximal accumulated oxygen deficit (4x200 m); MHb: total hemoglobin mass (CO rebreathing); HEM: hemogram; Fe: iron metabolism (including ferritin); OXI: prooxidant-antioxidant balance; IMM: immune status; ECHO: echocardiogram
What Do We Really Know About Altitude Training?

Checking the records of several swimming organizations and altitude training facilities around the world it becomes clear that altitude training (AT) plays an important role in preparing elite and sub-elite swimmers all over the world. They devote considerable amounts of time, effort, and resources to train in real or simulated altitude, with the expectation of improved sea level performance.

While acute hypoxia deteriorates swimming performance, chronic hypoxia may induce acclimatization effects, mostly through the acceleration of red blood cell production, which could improve aerobic capacity and therewith performance upon return to sea level. Other potential benefits such as improved exercise economy, enhanced muscle buffer capacity and pH regulation, and improved mitochondrial function have also been postulated.

Unfortunately, there is a remarkable lack of controlled studies on AT in swimming in the scientific literature, and the scientific evidence supporting most approaches to AT in general is inconclusive. Moreover, in spite of the important amounts of research carried out over the last decades, the physiological mechanisms through which AT should be effective in enhancing performance are still controversial. Field observations and research studies show that altitude/hypoxic training may work for some athletes and not for others.

Consequently, the ALTITUDE Project aims to study the effects of different strategies in AT on physical and swimming performance at sea level, on swimming technique, and on health status in elite athletes.

Scientific Background

Despite of the fact that benefits of real or simulated AT are still controversial in scientific literature, it still plays an important role in the preparation of elite athletes all over the world. This is why many countries, ours among others, have established altitude training sport centers. Despite the scientific controversy, they devote considerable amounts of time and material resources to train in real or simulated altitude (normobaric or hypobaric hypoxia attained through various methods), based on expectations raised on coaches and advisors by scientific studies mostly inconclusive, derived from uncontrolled or insufficiently controlled studies. In a recent review, it was concluded that accumulated results from five different controlled studies suggest that Hi-Hi (i.e. 1,500-2,500 m) does not improve sea level performance in elite athletes. In contrast, a recent meta-analysis concluded that the potential performance benefit from altitude training for elite athletes could be as high as 1.6%: the difference between a gold medal, and not even making it to the Olympic Games!

On the other hand, scientific research has focused on favorable aspects on performance or related physiological variables, including: (1) cardiorespiratory altitude acclimatization (ventilation, hypoxic ventilatory response, arterial oxygen saturation); (2) hematological responses and adaptations (EPO, erythropoiesis); and (3) effects on performance and aerobic capacity (athletic performance, exercise tolerance, ventilatory or metabolic thresholds, maximal oxygen uptake, etc.). These various adaptations depend on different parameters, some of which characterize the “dose” of hypoxia, while others refer to training and the clinical status of the subjects. In real altitude, these parameters include the degree of hypoxia (i.e. altitude over sea level), the duration of the exposure, the type of training, the specific characteristics of training, the subjects’ performance level, etc. This heterogeneity makes research in this area particularly complex.

Finally, few studies have focused on the less beneficial or even deleterious effects of AT on performance and health. For instance, it has been proved that cardiac output and blood flow to the skeletal muscles are impaired, and that tolerance to high-intensity training is reduced, and that signifi-

† The High Altitude Training Center CAR Sierra Nevada, dependent of the Spanish Higher Sports Council (Consejo Superior de Deportes), with a privileged location at 2,320 m of altitude, is one of the most prestigious altitude training centers. During 2009 more than 7,000 athletes, 20% swimmers, have used their facilities.
significant sleeping disturbances, anorexia and weight loss, and symptoms of acute mountain sickness during the first days of exposure—although generally mild or moderate and temporary—do actually occur. From a clinical perspective, preliminary evidence suggests that exercise in hypoxia may induce depression of the immune status in athletic subjects, as well as cellular damage due to increased oxidative stress evoked by exercise in hypoxia.

**Adaptive mechanisms to altitude training**

The complexity and interplay of adaptive mechanisms to altitude which could potentially improve sea-level performance is shown in Figure 1. The controversy on the role of the different mechanisms involved in the synergistic potential of training and exposure to hypoxia continues nowadays.

**Altitude training strategies**

AT for the enhancement of athletic performance is based on the principle of synergistic effects of some adaptive mechanisms of acclimatization to altitude and training. Thus, the ideal AT would be one which optimizes both types of stimuli (hypoxia and training) to induce central and peripheral changes enhancing oxygen transport and utilization (Figure 1), while avoiding the negative effects of inadequate training (under- and overtraining).

The common strategies of altitude/hypoxic training are:
- living and training at moderate altitude (LH-TH = Hi-Hi)
- living at altitude and training at low altitude (LH-TL = Hi-Lo)
- living at low altitude and training at high altitude (LL-TH = Lo-Hi)
- living and training at low altitude or at sea level (LL-TL = Lo-Lo)
Traditional AT consists on the athlete living and training at moderate altitude (Hi-Hi). In the 90s an alternative to this method was postulated, consisting in living at altitude but training at lower altitude (Hi-Lo), and thus combining altitude residence (2,500-2,700 m) with more intensive training sessions at lower altitude (e.g., 1,250 m). The physiological changes evoked by this strategy include increased soluble transferrin receptor (indicating enhanced erythropoiesis), total hemoglobin mass, maximal oxygen uptake (VO2max) and improved sea-level running performance (3,000 and 5,000 m) in college and club athletes, as well as in elite runners. This ergogenic effect was attributed to an increased erythropoietin (EPO) secretion and its subsequent erythropoietic effect, which in turn would enhance VO2max. The advantage compared to the Hi-Hi strategy would lie in the possibility of carrying out high intensity training sessions with an adequate oxygen flux to the active muscles, which would not be possible under hypoxic conditions. Despite promising results, the underlying mechanism has been recently challenged and is still controversial in the literature.

Effects of altitude acclimatization on metabolic capacities

Exercise at hypoxia does not affect equally aerobic and anaerobic metabolic capacities. Performance in sport disciplines mainly depending on the aerobic metabolism is impaired with ascent to altitude due to significant reduction of VO2max and slower oxygen kinetics during submaximal exercise loads. However, although VO2max remains impaired during altitude sojourns, it may be partially restored to values close to 50% in elite athletes after two weeks at altitude. The compensatory mechanisms are very complex and partially unknown, although the Bohr effect, respiratory alkalosis, and increased 2,3-DPG may optimize the Hb-O2 dissociation curve, thus contributing to improving the aerobic capacity during exercise. Moreover, blood lactate concentration for a certain moderate-intense workload increases, and the load (or VO2) at which the anaerobic threshold appears are reduced.

On the other hand, performance in high-intensity exercise of short duration does not seem to be affected by altitude. Reduced oxygen availability seems to increase the activity of the anaerobic metabolism for a given exercise intensity, as a compensatory measure to restricted aerobic metabolism. After sudden ascent, respiratory alkalosis occurs during the two first days, which may favor high-intensity efforts by improving the working conditions of the muscles. Subsequently, renal compensation of metabolic alkalosis induced by a change in the ventilatory pattern may reduce buffer capacity, which could be advantageous during training at altitude. The causes for this anaerobic improvement during altitude sojourns have not been fully investigated, although it seems independent of lactate response. The reduction of maximal blood lactate observed during long sojourns at altitude, the so-called “lactate paradox”, is still a debated phenomenon, which could reverse after 4-6 weeks of altitude exposure. Reduced glycolytic activity and/or limited capacity to store muscle glycogen are potential mechanisms. In summary, the effects of acclimatization and prolonged altitude sojourns on both the aerobic and the anaerobic capacities in high-level athletes are not fully understood.

Effects of altitude on sports technique

Acute exposure to hypoxia implies an increase of physiological exercise intensity, and, in order to maintain any given swimming speed over a fixed distance at sea level, stroke rate tends to increase and stroke length tends to decrease, with subsequent decrease of the so-called stroke index, a propulsive efficiency indicator. The behavior of technical variables during chronic exposure to hypoxia and later return to sea level, either for maximal or submaximal swimming workloads, have not been investigated. Whether a “technical acclimatization” to altitude takes place, beyond physiological acclimatization, is not known.

Impact of altitude training on health and performance

Opposite to favorable effects of AT, potential negative effects on performance and athletes’ health may also occur. For instance, there is risk of acute mountain sickness or impaired performance related, among other factors, to a decrease of VO2max and plasma volume, and subsequent appearance of early fatigue. Two key conditions for training at altitude are optimal health status and adequate iron stores allowing to successfully meet the requirements of erythropoietic

Recent publications by the same authors use the expression Hi-Hi-Lo to describe this strategy, since the major part of the training is actually conducted at altitude, while lower altitude training is used less frequently only for high-intensity sessions.
response to hypoxia. Most of our knowledge on the physiological adaptation to hypoxia and its impact on human health derive from studies performed over 3,500 m. However, many athletes experience minor symptoms of acute mountain sickness, mostly during the first days of their first altitude sojourns. Moderate sleep disorders with periodic breathing or apneic episodes, both during REM and non-REM phases, have been reported during moderate altitude exposure in cyclists. Also headache and minor gastrointestinal disorders need to be early detected and controlled if a correct adaptation to hypoxia is to take place. In most cases these symptoms are exacerbated during heavy physical exercise and, otherwise, tend to diminish as the acclimatization process occurs and during successive sojourns at altitude or exposures to hypoxia.

On the other hand, some studies suggest that prolonged exercise at altitude and acute exposure to moderate hypoxia may have acute deleterious effects on cardiovascular function. One must also consider the enhanced adrenocortical stimulus in hypoxia, particularly associated to intense and prolonged training. Although studies are inconclusive, it seems relevant to assess the impact of this factor considering its potential effects on muscle catabolism and the athlete’s immune system. As a matter of fact, many athletes experience respiratory or gastrointestinal infections during or following altitude sojourns, which can be related to a certain degree of immune depression not having been properly diagnosed and treated. In general, it may be said that the hypoxic stimulus implies a certain level of physiological and probably also psychological stress, which is likely to have a more negative impact on the athlete’s health and physical performance capacity compared to similar training loads at sea level.

Oxidative stress and antioxidant capacity

Physical exercise is an important factor in relation with oxidative stress, because of increased oxygen uptake and electron drain at the cellular respiratory chain. This process may also be strengthened at altitude due to environmental conditions (temperature, increased ultraviolet radiation), catecholamine increase, changes in aerobic metabolism, and tissular ischemia-reperfusion processes during exposure to hypoxia, among other factors.

However, studies on the prooxidant-antioxidant balance in elite athletes during acute and chronic exposure to moderate hypoxia are scarce and controversial. No significant changes in certain oxidative stress markers, such as malonildialdehde and other lipid hydroperoxides, have been detected during acute hypoxia. On the other hand, some studies suggest that prolonged sojourns at moderate altitude have a negative impact on this balance, increasing oxidative stress markers. Nevertheless, the degree of damage to the tissues depends on the balance between the speed of free radical formation and elimination by the various antioxidant systems. Despite the known fact that subjects with a good endurance training level may improve their antioxidant defenses, it’s not likely that this improvement would suffice to compensate the increase of free radicals and, thus, to reduce the risk of oxidative stress associated with intense training, particularly when the effects of exercise are added to the effects of hypoxia. In summary, prooxidant-antioxidant balance in high-level athletes exposed to AT is far from being known.

Impact of training and altitude on the immune system

Maintaining the capacity of response of the immune system is of utmost importance for elite athletes’ performance and, thus, it is necessary to preserve it during training and competition.

Intense training and altitude residence both may act as stressors in the organism, causing depression of the immune system. Some studies, even if far from being conclusive and homogeneous—probably because of different study models—seem to suggest different degrees of depression of the immune system, both cellular and humoral. In fact, the combined effect of hypoxia and training during a Hi-Lo altitude camp seems to have caused a decrease of IgA levels in elite cross country skiers, a condition which lasted after two weeks of active recovery. This condition is related to a higher risk of upper respiratory infections in athletes, even more frequent among swimmers. There are no reports of controlled studies trying to differentiate the type or degree of immune suppression due to training and to exposure to hypoxia, neither investigations on the effect on the entire immune system—cellular and humoral—, and on the impairment of immune competence on elite athlete’s health exposed to both factors.
Heart rate variability (HRV) and autonomous regulation

HRV analysis is acknowledged as a useful tool to determine changes in the activity of the autonomic nervous system. Spectral HRV analysis in acute hypoxia reveals an alteration of parasympathetic activity and an exacerbated sympathetic activity over the cardiac sinus node. Research on the adaptation to physical exercise has related training loads and HRV parameters, showing a relationship between total HRV, resting heart rate, and the intensity of the training load, and proving that such loads alter the autonomous balance of the heart towards a predominance of sympathetic over parasympathetic activity. Thus, it seems logical to hypothesize that the combined effects of training and altitude on HRV would allow to monitor the adaptation to AT, as suggested by recent studies in athletes exposed to the Hi-Lo strategy, in whom a clear increase of sympathetic activity has been observed. Whether this technique is able to discriminate between subjects who respond to different strategies of AT from the non-responders is not known. Which changes are related to chronic hypoxia or to training is not known either.
Current Hypothesis

Considering the controversy on the potential beneficial and deleterious effects of altitude training despite the time, material and human resources devoted to this type of preparation of elite athletes, we considered pertinent and relevant to undertake a controlled study examining the effects of training at moderate altitude on performance, physiological and coordinative capacities, and health status, and to compare them to those attained through conventional training. Moreover, we consider necessary to examine the adaptive or maladaptive mechanisms eventually operating, particularly those potentially affecting athletes’ performance and health, in order to attain higher levels of performance and preventing adverse effects.

1 The previously cited studies by Levine and Stray Gundersen support the hypothesis that Hi-Lo training would be more effective than classical altitude training (Hi-Hi), although these results have not been tested in sport disciplines of shorter duration (i.e. < 8 minutes). Moreover, results reported by Gore and coworkers suggest that the Hi-Lo strategy may increase muscle buffering capacity and efficiency in trained cyclists. Results obtained by the Spanish group, both independently and in collaboration with these investigators, suggest that a modality of Hi-Lo training based on intermittent exposure to severe hypobaric hypoxia (4,000-5,500 m) during 3 hours for 4 weeks evokes an increase of VO₂max and ventilatory threshold in competitive swimmers, without a concurrent increase of total hemoglobin mass.

2 Results obtained by Levine and Stray-Gundersen suggest that changes observed in trained runners exposed to the Hi-Lo strategy are caused by the activation of erythropoiesis as a result of hypoxia. However, this hypothesis is controversial in the literature.

3 Only one study in the literature, reported by the Spanish group, suggests that swimming technique is affected by acute exposure to moderate altitude, particularly for submaximal workloads during the first days of sojourn, showing an increase in stroke rate, and a decrease in stroke length and stroke index, which would suggest that technical parameters are sensitive to increased physiological stress by altitude exposure.

4 The combined effect of exposure to hypoxia and exercise during altitude training may be the cause of minor symptoms of acute mountain sickness, cardiovascular disturbances and increased oxidative stress. Moreover, decreased IgA levels have been observed in elite cross-country skiers, lasting up to two weeks after an active recovery period.
Aims

1. To contrast the hypothesis that living at moderate altitude (2,230 m) and training at low altitude improves swimming performance at sea level, metabolic capacities, and/or swimming economy in elite athletes more than living and training at altitude, or than living and training at low altitude (conventional sea-level training).

2. To elucidate whether the adaptive mechanisms are mainly hematologic in nature, via the activation of erythropoiesis by induced hypoxia, and to characterize its evolution in order to establish the optimal duration of exposure to hypoxia.

3. To elucidate whether training at altitude may impair swimming technique before physiological acclimatization to altitude occurs, as well as after descent to sea level.

4. To uncover eventual deleterious effects on athletes’ health by alteration of the cardiovascular regulation mechanisms (arterial pressure and heart rate variability), the immune system, or the prooxidant-antioxidant balance.
The first study of the ALTITUDE Project will be a joint research in which teams from two Spanish universities (INEFC-University of Barcelona and University of Granada), the High Performance Training Center (CAR) Sierra Nevada, and international experts from five countries (The University of Texas Southwestern Medical Center at Dallas, USOC, Australian Institute of Sport, University of Amsterdam, and the Royal Spanish and Dutch Swimming Federations) will collaborate, together with scientists of other countries joining the project. The laboratories, facilities, and equipment will be those of the Spanish institutions or those hired by them.

The sojourns at altitude will be held in the CAR of Sierra Nevada (2,230 m), one of the few centers in the world in which Hi-Lo interventions can be undertaken in practice due to its proximity to the city of Granada (only 30-45 minutes by car), where the needed sport, scientific, and logistic facilities are available.

Subjects
40 elite swimmers of international caliber from the different countries involved in the project will voluntarily participate in the study, according to previous agreements and contacts with their respective national swimming federations and Olympic committees.

Sample size has been calculated based on a potential increase of VO\textsubscript{2}max, as an eventual favorable result of the different interventions, of 5% (3 mL·kg\textsuperscript{-1}·min\textsuperscript{-1}, SD 3.2). This would require 11 athletes per group ($\beta = 0.80$, $\alpha = 0.05$), plus one more athlete per group anticipating drop-outs, and 4 reserves (total number: 12 x 3 groups + 4 reserves = 40 subjects).

Candidates can be selected only if they meet the following inclusion criteria:

1. participation in high-level international competitions.
2. optimal health status as accredited by the corresponding federation
3. availability during 3-4 weeks of training plus 2-3 days of testing, with random assignment to one of the two altitude experimental groups
4. ferritin levels within normal range, without analytical or clinical evidence of iron deficiency or anemia.

Experimental design
The study has been designed as a controlled, balanced, randomized experiment with three interventions:

1. Hi-Hi: living and training at moderate altitude (2,320 m);
2. Hi-Lo: living at altitude and training at low altitude (690 m, city of Granada); and
3. Lo-Lo: living and training at sea level.

After the first set of tests, subjects will be matched by gender, competitive level, and VO\textsubscript{2}max, and randomly assigned to one of the three groups (balanced random design will be used, at least, for the two altitude groups, Hi-Hi and Hi-Lo). The experiments will take place from **October 1st to November 22\textsuperscript{nd}, 2011**.

Before the experimental intervention (i.e. environmental and training conditions), all subjects will be tested twice in order to attain test familiarization, to minimize learning effects, and to establish test-retest reliability for the different assessments by calculating the technical error of measurement (TEM). During and after the intervention the subjects will be assessed according to the scheme shown in Figure 2.
Training and monitoring

All swimmers will undertake a training block (mesocycle) consisting of (time abroad in black):

- 1 week of lead-in training at home
- 1-2 days of initial testing at sea level
- 3-4 weeks of living-training at the assigned experimental conditions (Hi-Hi, Hi-Lo, or Lo-Lo)
- 1-2 days of final testing at sea level
- 2-3 weeks of regular training and follow-up time trials at home

Training will be planned and led by the swimmer’s personal coach, within a frame developed in consensus agreement with the scientific and coaching staff of the project, pursuing that training goals will be basically comparable among the three experimental groups. Training logs will be kept by each swimmer and coach, including training loads (i.e. sets, reps, pace, rest, recovery, etc.) and internal training loads (heart rate, session-RPE), plus data relative to diurnal and nocturnal resting
periods, clinical symptoms, diet, body weight, total fatigue score questionnaire, Lake Louis acute
mountain sickness questionnaire, and other relevant information. The Banister method will be used
to quantify the training load (TRIMPs). This method estimates the load of a training session based
on its duration and the average heart rate increase weighted by sex-specific factors.

Performance testing
The primary outcome variables of the study will be time trial results in 50-, 100/200-, and 400-m all-
out swims. Time trials will be performed under controlled conditions similar to actual competition
(previous training and rest, warming-up, swimming suit, etc.). Competition times before and after
the intervention period are to be recalled as well.

Swimming economy and metabolic capacities
All tests will be performed in 50-m indoor pools. After a fixed warm-up, all subjects will swim
3x400m freestyle at three submaximal speeds (1.0, 1.1, 1.2 m·s⁻¹ for women, and 1.1, 1.2, 1.3 m·s⁻¹
for men) followed by 2 min of passive recovery, in order to assess their swimming economy. After
a 3-min rest, they will swim 400 m at maximal speed to assess VO₂max, and to compute max-
imal accumulated oxygen deficit (MAOD) according to the method proposed by Medbø et al. by
relating measured oxygen uptake and that corresponding to the cubed swimming speed (V²). VO₂
will be measured breath-by-breath using a portable gas analyzer connected to a respiratory
valve designed and validated for measurements in the water.

Swimming technique
The following technical parameters will be analyzed: swimming velocity (SV), stroke rate (SR),
stroke length (SL), and stroke index (SI). All technical variables will be assessed twice in each 50-
m lap. SV (m/s) will be computed as the time to cover a fixed 5-m distance, previously marked with
a reference system. Its value will be computed as the ratio between the number of strokes (5) and
the time invested, times 60 s. SL (m/stroke) will be obtained from the ratio between swimming
speed and SR in strokes per second (Hz). Finally, SI will be computed as SV times SL. All tests will
be recorded by ferDuring the submaximal swimming economy tests (3x200 m), an underwater
pacer will be used, consisting on 50 lights 1 m apart, connected to a controller (SwimMaster) which
sets the speed of activation and, thus, the swimming pace. Turning times will be individually ad-
justed in order to compensate for the wall impulse. The system will be located at the bottom of the
pool.

Hematological assessment
Duplicate measurements will be performed before the intervention, followed by four measurements
during the intervention, and one post-intervention, according to the scheme in Figure 2. These
measurements will be taken in venous blood, including the following:

(1) hemogram: leukocyte count and formula, erythrocyte/red blood cell count (RBC), hemoglo-
bin (Hb) concentration, hematocrit, mean corpuscular volume (MCV), mean corpuscular Hb
(MCH), mean corpuscular Hb concentration (MCHC), erythrocyte dispersion index (EDI),
platelet count, mean platelet volume (MPV), platelet count, and platelet dispersion index
(PDI) (Coulter AcTdiff, Beckman Coulter,USA)

(2) serum erythropoietin (EPO) and soluble transferrin receptor (sTfr) by chemoluminisence
immunoassay in solid phase (Diagnostic Products) and immunonephelometry (Dade Behr-
ing), respectively

(3) erythrocyte and reticulocyte parameters by flux cytometry (ADVIA 120 hematology analyz-
er, Bayer Diagnostics)

(4) serum ferritin by photometry (Roche Diagnostics)

(5) total Hb mass using the CO rebreathing technique and diode-array spectrophotometry
(OSM 3 hemoximeter, Radiometer). The optimized technique developed by Schmidt &
Prommer (Eur J Appl Physiol 2005) will be utilized.

Prooxidant-antioxidant balance
Prooxidant-antioxidant balance will be assessed at systemic level from venous blood samples ob-
tained in the same extractions used for hematology and immunology measurements, according to
the scheme in Figure 2. Samples will be separated into plasma and cell-containing concentrate and three type of measurements will be undertaken:

1. free radicals production: spectrophotometric techniques, reactive oxygen species (ROS) and reactive nitrogen species (RNS) will be quantified
2. damage to macromolecules: oxidative damage to lipids or lipidic peroxidation by TBARS technique, residual protein oxidation by the Western Blot technique, and induced DNA damage by spectrophotometric quantification of 8-hydroxy-2’-deoxyguanosine
3. antioxidant capacity, both enzymatic (reduced and oxidized glutathione, glutathione peroxidase and reductase, catalase, and superoxidodismutase), and non-enzymatic (alpha-tocopherol and beta carotenotes).

**Immunology**

The immune status will be assessed at systemic level from venous blood samples obtained in the same extractions used for hematology and prooxidant-antioxidant balance measurements, according to the scheme in Figure 2. The analytical determinations will include:

1. serum immunoglobulins (IgM, IgG, IgA) using Roche modular analyzer
2. acute-phase interleukins produced by monocytes (IL-1-alpha, IL-6, IL-8, IL-12, and TNF-alpha), and cellular response interleukins (INF-gamma, IL-2, IL-4, IL-5, and IL-10); all these determinations by fluorometry, based on xMAP technology (Luminex 100)
3. lymphocyte subpopulations, with cellular markers CD19, CD3, CD4, CD8, CD56, and CD16 by flux cytometry (BD FACS Canto).

**Heart rate variability (HRV) and arterial blood pressure**

According to the scheme in Figure 2, blood pressure will be assessed by non-invasive beat-by-beat arterial pressure recording (Finapres) in quiet, controlled environmental conditions. Resting RR recordings will be obtained in supine and orthostatic positions using Polar RS800CX beat-by-beat heart rate monitors. Different mathematical models will be used to analyze RR time series, including time-domain (statistical and geometrical indices), frequency-domain (spectral analysis) and nonlinear methods (Poincaré plot and detrended fluctuations).

**Clinical and echocardiographic monitoring**

Before the intervention period all subjects will undergo a complete medical and anthropometric assessment, including medical history, physical examination, and an echocardiographic examination (2D/3D eco-Doppler). This last assessment will be repeated after the intervention. During the study (i.e. along 8 weeks), training logs will be kept by each swimmer, including external and internal training loads, as well as data relative to diurnal and nocturnal resting periods, clinical symptoms, diet, appetite, body weight, total score of fatigue questionnaire, Lake Louis acute mountain sickness questionnaire, as well as information about any alteration of their health status (clinical symptoms, injury, infection, etc.), which will be necessarily consulted with a staff physician.

**Ethical issues**

The highest ethical standards for research with human subjects will be adopted. All subjects will participate voluntarily and will sign an informed consent document prior to their participation. All personal data will be confidential and will be protected from any undue or improper use. The project has been positively assessed by the Ethics Committee for Clinical Investigations of the Sports Administration of Catalonia (Spain) and written approval has been released. Worthy of note, AT is a legal method for in the preparation of athletes, not banned or questioned by the WADA (World Anti Doping Agency). According to all current standards, AT is a legal and ethically acceptable alternative to blood doping and use of erythropoietic drugs.
Expected Results

A group of experts in altitude training research
Some of the most recognized researchers in the area of altitude training will participate in this project. Among these experts outstand the American scientists Ben Levine and Jim Stray-Gundersen, first to prove the effectiveness of “live high-train low” in runners back in the 90s, first published in a milestone article with more than 180 cites in sport science literature (ISI). Not less outstanding is the Australian researcher Christopher Gore, currently head of the Physiology Department of the Australian Institute of Sport (AIS), with several publications among the most cited in this topic. The core of the scientific team working at project has already collaborated in an international research project developed in Dallas, Texas, in 2003. The study, led by Ben Levine and Ferran Rodríguez of Spain, was financed by the USOC, the AIS, the ACSM, the Department of Universities and Research of the Government of Catalonia (Spain), and three universities (Texas University, Free University of Amsterdam, and University of Barcelona), and resulted in several publications in high-impact peer-reviewed journals.

Scientific and technical contribution
The ALTITUDE Project is an ambitious and robustly-designed research study which can hardly be undertaken by only one country. The international collaboration in this project is justified by:

- the complexity of the research topic
- the need for collaboration in different critical issues, such as the recruitment of elite swimmers and coaches and the management of specific research methods and techniques
- the foreseen enrichment through collaboration among athletes, coaches and scientists from various countries, some of them of outstanding prestige in their particular field.

Expectedly, this investigation will enable to obtain new, relevant information concerning:

- the effectiveness of different strategies of AT in enhancing performance capacity in elite swimmers
- the characteristics of cardiopulmonary and metabolic acclimatization to moderate altitude
- the erythropoietic adaptation to moderate altitude
- the effects on the prooxidant-antioxidant balance of the body exposed to training and/or chronic hypoxia
- the effects of AT on athletes’ health and cardiovascular function
- the impact on the immune status caused by intensive training and hypoxia
- the impact of AT on swimming technique in elite athletes.

Moreover, this research will improve our knowledge of a technological procedure used by a large number of athletes, not only in swimming, but also in sports such as track & field (race walking, middle and long distance running), triathlon, cycling (route and track), rowing, canoeing and kayaking, cross-country and alpine skiing, etc., as well as in team sports (football, basketball, water polo, rugby, handball, etc.).

Reports and publications
Upon completion, the research staff will give all participant athletes a report containing his/her individual data and a summary of the main results of the study. Group data will also be provided to all participant coaches and scientists.

Additionally, this international collaborative project aims at devoting a significant effort to the diffusion of its results through detailed scientific and technical reports addressed at first instance to the funding agencies and scientific and sports institutions participating in the project. Subsequent submission to high-impact international scientific journals, and presentation at international congresses and symposia is also anticipated.


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