SHORT REPORT

Live high-train low associated with increased haemoglobin mass as preparation for the 2003 World Championships in two native European world class runners

J P Wehrlin, B Marti

Br J Sports Med 2006;**40**:e3 (http://www.bjsportmed.com/cgi/content/full/40/2/e3). doi: 10.1136/bjsm.2005.019729

Background: It is unclear whether world class endurance athletes, in contrast with less well trained subjects, increase their haemoglobin mass on a regimen of living high and training low (LHTL).

Objective: To assess whether haemoglobin mass increases in world class athletes on LHTL and whether this increase is associated with peak performance at a subsequent important competition.

Methods: Two Swiss world class runners (one 5000 m and one marathon) lived for 26 days (18 hours a day) at an altitude of 2456 m and trained at 1800 m. This LHTL camp was the preparation for the World Athletic Championships taking place 27–29 days after the end of the camp. Haemoglobin mass and other haematological variables were measured before and after the LHTL camp. The performance parameter was the race times during that period.

Results: Haemoglobin mass increased by 3.9% and 7.6%, and erythrocyte volume by 5.8% and 6.3%. The race times, as well as the ranking at the World Championships, indicated clearly improved performance after the LHTL camp.

Conclusions: The results suggest that LHTL with an adequate dose of hypoxia can increase haemoglobin mass even in world class athletes, which may translate into improved performance at important competitions at sea level.

In the last few years, the concept of living high and training low (LHTL) has become very popular with endurance athletes. By living at altitude, the athlete should theoretically benefit from an increased haemoglobin mass (Hb_{mass}) and erythrocyte volume (EV), whereas training at low altitude should minimise the disadvantage of reduced absolute training intensity achieved when training at moderate altitude.[1] Together, this should lead to an improved performance at sea level.[2] Apparently at variance with this concept, several studies have shown unchanged Hb_{mass} and/or EV after LHTL or living high and training high,[3–10] but critical inspection of their data indicates that either the selected altitude for ''living high'' was probably[11] too low,[6 8–10] and/or the duration was too short.[3–5] Rusko *et al*[12] indicated that the hypoxic stimulus to increase Hb_{mass} and EV should be least 400 hours at 2300–2500 m. Several studies[2 13–15] have shown increased Hb_{mass} or EV after LHTL with this stimulus. However, the athletes in these studies were not reported to be world class. In the only study with world class athletes[7] and an appropriate hypoxic stimulus, Hb_{mass} and EV failed to increase. Thus it is not clear whether it is possible to increase further an already high Hb_{mass} in world class athletes. There is a lack of documented observations of world class athletes who successfully increased Hb_{mass} (or EV), especially when preparing for an important competition. The aim of our ''double case'' study was therefore to measure Hb_{mass} and performance before and after a LHTL camp, with a presumably high enough hypoxic stimulus, in the immediate preparations for the World Athletic Championships (Paris 2003) in two world class Swiss runners.

METHODS

The best Swiss 5000 m runner (personal best (PB) = 13:36:54) and the best Swiss marathon runner (PB = 2:10:56) participated in this study. Both are native Swiss citizens, were 29 years old at time of the study, and had participated in the European Championships in 2002. The subjects gave their written informed consent to the study, which was approved by the institutional review board of the Swiss Federal Office of Sport. The two runners had participated since winter 2002 in the project ''Doping-free top-class sport'', conducted by the Swiss Federal Institute of Sports and the WADA accredited Swiss laboratory of anti-doping. Besides a public written anti-doping statement from the 20 best Swiss athletes in endurance disciplines, this project included seven additional unannounced doping tests per year (in which these athletes among others were checked for erythropoietin abuse). The two iron supplemented athletes had no injuries or ill health during the study period. They lived for 26 days (~18 hours a day) at a natural altitude of 2456 m and trained at an altitude of about 1800 m. The 5000 m and marathon competitions at the World Championships were due to take place 27–29 days after the end of the LHTL camp. One week before and one week after the LHTL camp, Hb_{mass}, EV, plasma volume, and blood volume were determined by the CO rebreathing method described by Burge and Skinner[16] with minor modifications.[17] Carboxyhaemoglobin (COHb) was determined with an ABL 520 (Radiometer, Copenhagen, Denmark). The amount of CO during the rebreathing period was 80 ml in both subjects, leading to a ΔCOHb of 5–6%. In a separate study, we determined the accuracy of our method by performing two tests separated by 24 hours (n = 12). Coefficients of variation of 1.6% (Hb_{mass}), 2.2% (EV), 4.1% (plasma volume), and 3.1% (blood volume) were obtained. For the measurement of packed cell volume and haemoglobin concentration, a whole blood sample (2.7 ml) was drawn from the antecubital vein after the subject had lain supine for 15 minutes. The blood was immediately analysed with a haematology analyser (CELL-DYN 3200, Abbott Laboratories, Abbott Park, Illinois, USA). The performances of the two world class athletes were evaluated from their competition results.

Abbreviations: EV, erythrocyte volume; Hb_{mass}, haemoglobin mass; LHTL, live high-train low; PB, personal best

Table 1 Haematological variables before and after 26 days of living high and training low in two world class runners

	5000 m runner			Marathon runner		
	Before	After	% change	Before	After	% change
Packed cell volume	0.388	0.386	−0.5	0.427	0.438	+2.5
Haemoglobin (g/l)	132	133	−0.8	156	157	+0.6
Haemoglobin mass (g)	878	945	+7.6	952	988	+3.9
Erythrocyte volume (ml)	2581	2742	+6.3	2605	2757	+5.8
Plasma volume (ml)	4728	5064	+5.8	4099	4160	+3.9
Blood volume (ml)	7309	7807	+6.8	6704	6917	+3.2

RESULTS

The absolute blood values (Hb_{mass}, EV, plasma and blood volume) had increased after the LHTL camp, whereas there was no change in packed cell volume and haemoglobin concentration (table 1).

Figure 1 presents the results of the marathon and 5000 m competitions before and after the LHTL camp. Both the marathon runner (14th place) and the 5000 m runner (13th place, best European runner) achieved their best individual results at an important championship.

DISCUSSION

Blood variables

The increase in Hb_{mass} (+7.6% and +3.9%) and EV (+6.3% and +5.8%) in relation to the reproducibility of the measurement (the increase was about 3–4 times the typical error of measurement for both Hb_{mass} and EV), the fact that the magnitude of these changes was in line with previous findings,[2] the fact that the use of erythropoietin was unlikely, and the fact that there were no changes in the packed cell volume and haemoglobin concentration lead us to the interpretation that there was a real change in Hb_{mass} and EV. Gore *et al*[7] questioned whether their failure to increase Hb_{mass} in world class cyclists after 31 days of living and training at 2690 m could be due to the Hb_{mass} (14.3 g/kg) already being near to the natural physiological limits. In our study, the 5000 m runner started with a Hb_{mass} of 14.3 g/kg and increased it to 15.4 g/kg. The relative Hb_{mass} of the marathon runner increased from 15.7 to 16.3 g/kg. These high values are in line with other world class athletes[17] measured with the same technique. Interestingly, the high Hb_{mass} (and EV) of the 5000 m runner was associated with a very low packed cell volume (below 0.4), which is also explained by the high plasma volume.

Performance

The 5000 m runner ran 40 seconds faster (13:12:69) on the first day after the LHTL camp than on the first day (Swiss Championships) before the LHTL camp. Even related to his PB (13:36:54), he had improved by about 24 seconds. Also in the final of the World Championships, he ran in a time of 13:26:06, about 10 seconds faster than his previous PB. When comparing the marathon times, one has to take into account that the course in Paris had several inclines and was run at a somewhat irregular pace, which was not conducive to PB times. With this in mind, the marathon time reached in Paris (2:11:14) could be interpreted as an improvement on the performance achieved three months before (2:11:05) in a race that was also prepared for with altitude training. The absence

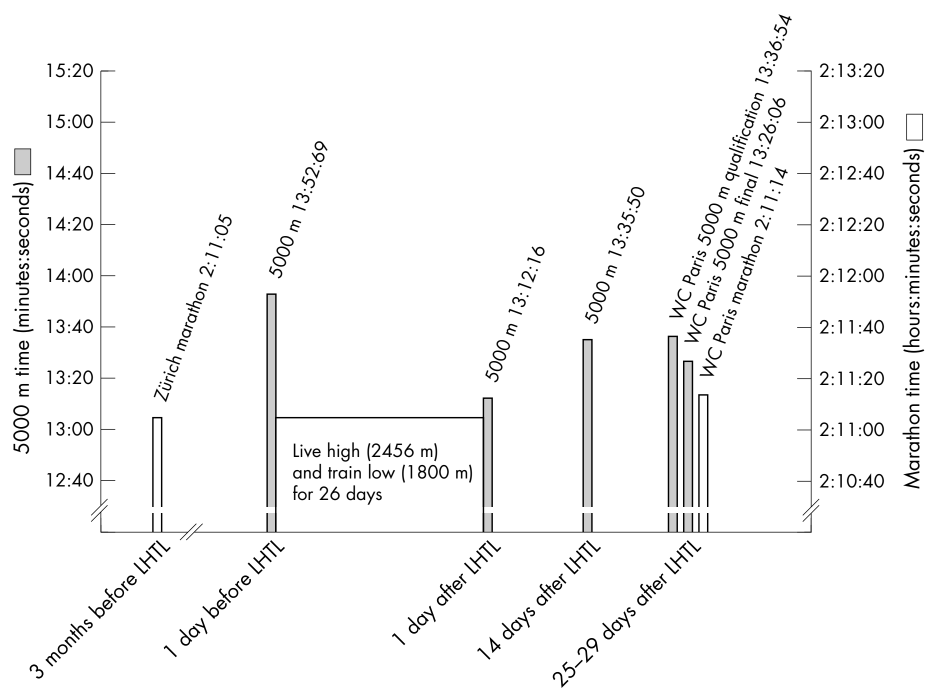

Figure 1 Competition results of one marathon runner and one 5000 m runner before and after 26 days of living high and training low (LHTL) in preparation for the World Championships (Paris 2003). WC, World Championships.

of a control group and the anecdotal nature of the report are weaknesses of the study. This is mainly due to the limited number of world class runners available. However, it can be argued that it is very difficult to substantially improve the performance of world class athletes, especially when they are already approaching 30 years of age. In addition, our performance observations agree with previous findings in a well controlled study of elite runners.[18] Taken together, this seems to be one of the first documented observations of increased Hb_{mass} and EV after an LHTL camp, followed by a successful endurance performance at an important championship of native European world class endurance athletes approaching their thirties.

ACKNOWLEDGEMENTS

We gratefully acknowledge the cooperation of the world class runners Christian Belz and Viktor Röthlin.

Authors' affiliations

J P Wehrlin, B Marti, Swiss Federal Institute of Sports

Competing interests: none declared

Correspondence to: J P Wehrlin, Swiss Federal Institute of Sports, Hauptstrasse 247, 2532 Magglingen, Switzerland; jon.wehrlin@baspo.admin.ch

Accepted 12 April 2005

REFERENCES

1 **Levine BD**, Stray-Gundersen J. A practical approach to altitude training: where to live and train for optimal performance enhancement. *Int J Sports Med* 1992;**13**(suppl 1):S209–12.
2 **Levine BD**, Stray-Gundersen J. ''Living high-training low'': effect of moderate-altitude acclimatization with low-altitude training on performance. *J Appl Physiol* 1997;**83**:102–12.
3 **Ashenden MJ**, Gore CJ, Dobson GP, *et al*. ''Live high, train low'' does not change the total haemoglobin mass of male endurance athletes sleeping at a simulated altitude of 3000 m for 23 nights. *Eur J Appl Physiol Occup Physiol* 1999;**80**:479–84.
4 **Ashenden MJ**, Gore CJ, Martin DT, *et al*. Effects of a 12-day ''live high, train low'' camp on reticulocyte production and haemoglobin mass in elite female road cyclists. *Eur J Appl Physiol Occup Physiol* 1999;**80**:472–8.
5 **Dehnert C**, Hutler M, Liu Y, *et al*. Erythropoiesis and performance after two weeks of living high and training low in well trained triathletes. *Int J Sports Med* 2002;**23**:561–6.
6 **Friedmann B**, Jost J, Rating T, *et al*. No increase of total red blood cell volume during three weeks of training at an altitude of 1800m. *Med Sci Sports Exerc* 1996;**28**:S67.
7 **Gore CJ**, Hahn A, Rice A, *et al*. Altitude training at 2690m does not increase total haemoglobin mass or sea level VO2max in world champion track cyclists. *J Sci Med Sport* 1998;**1**:156–70.
8 **Gore CJ**, Hahn AG, Burge CM, *et al*. VO2max and haemoglobin mass of trained athletes during high intensity training. *Int J Sports Med* 1997;**18**:477–82.
9 **Svedenhag J**, Piehl-Aulin K, Skog C, *et al*. Increased left ventricular muscle mass after long-term altitude training in athletes. *Acta Physiol Scand* 1997;**161**:63–70.
10 **Telford RD**, Graham D, Sutton JR, *et al*. Medium altitude training and sea-level performance. *Med Sci Sports* 1996;**28**:S91.
11 **Levine BD**. Intermittent hypoxic training: fact and fancy. *High Alt Med Biol* 2002;**3**:177–93.
12 **Rusko HK**, Tikkanen HO, Peltonen JE. Oxygen manipulation as an ergogenic aid. *Curr Sports Med Rep* 2003;**2**:233–8.
13 **Rusko H**, Tikkanen HO, Pavolainen L, *et al*. Effect of living in hypoxia and training in normoxia on sea level VO2max and red cell mass. *Med Sci Sports Exerc* 1999;**31**:S86.
14 **Laitinen H**, Alopaeus K, Heikkinen R, *et al*. Acclimatization to living in normobaric hypoxia and training in normoxia at sea level in runners. *Med Sci Sports Exerc* 1995;**27**:S109.
15 **Friedmann B**, Frese F, Menold E, *et al*. Individual variation in the erythropoietic response to altitude training in elite junior swimmers. *Br J Sports Med* 2005;**39**:148–53.
16 **Burge CM**, Skinner SL. Determination of hemoglobin mass and blood volume with CO: evaluation and application of a method. *J Appl Physiol* 1995;**79**:623–31.
17 **Heinicke K**, Wolfarth B, Winchenbach P, *et al*. Blood volume and hemoglobin mass in elite athletes of different disciplines. *Int J Sports Med* 2001;**22**:504–12.
18 **Stray-Gundersen J**, Chapman RF, Levine BD. ''Living high-training low'' altitude training improves sea level performance in male and female elite runners. *J Appl Physiol* 2001;**91**:1113–20.

COMMENTARY

The absence of a control group in this study does not allow the conclusion that the measured effects are purely the result of living high and training low. In addition, in all similar studies it is difficult to be certain that extraneous factors such as the covert use of erythropoietin (EPO) by the athletes was also not a factor contributing to their increased exercise performance. However, this would seem unlikely in this case as elite Swiss athletes are exposed to one of the toughest anti-doping controls in the world. In addition, the athletes did not show an increase in packed cell volume—an expected effect of EPO use. One strength of the study is that the athletes' performances were measured in real competition so that they probably tried equally hard in the performance tests before and after training. An obvious criticism of similar studies is: how do you ensure that athletes perform maximally in both the performance trials, before and after an intervention? For the subconscious tendency would surely be to try less hard before the intervention and harder after the intervention. Hence the need for adequate control groups. The balance of probability is that the large measured performance effects were indeed the result of training low and living high, although an effect simply of training in a novel environment cannot be totally excluded. The study invites similar well conducted studies that include an appropriate control group. It is appreciated that such studies are probably prohibitively expensive so that we are left to interpret findings from the less definitive uncontrolled trials.

T Noakes
University of Cape Town, Newlands, South Africa;
tdnoakes@sports.uct.ac.za