ALTITUDE AND ENDURANCE TRAINING CRITERIA

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" An investigative paper researching the various physiological responses and training criteria experienced at altitude "

Athletes experience normal gravitational forces at sea level. However barometric pressure is reduced at altitude. We refer to this as a Hypobaric Environment or low atmospheric pressure

This lower partial pressure of oxygen limits pulmonary diffusion and the transporting of the oxygen to the tissues of the body. This results in Hypoxia or oxygen deficiency

The term altitude refers to elevations above 1500m (4 921 feet) as there appears to be few physiological effects on performances below that level

Endurance Training Criteria

Success in the endurance events appears to be dictated by the following factors

- **High VO2 Max value**

VO2 Max or maximal oxygen uptake is the maximal capacity for the consumption of oxygen by the body during maximal exertion. It can also be referred to as aerobic power or maximal oxygen intake/consumption

- **High Lactate Threshold or OBLA**

High lactate threshold or OBLA (Onset of Blood Lactate) is the point during exercise, of increasing intensity, at which blood lactate begins to accumulate above resting levels. It is also referred to as the anaerobic threshold and can be set at 2-4 mmol as a common reference point

- **High Economy of Effort**

High economy of effort, or a low VO2 value for the same rate of work is crucial ie reduced energy demands at a given rate of exercise. Crucial here is that an athlete be able to (a) work at a very high percentage of his VO2 max and (b) establish a lower energy use at a given speed during competition which provides a distinct competitive advantage

- **High Percentage of ST Fibre**

There are two main types of muscle fibre

- **Slow twitch (red) fibres of Type 1** are described as 'slow oxidative' and have a high level of O2 endurance. Athletes have approximately 50% of ST fibres in their legs

- **Fast Twitch (white) fibres or Type 2** are found in three categories

FTa

FTb; and

FTc

They all have high levels of anaerobic endurance. They are normally found as FTa (25%)(fast, oxidative and glycolytic), FTb

(25%)(fast and glycolytic) and FTc (1-3%) of which little is known

Changes Produced by Aerobic Endurance Training

These include

- **Muscle Fibre Type**

Aerobic training stresses the ST fibres more than the FT fibres. They tend to enlarge with training. Percentages of ST and FT fibres do not appear to change. As described above training may cause the FTb fibres to take on more of the FTa fibre characteristic

- **Capillary Supply**

The number of capillaries supplying each muscle fibre increases with training

- **Myoglobin Content**

Training increases muscle myoglobin content by about 75-80%. It is a compound similar to haemoglobin, found in muscle tissue, that stores and carries oxygen from the cell membrane to the mitochondria

- **Mitochondrial Function**

The mitochondria is where the aerobic energy production is conducted. The ability to use oxygen and produce ATP via oxidation depends on the number, size and efficiency of these mitochondria. All three of these qualities improve with endurance training

- **Oxidative Enzymes**

The activities of many oxidative enzymes are increased with training

Changes Produced by Anaerobic Endurance Training

Similarly these include

- **ATP-PC and Glycolytic Enzymes**

Anaerobic training increases both these enzymes

- **Buffering Capacity**

Training improves the muscles capacity to tolerate acid accumulating within them during anaerobic glycolysis. Buffers such bicarbonate and muscle phosphates combine with hydrogen to reduce the fibres acidity. Muscle buffering capacity can be increased by 12-50%

- **Aerobic Energetics**

Sprints that last at least 30 seconds increase the muscle's aerobic capacity and part of this energy from oxidative metabolism

- **Efficiency of Movement**

Training at high speeds improves skill, co-ordination of movement and optimises fibre recruitment. This allows for more efficient movement and economises the use of the muscles energy supply

Environmental Conditions at Altitude

Air has weight. The barometric pressure at any point on earth is related to the weight of the air in the atmosphere above that point. The outermost reaches of the earth's atmosphere is approximately 24 kilometers above sea level

The percentages of gases in the air we breath remains constant regardless of altitude ie 20.93% oxygen, 0.03% carbon dioxide and 79.05% nitrogen. However the partial molecular pressure of each of these gases is reduced in direct proportion to the increase in altitude

Air temperature drops at a rate of 1°C for every 150m of ascent. Cold air can hold little water so air at altitude is dry. These two factors make athletes susceptible to cold-related disorders and dehydration

Similarly because the atmosphere is thinner and drier, solar radiation is more intense

Altitude (m)	Pb (mmHg)	PO2 (mmHg)	Temp (°C)
0	760	159.2	15.0
1000	674	141.2	8.5
2000	596	124.9	2.0
3000	526	110.2	-4.5

Physiological Responses to Altitude

The main areas of concern are

Respiratory

Cardiovascular; and

Metabolic

(1) Respiratory Responses

Greater volumes of air must be ventilated at altitude because the air is less dense. This results in a state of hyperventilation. Too much carbon dioxide is cleared from the body resulting in respiratory alkalosis causing the kidneys to excrete more bicarbonate ions. The end result is that less acid can be buffered in the body

Pulmonary diffusion is not hindered by altitude. However oxygen transport is slightly impaired because haemoglobin saturation is reduced by a small amount. This is caused by the decrease in partial pressure of oxygen within the alveoli and pulmonary capillaries

The difference between arterial PO2 and tissue PO2 causes the oxygen exchange between blood and active tissue to be substantially reduced at altitude ie oxygen intake is impaired. This is partially compensated by a decrease in blood plasma, concentrating the red blood cells and allowing more oxygen to be transported per unit of blood. Maximal oxygen consumption decreases along with atmospheric pressure. Below an altitude of 1600m (5 248 feet) there appears to be little effect on VO2 max and endurance performance. Above 1600m VO2 max decreases approximately 11% for every 1000m increase

(2)….Cardiovascular Responses

As the respiratory system is stressed so is the cardiovascular system which undergoes substantial changes to compensate for the increase in altitude.
On arrival at altitude blood plasma begins to decrease and then plateaus at the end of the first few weeks. This results in an increase in the hematocrit allowing more oxygen to be delivered to the muscles. Hematocrit is the percentage of red blood cells in the total blood volume. The diminished plasma volume is eventually restored to normal levels. The high altitude triggers an increase in the production of red blood cells. The greater total blood volume allows for a partial compensation of the lower PO2

Cardiac output is the product of stroke volume and heart rate. Increasing either of these will increase cardiac output. During submaximal work at altitude the body increases its cardiac output. It does this by increasing the heart rate to compensate for the decrease in the pressure gradient and drop in stroke volume due to the lower blood plasma.

After a few days the muscles begin extracting more oxygen from the blood . This reduces the demand for the increased cardiac output and heart rate. At maximal or exhaustive work level stroke volume and heart rate are both lower resulting in a reduced cardiac output. This combined with the reduced pressure gradient severely impairs oxygen delivery and uptake.

Blood pressure in the pulmonary arteries during exercise at altitude also increases. The causes are not fully understood

- **Metabolic Adaptations**

At altitude there is an increase in the blood lactate levels for a given submaximal work rate. However at maximal work rate these levels are lower perhaps because the body must work at a rate that cannot fully stress the energy systems

Prolonged Exposure to Altitude

Endurance activities suffer most at altitude because the oxidative energy production is limited. Anaerobic sprint activities lasting less than one minute are generally not impaired at moderate altitudes. The thinner air at altitude provides less resistance to movement

When athletes train at altitude for days and weeks their bodies gradually adjust to the lower oxygen tension in the air. Irrespective of how well they acclimatize or how long they live at altitude athletes never attain the VO2 max values that they might achieve at sea level

Some of the changes that occur with prolonged altitude exposure are

Blood adaptations

Muscle adaptations; and

Cardiorespiratory adaptations

- **Blood Adaptations**

Conditions at altitude stimulate the release of erythropoietin (the hormone responsible for stimulating erythrocyte or the red blood cell production). More red blood cells means more haemoglobin. The blood plasma volume decreases initially. It eventuaklly returns to normal which, together with the additional red blood cells, increases the total blood volume. All this increases the blood oxygen carrying capacity

- **Muscle Adaptations**

Total body weight and total muscle mass decrease when at altitude. This is caused by dehydration and suppression of the appetite leading to a protein breakdown in the muscles

Other muscle adaptations include decreased fibre area, increased capillary supply and decreased metabolic enzyme activity

- **Cardiorespiratory Adaptations**

The decrease in VO2 max with initial exposure to altitude does not improve much after several weeks of exposure

Physical Training and Performance

The problem for athletes training at altitude is that they cannot run at the same volume and intensity as they can at sea level

Altitude training can often be an expensive exercise due to transportation, housing, food etc. Its effectiveness is not fully supported by existing research

However a strong theoretical argument can be made for this type of training. It evokes a substantial tissue hypoxia (reduced oxygen supply) thought to be essential for initiating the conditioning response. The increase in the red blood cell count and haemoglobin levels improve oxygen delivery on return to sea level. Though the effects are transient there should be some advantage to the athlete. Many coaches and athletes are convinced that training at moderate altitudes and competing at sea level enhances performance. However more definite scientific results are needed

To compete at altitude two options are open. One is to compete within 24 hours of arrival thus avoiding the usual symptoms of altitude ie dehydration and sleeplessness

The second option is to train at higher than competition altitudes

Optimal training for adaptation at altitude requires elevations between 1500m (considered to the lowest level at which an effect will occur) and 3000m (the highest level for efficient conditioning)

A Coaching Perspective

Many top athletes train 2-4 times per year at altitude for the benefits it will give them at subsequent sea level competition

Leaders in the research of training at altitude were the old USSR, including the GDR and Bulgaria who pursued this avenue since the 1968 Olympic Games in Mexico City

They developed their own training centres ie Tsahkadzor (1700m) and Belmeken (2100m). Their extensive research and development culminated in the success of Kazankina, Shtreva, Zinn, Weiss and others at the 1976 Olympic Games in Montreal, Canada. Since then all the Russian, East German and Bulgarian athletes, from 800m to the Marathon, have prepared at altitude for all major championships

Two points became abundantly clear

+ Altitude training works for each individual; and

+ Success in this type of training can only be gained through experience and research

Other countries have now developed their own training camps and methods for preparing their athletes for major competitions ie Italy, Switzerland, Morocco, Romania, France, Algeria, USA, Kenya, Ethiopia, Mexico and to a lesser extent our own South Africa

Most of the North African athletes prepare at altitude eg Aouita, Morcelli, Skah, El Guerrouj and others. Some train at a variety of centres ie Mexico City, some at least 4 times within a year and sometimes for as long as 6 weeks in one visit

Unfortunately most research has been conducted on sea level athletes travelling to altitudes of between 1800-2200m. Little research can be found on athletes who have lived all their lives at 1400-1700m training at 2000-3000m. The suggestion is that the latter will benefit proportionally just as the sea level athletes do. There is considerable interest in South Africa to investigate this question. Many countries have persevered with their research but not so, it would appear, Britain and Australia. However success has been achieved by small independent groups and individuals from Britain in particular the late Ron Holman and Frank Horwill (both British coaches) and athletes such as Hutchings, Nerurkar, Solly, Binns, Edwards, Williams etc

British coach Norman Poole reports that in the 1996 World Championships in Tokyo, Japan the first 8 finishers from the 800m to the Marathon utilised altitude in their preparations. Additionally he identified 26 of 32 athletes, who prepared at altitude, among the first 8 finishers in the mens and womens 800m and 1500m finals in the same championships

Three of the most successful and experienced coaches in this area of training are

Alexander Polunin (former USSR National Distance Coach)

Peter Bonov (former Bulgarian National Distance Coach); and

Walter Gladrow (former GDR National Middle Distance Coach later to become the German National Event Coach for the same events)

Asked whether altitude training worked and how well it worked their independent replies were of one accord

+ Altitude training works !

+ Between 0.75secs and 1.25secs of improvement for each 60secs of competition if you get the training right

These figures could relate to improvements of 1.5secs in the 800m, 3secs in the 1500m and 20secs in the 10 000m within a period of several days, at some stage, after descending from altitude

Altitude Training Centres

No	Place	Country	Altitude (m)
1	Belmeken	Bulgaria	2000
2	Tzahkadzor	Armenia	1970
3	Font Romeau	France	1895

4	St Moritz	Switzerland	1820
5	Sestriere	Italy	2035
6	Pyatra Arsa	Romania	1950
7	Issyk-Kull	Kirgizia	1600
8	Zetersfeld (Linz)	Austria	1950
9	Addis Ababa	Ethiopia	2400
10	Nairobi	Kenya	1840
11	Thompson Falls	Kenya	3000
12	Ifran	Morocco	1820
13	Kunming	China	1895
14	Mexico City	Mexico	2200
15	Toluca	Mexico	2700
16	Colorado Springs	USA	2194
17	Keystone	USA	2835
18	Flagstaff	USA	2300
19	Boulder	USA	2000
20	Bogota	Colombia	2500
21	La Paz	Bolivia	3100
22	Quito	Ecuador	2218
23	Davos	Switzerland	1560
24	Pontresina	Switzerland	1900
25	Crans Montana	Switzerland	1500
26	Kaprun	Austria	1800
27	Zilvretsha	Austria	1800
28	Medeo	Kzakstan	1693
29	Kesenoy-Am	Russia	2000
30	Pzhevalsk	Kirgizia	1800
31	Tamga	Kirgizia	1700
32	Ifrene (Ifram)	Morocco	1900
33	Atlas Mountains	Algeria	1700
34	Albuquerque	USA	1500
35	Oregon	USA	1500
36	Alamosa	USA	1500
37	Los Alamos	USA	2200
38	South Lake Tahoe	USA	2200
39	Cortina de Paso		1700
40	Johannesburg	South Africa	1600

41	Oxbow	Lesotho	2500

Altitude – How High and How Long

Altitude exponents agree that the ideal height for effective altitude training ranges from 2000-3000m. In the first instance heights of 1000-2000m should be experienced unless the athletes already live at that altitude

Above 3000m the limitation on the amount of training that can be done tends to cancel out any beneficial effect. Bruno Balke, the renown Sports Physiologist, is of the opinion that athletes who have acclimatised to about 2500m can be moved up to 3000m for 2-3 days. They can then be brought down to 2500m for a week before going back to 3000m for 3 days

The majority view is that the minimum period should be 14 days, 3 weeks is preferable and 1 month ideal. The old GDR reported good results with 10 days up, 7 days down and 10 days up again

It is extremely risky to take athletes to altitude for the first time immediately before a major championship

The ideal may be 3 or more exposures of 14 days (or up to a month) at a time with 1 month at sea level in between

There are a number of variations eg a suggestion from Norman Poole is 3 weeks at altitude, a minimum of 7 weeks down and then 2 weeks for a second ascent to altitude.

Other variations will be based on how experienced the athletes are and at what altitude they are normally resident. Regardless altitude training is only for the committed athlete

All major competitions must be completed within a 28 day period after returning from altitude. Only experience will tell the athlete and coach when best performances can be experienced within that period

There have been some variations to this theme and they are

Live high, train low (Prof Tim Noakes from Cape Town)

and from Rob de Castella (Australian Institute of Sport) a 3-group research

Group 1 : Living and training at altitude (2000m)

Group 2 : Morning training at 3000m, afternoon living at 2000m

Group 3 : Living at 2000m, travelling down to sea level for training (ie

Noake's theory)

The type of training undertaken at altitude might include the following. This will be subject to interpretation and variation

> Continuous aerobic runs with the speed reduced by 10%

> Hill sessions

> Strength work

> Interval sessions with recovery times increased by 300-400%

All training needs to be meticulously documented to find out what suits the individual athlete

Conclusion

South Africa has those athletes (a) living and training at sea level ie Durban, Port Elizabeth and Cape Town and (b) those resident on the Highveld and surrounds which could be any altitude from 1200-1700m

Research is needed, plus a venue, to take South African athletes into the 2000-3000m range

Oxbow in the Northern Lesotho Highlands and Bethlehem in South Africa have possible training venues as follows

- Oxbow Lodge at 2250m where the athletes could live and train

- The Northern Lesotho Highlands (12kms from Oxbow Lodge) where the athletes could experience altitudes of 3000-3100m

- At Goble Park in Bethlehem (at 1420m), 125kms from Oxbow, the municipality has a Recaflex S synthetic 8 lane track with a steeplechase (including water jump) facility

All the access roads from Johannesburg to Oxbow and Bethlehem are tarred. Oxbow is 340kms from Vanderbijlpark and the trip takes a comfortable 4hrs and 30mins

The altitudes indicated above provide ideal variations for the ‘medium' altitude athlete as well as the sea level athlete

The possibilities for a ‘home grown' International Altitude Training Camp for South Africa, the Southern African region and the international athletics community are limitless and exciting

The facility would have to be developed and at this stage should be restricted to middle and long distance runners. The location is extremely isolated though very stimulating

This document should be read in conjunction with the paper “Operation Oxbow – A Feasibility Study for the Establishment of a Medium/High Altitude Training Camp for Athletes in Lesotho”