SUMMARY

HIGH ALTITUDE TRAINING SYMPOSIUM

19TH & 20TH March Hong Kong Sports Institute, Hong Kong

By Dr John Hellemans

This conference was organised by the Hong Kong Sports Development Board in conjunction with the China Association of Sports Medicine.

I was privileged to attend this conference and present on the topic of Intermittent Hypoxic Training. This is the first time that Chinese representatives reported on altitude research in China to an international conference audience. This in particular, made the conference interesting, but also challenging. Interpreters were provided when required and Power Point slides were presented in two languages simultaneously.
The Chinese have 18 government supported altitude training centers, most of which have been in existence for many years. In addition in recent years artificial altitude simulation facilities have been established in major centers. Applied altitude training has gone hand in hand with ongoing scientific research into optimizing the benefits from exposure to the different altitude training methods.
Japan has also established altitude simulation facilities in addition to already established natural altitude training centers.
At the conference the different methods of altitude training and their effect on physiological parameters and performance were extensively discussed. There is general agreement that the high-low model (live high and train low), either accomplished in a natural environment or through artificial means (altitude simulation) is currently the most effective method of altitude training. Some training completed at altitude may provide additional benefits especially for more experienced athletes.
There is a significant number of athletes who do not seem to respond to altitude training (some studies suggest up to 40%) and the reasons for this are still a mystery. The answer might be in the requirement that altitude training programs need to be individually prescribed to athletes in regard to dose (level of altitude), duration and periodisation of altitude exposure. The training intensity at altitude is also likely to play a significant role in outcome. Ongoing research is required to answer some of these questions.

Summaries of the presentations are attached, followed by some of the scientific key points presented and a general recommendation for New Zealand High Performance Sport.

Current Practices and Future Trends in Altitude Training

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Development in the early 1990s of "live high- train low" (LHTL) altitude training has led to the use of several new altitude training strategies and devices by elite athletes. These include: 1) normobaric hypoxia via nitrogen dilution (nitrogen apartment), 2) supplemental oxygen, 3) hypoxic sleeping devices, and 4) intermittent hypoxic exposure.

Several investigations have demonstrated that chronic use of a normobaric hypoxic apartment (12 to 18 hours per day for 10 to 25 days at 2000 m to 3000 m / 6560 ft – 9840 ft) stimulates the release of serum erythropoietin (sEPO) and significantly increases reticulocyte count. In turn, these erythropoietic changes have been associated with improvements in postaltitude VO_{2max} and endurance performance. However, other studies have failed to demonstrate any significant erythropoietic effect as a result of normobaric hypoxic exposure. These discrepancies between studies may be the result of differences in assessment methods, hypoxic stimulus, and/or the athlete's training status. Although limited, published data regarding the efficacy of supplemental oxygen training (LH + TLO_2) suggest that high-intensity workouts at moderate altitude and endurance performance at sea level may be enhanced via hyperoxic training utilized over a period of several weeks. At present, no scientific studies have been published that document the effect of hypoxic sleeping devices on erythropoiesis, VO_{2max} and/or performance in elite athletes. However, preliminary research suggests that hypoxic sleeping units provide a relatively safe and comfortable normobaric hypoxic environment, but do not significantly alter hematocrit levels over a four-week period.

Intermittent hypoxic exposure (IHE) is based on the assumption that brief exposures to hypoxia (1.5-2.0 hrs) are sufficient to stimulate the release of sEPO, and ultimately bring about an increase in red blood cell (RBC) concentration. Athletes typically use intermittent hypoxic exposure while at rest (passive IHE), or in conjunction with a training session (intermittent hypoxic training [IHT]) . In effect, this allows the athlete to "live low-train high" (LLTH). At present, it is unclear whether IHE or IHT lead to improvements in RBC, hematocrit and hemoglobin. In addition, there are minimal data to support the claim that IHE or IHT enhance VO_{2max} and endurance performance. Preliminary data, however, suggest that anaerobic power and anaerobic capacity may be improved as a result of IHT.

The use of these novel altitude training strategies and devices has raised issues regarding the ethical integrity of their utilization for the enhancement of athletic performance. The World Anti-Doping Agency (WADA) currently considers the "enhancement of oxygen transfer" as a Prohibited Method (January 2004). The enhancement of oxygen transfer is specifically defined by the WADA as: 1) blood doping, i.e., "the administration of autologous, homologous or heterologous blood or red blood cell products of any origin, other than for legitimate medical treatment", or 2) "the administration of products that enhance the uptake, transport or delivery of oxygen, e.g., modified haemoglobin products including but not limited to bovine and cross-linked haemoglobins, microencapsulated haemoglobin products, oxydrene, perflourochemicals, and efaproxiral (RSR13)". Based on these definitions, some have objected to the use of normobaric hypoxic apartments, supplemental oxygen, altitude tents, etc. on ethical and legal grounds claiming that they provide an unfair advantage to those athletes who use them in preparation for athletic competition. This ethical issue remains open to debate.

Effects of Hypoxic Training on Aerobic Capacity and Performance

—Studies from the Hypoxic Training Laboratory at Beijing Sport University

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Data from some studies exploring the effects of “Living high-training low” (HiLo), on athletes’ aerobic capacity and performance have demonstrated that HiLo not only ameliorates the oxygen transport system due to hypoxia-induced increases in hemoglobin, but also helps to avoid decreases in training intensity and volume which occur during high altitude training. In our opinion, therefore, HiLo is a better approach for increasing aerobic capacity than is traditional altitude training. The availability of HiLo, however, and scientific methods of application remain to be elucidated. In order to study hypoxia training, a laboratory was set up in Beijing Sports University at the end of 2002. There are three rooms, with two hypoxic bedrooms, in which the temperature, humidity and oxygen concentration can be adjusted. The third room is a monitoring laboratory for inspecting the concentrations of O_2 and CO_2 in real time. Our studies have shown that, 1) the HiLo period needs to be more than 3 weeks to effect increases in hematology; 2) HiLo with hypoxic exercise (HiHiLo) appears to positively affect aerobic performance; 3) Maintaining the normal immune function is important during HiLo; 4) There is significant individual variation in adaptation to hypoxia. Therefore, pre-estimation for individual adaptive ability to hypoxia is important for increasing the effects of hypoxic training.

Effect of Live-High-Train-Low and Intermittent Hypoxic Exposure on EPO and Other Blood Parameters

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Objective The purpose of our study was to investigate the effects of live-high-train-low and intermittent hypoxic exposure on EPO and other blood parameters.

Methods Subjects were 28 physically fit and healthy male students. They were randomly assigned to four groups with the following protocols: r-HuEPO injection (r-HuEPO n=8), intermittent hypoxic stimuli (IH, n=7), live-high-train-low (MH, n=5) and control group (C, n=8). This double-blind experiment comprised a four-week training period and a two-week recovery period. During the training period, the IH group breathed a hypoxic gas mixture for 30 min each day; the MH group was exposed to a hypoxic environment for 8 hours each night; and the r-HuEPO group was administered 50 Ukg^{-1} of r-HuEPO at a frequency of 3 wk^{-1}.

Results: 1) During the training period, from day 3 to day 9, there was a significant increase in EPO concentration in the r-HuEPO group compared with that prior to the training period ($p<0.05$). EPO levels in the IH and MH groups were significantly higher than those prior to the training period on days 3, 17, 22, and 15, 17, 22, 24 ($p<0.05$).This difference was also observed in the recovery period ($p<0.05$). No significant changes were found in the control group. 2) From the third training period day to the recovery period, the level of sTfR in the r-HuEPO group was significantly higher than that prior to the training period ($p<0.05$); similarly in the IH group, sTfR levels were consistently higher on training period days 3, 9, and 17, and during the whole recovery period ($p<0.05$); but in the MH and C groups, no significant changes were observed sTfR levels. 3) VO_2max in both the r-HuEPO and the IH groups significantly increased after training, but HR and La significantly decreased. No significant differences in these parameters were observed in the C group.

Conclusion: 1) EPO and sTfR in blood serum may be increased by hypoxic environment stimuli during long periods. 2) EPO and sTfR concentrations mayt be significantly affected by exercise, but may be effected by particular applications and timing of different hypoxic stimuli. 3) Intermittent inhalation of low-concentration O_2 combined with exercise may increase VO_2max, and hypoxic stimuli combined with exercise may delay the decrease of EPO concentration.

Hypoxic Training System and Altitude Training

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Since 1990, many Japanese long distance runners have been training at moderate altitudes of 1600-2300m. Sometimes they prefer to train at higher altitudes of more than 3000m above sea level. Many medical and scientific studies have been conducted with athletes from different sports. The effectiveness of altitude training has been confirmed not only for long distance running but also for other sports events, such as swimming, skiing, speed skating and other endurance sports.

In 1995, Kobayashi proposed that altitude training during short periods, e.g., 3 nights and 4 days, was effective. The effects of short term altitude training were thoroughly investigated. Maeshima (1995) developed an innovative method of training using a hypoxic room of 16% O_2 for speed skating athletes. In 1998, a hypoxic tent with a 30m running lane was built on campus at the University of Tokyo. Using this hypoxic tent, it was found that exercise training in hypoxic conditions of 16.4 - 4.5 % O_2 (similar to 2000-3000m altitude) is physiologically effective in improving endurance ability.

The most reliable index in a hypoxic environment is SpO_2. In the hypoxic environment of 14.5 % O_2, SpO_2 decreased to 83 % during a 45 minute bicycle exercise on the first training day. The rate of decrease in the level of SpO_2 slowed as the training progressed.

Combined training using a hypoxic room and natural altitude training may be effective in improving endurance performance.

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A Pilot Experimental Study on Simulated Altitude Training

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In order to study the effects of different simulated altitudes on physical capacity, our Institute carried out experiments on rats to investigate their responses to training at simulated altitudes of 2000m, 3000m, and 4000m. Erythrocyte deformability (Dimax) of RBC, and changes in Hb and RBC were compared among the following groups: the control group, altitude training group (1 week), post altitude training group (1 week), and post altitude training group (2 weeks). At the simulated altitude of 2000m, exercise training was found to be the dominant factor affecting erythrocyte deformability, while at 3000m to 4000m, altitude was the dominant factor.

Aditionally, in different simulated training phases, the changing pattern of total RBC was the same as that of Hb. The change in total RBC in the altitude training group (1 week) was the largest at the simulated altitude of 3000m, and total RBC in different groups at this simulated altitude was larger than the corresponding group at sea-level.

For the purpose of further investigating the effects and mechanism of simulated altitude training on physical capacity, our Institute developed the “Live High Train Low” and “Live Low Train High” systems, that simulated an altitude of 2500m, for carrying out experiments on animals. Through comparison between the two simulated altitude training systems, practical information for altitude training has been been collected. Changes in RBC, Hb, and Hct after 5 weeks of simulated altitude training are shown in Table 1. Exercise performance after simulated altitude training is illustrated in Table 2, which shows the time to fatigue of continuous running at 35 m/min under normoxic conditions.

Table 1. RBC, Hb, and Hct of Rats in Different Training Systems.

Group	RBC ($*10^{12}$/L)	Hb (g/L)	Hct (%)
Live Low Train High	7.39±0.52	150±8	0.444±0.024
Live High Train Low	7.65±0.69	152±12	0.452±0.034*
Live Low Train Low	7.59±0.56	152±9	0.449±0.024*
Basal Reference	7.47±0.53	145±12	0.423±0.028

Comparing with Basal Reference *p<0.05, **p<0.01

Table 2. Time to Fatigue of Rats in Live Low Train High and Live High Train Low Systems

Group	Live Low Train High	Live High Train Low
Time to Fatigue	232.4±71.3	349.3±64.9**

Comparing to Live Low Train High Group **$p<0.01$

The results showed that “Live High Train Low” was more effective in improving physical performance than “Live Low Train High”. These data indicate that the simulated altitude in the “Live High Train Low” environment should be at least 2500m.

Normobaric Intermittent Hypoxic Training

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Dr Mike Hamlin (Lincoln University, Canterbury, New Zealand)

The main methods of altitude simulation include hypobaric chambers, the altitude tent and intermittent hypoxic training. This presentation focuses specifically on the method of intermittent hypoxic training.

Intermittent hypoxic training consists of intermittent exposure to hypoxic (9-15%), and nomoxic air for 1-2 hours per day. There is evidence that this creates significant adaptations in the body, which are comparable to those of more chronic exposure to hypoxia at lower altitudes. In addition, intermittent hypoxic exposure results in unique bodily adaptations that have therapeutic benefits. Adaptations in the area of the oxygen delivery system, the respiratory system, the neuro-endocrine system, the metabolic system and the immune system will be discussed. Medical applications as well as contra-indications of IHT will also be mentioned. Examples of IHT protocols will be presented based on current evidence, sound physiological principles and the presenter's personal experience.

Results of a research project on performance benefits of IHT in a group of multi-sport athletes demonstrate that the use of intermittent normobaric hypoxia is sufficient to elicit significant and worthwhile improvements in 3km time trial performance in well-trained subjects. Haematological indices suggest acceleration in erythropesis. It is not clear as yet how to distinguish responders from non-responders. IHT can be considered as an additional training modality. IHT therefore needs to be carefully periodised in the overall training process.

A Study of the Application of Simulated Altitude Training on Elite Endurance Athletes of China

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A "Live High-Train-Low" study was conducted on elite race walkers and mid-distance runners recently by the Simulated Altitude Training Study Group of the Shandong Sports Science Centre, using the CSDF-40 hypobaric hypoxic chamber developed by the Centre. The study was successful and valuable experience was gained. The current report introduces in detail three applied studies previously conducted by the Study Group. The first study served the function of providing information for setting the optimal altitude and training method for later studies. The study involved monitoring the athletes' acclimatization to different simulated altitudes, haemoglobin changes, and athletes' performance. The purpose of the second study was to prepare the athletes to compete in the 2000 Olympic Games. In this study, we investigated the optimal simulated altitude training protocol for elite Chinese 20K race walkers before international competition. The third study aimed at verifying the methods of "Live-High, Train-Low" and its effects on the performance of endurance athletes, through testing on mid-distance runners. In the current study we monitored changes of haemoglobin, running speed at anaerobic threshold, body composition, and urea. A detailed report of the test results is included. An in-depth description of "Live High-Train-Low", including scheduling and planning of different phases of training, daily hours spent in and out of the hypoxic chamber, altitudes simulated, and precautions for using the chamber.

In conclusion, the current study indicates that "Live High-Train-Low" can significantly improve oxygen carrying capacity and performance of endurance athletes. It is also easy to incorporate "Live High-Train-Low" into training and racing schedules, and it enhances training monitoring, and generates training effects similar to altitude training. Therefore, "Live High-Train-Low" is an ideal alternate training method for altitude training.

“Sleep High-Train low”.
The Known and Unknown of Intermittent Hypoxic Exposure

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The “live high-train low” approach to altitude training makes use of intermittent hypoxic exposure (IHE), which relies on passive exposure to hypoxia to reproduce some of the key physiological adaptive mechanisms of altitude acclimatization to improve sea level athletic performance. Benefits of “high-low” training include increased aerobic power ($V0_{2max}$), improved endurance and aerobic efficiency, and greater recovery after high-intensity exercise. Improved sea level athletic performance following IHE is the result of increased red cell mass, improved ventilatory function, and adaptive changes in the cardiac function and skeletal muscles. The most appropriate “dose” of hypoxia is dependent on the number of hours of hypoxic exposure per day; the degree of hypoxia (determined by the simulated altitude); and the number of consecutive days of hypoxic exposure. Based on the current literature it would appear that the most appropriate dose for “high-low” training entails 12 hours hypoxic exposure per day, at a simulated altitude of 2500-3500m, for at least 30 consecutive days. The variable response observed between athletes with “high-low” training have been attributed to individual differences in iron levels and iron metabolism, and genetic differences in erythropoietin production and decay.

The Recent Development of Altitude Training in China

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I. Brief history

Altitude training of athletes from sea-level.

Altitude training in China started in the 1960's. Starting from the 1980's, sports teams from about 20 provinces had taken part in altitude training. A number of coaches accumulated experience (20-30 times) in altitude training. Around 20 sports events in China have been involved in altitude training.

II. Characteristics of Chinese research on altitude training :

1) Research studies have concentrated on tackling key problems of important sports events (the National Games, the Asian Games and the Olympic Games).
2) Simulated altitude training.
3) Promoting academic exchanges in altitude training nationally and internationally.

III. Altitude Training Knowledge Base in China

1) The "slump phenomenon" after altitude training.
2) The advantages of varying altitudes for training.
3) The different methods of simulated altitude training.
   a) living low-training high (low pressure chamber)
   b) living high-training low (altitude house)
   c) living high-training high (low pressure chamber)
   d) living low-training low (intermittent hypoxic exposure)

IV. Altitude Training Bases in China

The number of altitude training bases has increased rapidly in the past few decades, and so has the number of participants. China has a number of high altitude plateaus, with 18 bases currently available for altitude training.

SCIENTIFIC SUMMARY of some of the key points presented

- The primary feature of IHT is the presence of periods of recovery, providing windows of time for an anaerobic response, thereby avoiding detrimental effects of long-term oxygen deprivation (in contrary to chronic hypoxic exposure).
- There is confusion in terminology. It is recommended that passive altitude training be termed “hypoxic exposure” e.g. intermittent hypoxic exposure versus training under hypoxic condition, which is “hypoxic training” e.g. intermittent hypoxic training or hypoxic training.
- Different types and levels of hypoxic exposure may initiate different adaptive responses. These responses may be further influenced by exercise.
- The main adaptive strategy of the body seems to relate to the ability of the cell to extract (and process) available oxygen.
- It is known that physical training mildly stimulates HIF-1A (Hypoxic Inducible Factor).
  (HIF is an oxygen regulated transcriptional activator). Hypoxic training has additional cardiovascular benefits over and above physical training, by more rigorous stimulation of HIF-1A.
- VEGF (Vascular Endothelial Growth Factor) shows an increased expression by hypoxia. VEGF is produced by osteoblasts and provides and angiogenic stimulus (new blood vessel growth). VEGF is in particular, stimulated by hypoxic training.
- Of concern when sleeping in altitude tents, is a build up of CO2, up to 0.7% (normal 0.03%).
- When doing blood testing, reticulocytic haematocrit and reticulocytic haemoglobin are more reliable than straight haematocrit and haemoglobin (not dependent on hydration).
- STFR (Soluble Transferritin Receptors) is a more accurate measure for erythropoiesis than other measures.
- It seems that erythropoiesis increases by 3% by week 3, but by 7% by week 4, hence the recommended extension of altitude exposure from 3 weeks to 4 weeks.
- General agreement that it is not clear how long altitude benefits last, but consensus is between 3-4 weeks. Little scientific evidence is available.
- When doing conventional altitude training increase recovery by 200% and reduce this by 25% per week. Reduce the duration of training by 10% and reduce intensity by 10% as a general guideline.
- *Altitude exposure positive effects*: Increase in oxygen processing mechanisms (RBC, HB, HC, FFA mobilisation, capillary increase, improvement in lactic acid thresholds, improved muscle buffering).

Altitude exposure negative effects: Increase in blood viscosity, decrease in blood flow in muscle, fibre atrophy, decrease in anabolic processes, cardiac output decreases, decrease in heart rate max and decrease in VO2 max at altitude. The outcome depends on the balance between the good and bad effects.

- **The high/low model can be improved by doing some training at altitude to increase training stress on the respiratory and circulatory systems.** (High High/Low model.)
- Hypoxic induced desaturation of oxygenisation in the blood in rest tends to improve over time. A more dramatic improvement finds place with oxygen saturation during exercise under hypoxic conditions after a period of hypoxic exposure and/or training. Also a significant reduction of heart rate at a certain workload during exercise.
- There is an increase of general microcirculation during hypoxic exposure for the first 2-3 weeks then a return to normal pre-exposure levels.
- Molecular parameters decide regarding responders versus non-responders?
- **The high high/low model causes an impairment of the immune system comparable to the high/high system**.
- Many studies show no change in haemoglobin, but an increase in haematocrit.
- In Japan a study was done, where athletes would go up to altitude for 4 days and 3 nights (approximately 2000m). When returning to sea level, significant improvements in lactate response and oxygen saturation during exercise confirmed the benefits of this model. (Short-term altitude exposure).

- Oxygen deprivation:

	N2 (Nitrogen)	O2 (Oxygen)	CO2 (Carbon Dioxide)
Normal Air	78.04%	20.93%	0.03%
Low Oxygen	78.04%	15%	6.0% (not compatible with life)
Hypoxic Tent	84% 86%	15% 13%	1% 1%

- Amino acid supplementation including the use of arginine increases blood flow and prevents drop in oxygen saturation during exercise. (Japan)
- Hypoxia results in a decrease in oxygen saturation in the blood, which results in an increase in EPO (haematopoesis), an increase in NO (increased blood flow).
- The Chinese emphasised the importance of the level of training intensity under hypoxic conditions.

- Conclusion: Results of Rat Studies:
  Based on RBC and 2,3/DPG results low/high is better than high/low, but taking all results into consideration, high/low is better than low/high.
- Selection of training intensity will determine the effectiveness of high altitude training.
- Optimal height for classical high altitude training is 2,000-2,500m.
- Optimal height for high/low is to 2,500-3,000m. Questions still remain regarding the optimal altitude for the high/low model and the mechanisms of high altitude training and the high/low model and low/high model.
- The Chinese have extensively researched what they call the "Slump Phenomena", which is a period of 5-7 days following return to sea level, in which performance is compromised due to a reduction in stroke volume and ejection fraction of the heart. This slump phenomena always happens and the duration varies depending on training intensity and the height of altitude e.g. the harder the training and the higher the altitude, the longer the slump period.
- The Chinese work with the "4 P's"
  1. Use of Proper Height (1500m +)
  2. Use of Proper Length of Time (3-4 weeks)
  3. Use of Proper Training Intensity
  4. Use of Proper Initerval before competition

  Of these, proper height and proper length of time are reasonably agreed on, but the proper intensity of training and interval prior to competition is still not that clear.
- The Chinese have used programmes, where their athletes, over a short period of time, trained at different altitudes which showed advantageous results e.g. alternating between 1500m and 2000m. The Chinese have studied the following models:
  1. Live low/Train high (2000m) – *good results*
  2. Live low/Train low, but with intermittent hypoxic exposure – *good results*
  3. Live high (4000m)/Train high (2,600m) – *results not good, but significant increase in VEGF*
  4. Live high/Train low – *good results*
- There are 18 Altitude Training Centres established in China. They are characterised by:
  1. Good training facilities
  2. Appropriate accommodation
  3. Suitability for altitude training

RECOMMENDATION

It is clear that many countries now have comprehensive altitude training programmes available for elite sports. This includes access to varying forms of altitude training and exposure. In New Zealand altitude training is still practiced on an ad-hoc basis and no systems or structures are in place to support sports or individual athletes with their altitude training programmes. New Zealand has a unique opportunity to catch up and surpass the rest of the world by establishing a high altitude training facility that can incorporate all methods of altitude training.

Currently the Snow Farm, near Wanaka is the ideal place to establish an altitude training facility. Excellent accommodation is already provided and support structures are in place to quickly establish specialised training facilities. The high/low level can be practiced in a natural environment already. It is recommended that through artificial means (altitude chambers and/or intermittent hypoxic training) higher altitudes are incorporated. The establishment of a high altitude training facility in New Zealand requires input from key players including SPARC, The New Zealand Academy of Sport, an established research institution (University based),
Coach Representatives, Athlete's Representatives and the Snow Farm and potential private stakeholders.