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Exercise induced hypoxemia at moderate altitude: comparison between running and roller skiing field test in young elite biathletes

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***Aim*. Exercise induced hypoxemia (EIH) can develop in highly trained endurance athletes in terms of exercise mode, muscle mass involved in the exercise, training status and altitude. With this background, the present study compared EIH development and cardiorespiratory responses, in younger highly trained biathletes, at moderate altitude, during running and roller ski field tests.**

***Methods*. Ten younger (15.3±1.5 years) highly trained biathletes performed two incremental maximal field tests (Leger Boucher test) in running (R) and in roller skiing (RS), at 1850 meters altitude. EIH (haemoglobin O_2 saturation (SpO_2) decreased ≥4% from baseline) was measured indirectly using an ear-lobe pulse oximeter included in the K4 (Cosmed) used for measured cardiorespiratory responses.**

***Results*. During the R test, 9 athletes developed EIH whereas only 7 in SR test. Tests duration was the same furthermore at the end of tests, fall of SpO_2 was significantly higher in R compared to RS (-9.11±1.51 *vs*. -5.89±1.09; P<0.01). SpO_2 was significantly lower in R compared to RS from 75% of VO_{2max} to VO_{2max} (P<0.05). VO_{2max} was significantly higher in R than in RS (61.33±6.36 *vs*. 57±6.60 mL.min^{-1}.kg^{-1}; P<0.001). No difference of maximal heart rate, global ventilation, tidal volume or respiratory frequency was present during and at the end of tests.**

***Conclusion*. We concluded that prevalence and severity of EIH was more important during R than RS exercises and that EIH differences may be due to a greater gas exchange abnormality in R.**

KEY WORDS: Exercise - Oxygen - Skating - Running - Altitude.

It is now well accepted that exercise-induced hypoxemia (EIH) occurs in endurance-trained athletes.[1, 2] Physiopathology is still unclear with a probable relative hypoventilation which is link with training adaptation and gas exchange abnormality.[3] More important is the incidence of EIH during sport practice, including training and/r competition and its consequences. In fact EIH may negatively affect VO_{2max} [1] and subsequently exercise performance.[4] The degree of hypoxemia is function of training status and/or exercise mode and/or muscle mass involved and/or altitude exposure. Indeed several studies have been demonstrated that a higher level training leads to a greater severity of EIH.[5, 6] In addition gender and age are particularly involved in the amplitude of EIH.[7, 8] Endurance-trained women and younger athletes who are characterized by smaller lung volumes and diffusion, *i.e*. an inadequate system to cope with high level demands, exhibit greater EIH. Other authors [9, 10] observed that EIH is more apparent in exercise modes engaging a large fraction of the total muscle mass. Most studies compared running and cycling laboratory tests,[11, 12] and all reported a higher EIH during running exercises. However, all this studies used laboratory and not field tests and were unfolded at sea level. It is know that athletes exhibiting EIH at sea level suffer more severe gas exchange impairments during short-term exposure to altitude than athletes or no athletes who do not exhibit EIH at sea level. Compared with a 7% decrease in O_2 arterial saturation at sea level, the reduction is

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15% at 3000m of simulated altitude.[13] This phenomenon explains much of the observed variance in the decline in VO_{2max} among individuals during short-term altitude or hypoxia exposure.[2]

Biathlon is a winter endurance sport specialty in which athletes are highly endurance trained. So biathletes probably present EIH even more when they exercise at moderate altitude. High level biathletes involved in competition have to train all the year. So during the offseason (autumn and summer) biathlon training consists essentially of running (R) and diagonal roller skiing (RS) at moderate altitude. These exercises modes implicate a large fraction of the total muscle mass and then could be sufficient to generate EIH in some biathletes. Moreover the fact that upper and lower body muscles are differently engaged in each exercise mode could influence EIH. So it seems of interest to study EIH and cardiorespiratory adaptations for each exercise mode realized during the offseason training, particularly in young athletes involved in high level biathlon.

Materials and methods

Subjects

Ten younger highly trained biathletes (3 women and 7 men) living and training at moderate altitude (1850 m) volunteered to participle in this study through the monitoring of their training. All young biathletes were athletes of the high level national pole of biathlon of Font Romeu, France. They were aged 15.3±0.5 years, trained regularly for at least 4 years prior to the study. Their average training was 15 hours per week. All were healthy, non-smokers, with no history of cardiopulmonary disease. This protocol was performed with coach for master the training of young biathletes. The study was approved by the committee on research ethics at the institution in which the research was conducted and any informed consent from human subjects was obtained as required.

Incremental exercise protocols

During the offseason in autumn, athletes were asked to perform 2 incremental maximal field tests on a track of 400 m, at approximately the same time of day 48 h apart. The R test was a classical Leger Boucher test.[14] It is a continuous and maximal multistage track test based on the energy cost of running. This test have been reported to deliver high precision, reproducibility and validity for VO_{2max} predicted when compared with VO_{2max} measured directly during a multistage running treadmill test (correlation coefficient of 0.96 and a standard error of 4.5%). The RS test was also a Leger Boucher test but adapted to roller skiing. Tests began at a speed between 8 to 14 $km.h^{-1}$ depending of the level of subject. Speed was increased first 2 minutes by 1 $km.h^{-1}$ then every minute by 0.5 $km.h^{-1}$ until subject exhaustion. In both tests, to be sure that subject sustained the fixed speed; we marked the runway with flags every 50 m. Subjects needed to be localized near a flag (±3 m) each time they received a toot. The test was stopped when the subject became exhausted or when they could not catch up on their delay. During both tests, subjects were verbally encouraged to continue for as long as possible. The weather during tests was sunny: temperature 22.1±1.3 °C and relative humidity 49.9±0.1%.

Measurements

EIH

EIH was considered to exist when a SpO_2 fall ≥4% was observed between rest and maximal condition of the field test during at least 3 minutes.[15] SpO_2 was measured continuously during tests using an ear-lobe pulse oximeter (Cosmed, Rome, Italy). This method has been reported to deliver high precision, reproducibility and validity for O_2 saturation above 85% when compared to O_2 saturation measured from arterial blood gases in highly trained athletes.[16] The instrument's conducting cable was secured to prevent movement artefacts and before the probe was placed, the ear lobe was warmed up by massage to active arterialized circulation.

Cardiorespiratory parameters

A K4b² breath-by-breath telemetric and portable gas analyser (Cosmed, Rome, Italy) was used to collect the metabolic data: oxygen uptake (VO_2, $mL.min^{-1}.kg^{-1}$), respiratory exchange ratio ($RER=VCO_2/VO_2$), minute ventilation (VE,

TABLE I.—*Maximal values under both experimental conditions.*

	Running	Roller skiing
VO_2, $mL.min^{-1}.kg^{-1}$	61.3±2.1	57±2.2 *
VE, $L.min^{-1}$	121.5±11.4	123.52±11.6
V_T, L	2.1±0.2	2.2±0.2
B_F, $breaths.min^{-1}$	58.1±2.7	56.6±5.0
SpO2, %	87±1.4	91±1.2 *
HR, $beats.min^{-1}$	197±4.2	198±3.3
RER	1.1±0.04	1.1±0.06
VT1, % VO_2 max	75.4±1.7	78±2.4
VT2, % VO_2 max	92.7±0.4	93.1±1.6

Values are means ±SEM.
VO_2: oxygen uptake; VE: minute ventilation; V_T;, tidal volume; B_F;, breathing frequency; SpO_2: haemoglobin O_2 saturation; HR: heart rate; RER: respiratory exchange ratio; VT: ventilatory threshold.
*Significantly different from running (P<0.05).

$L.min^{-1}$) tidal volume (V_T, L), breathing frequency (B_F, $breaths.min^{-1}$). The pneumotachographe and analysers of the Cosmed K4b² system were calibrated before every test session according to the manufacturer's specifications, using respectively a 3-l syringe and a gas bottle of know O_2 and CO_2 concentrations (16% and 5% respectively). Each subject was also equipped during field maximal tests with a chest belt (Polar Electro, Kempele, Finland) to collect heart rate continuously (HR, $beats.min^{-1}$).

The highest VO_2 and HR obtained during the incremental test for 15 s were defined respectively as the VO_{2max} and the HR_{max}. Criterions used to verify that the test was performed at maximal subject's capacity were 1) an increase of VO_2 of <100 mL with the last increase in work rate; 2) attainment of age-predicted maximal heart rate (HR) (210-[0.65 age] ±10%]; 3) a RER superior to 1.1 (Table I); 4) the incapacity of the subject to maintain the speed desired despite maximum effort and verbal encouragement. All subjects achieved three of criteria at least.

Statistical analysis

The results are expressed as means ±SEM. Differences in values obtained at VO_{2max} between the R and RS exercise were analysed using Student's *t-test* for paired samples. Differences in all SpO_2 and respiratory variables were analysed with a two-way repeated measure ANOVA which examined the main effects and interaction between exercise time (rest, 40, 60, 75, 80, 100 % VO_{2max}) and exercise modality (running or roller skiing). Where overall significance was obtained, differences between means were identified using Student-Newman-Keuls post hoc analysis. Correlations between the variables were tested using Pearson's product-moment correlation coefficient test. For all tests, the level of statistical significance was set at P<0.05 and analyses were conducted using SigmaStat software (Ver 2.03).

Results

Young biathletes were aged 15.3±0.5 years. Body mass and height were respectively 54.4±3.1 kg and 168±2.9 cm. SpO_2 at rest measured before each test was 97.4±0.7 and 97.3±0.4% respectively for R and RS tests. There is no statistical difference. Table I reports maximal data and ventilatory threshold (VT) under both experimental conditions. VO_{2max} is 8% significantly lower during maximal RS when compared to R tests, although VT1 and VT2 are no different. The duration of the exercise tests were the same between R and RS, in mean 11 minutes.

VE, V_T and B_F values at rest, submaximal (40, 60, 75 and 80% of VO_{2max}) and maximal intensities are similar for R and RS tests (Figure 1).

SpO_2 decreases significantly from rest to maximal in both tests (P<0.001). Delta of SpO_2 between rest and maximal exercise is -9.1 in R whereas -5.9 in RS (P<0.05). During the R test, 9 athletes developed EIH (Figure 2). Their SpO_2 decreases from 98% at rest to 87% at maximum. In contrast, only 7 of these same subjects demonstrated EIH during RS, which SpO_2 falling from 98% at rest to 91% at maximum.

Kinetics of SpO_2 decreased show that SpO2 is significantly lower in R compared to RS from 75% of

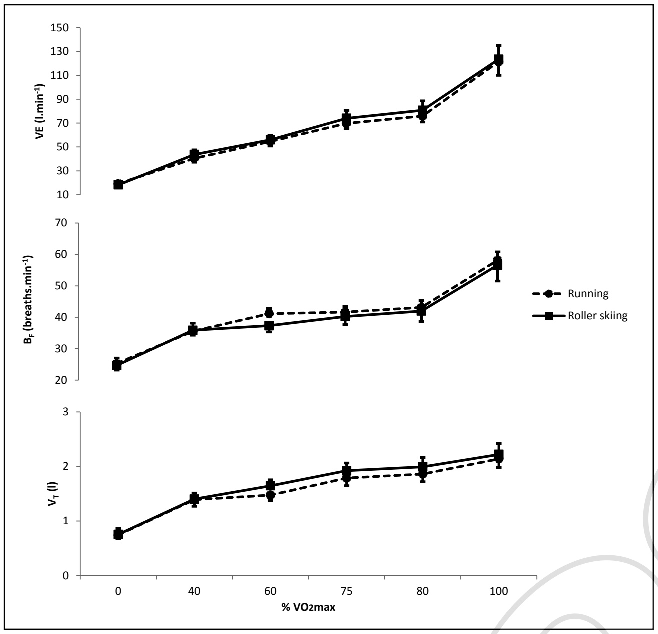

Figure 1.—Part a: minute ventilation (VE, l.min^{-1}); Part b: breathing frequency (B_F, breaths.min^{-1}); and part c: tidal volume (V_T, l), during rest and incremental maximal exercise under both experimental conditions.

VO_{2max} (P<0.05; Figure 3) to VO_{2max}. This difference is more important between 80 to 100% of VO_{2max} (P<0.005). At the end of tests SpO2 is 5% lower in R compared to RS (P<0.05).

There is a significant correlation between delta of SpO_2 in R and RS (r=0.76, P<0.05). VO_{2max} in R is correlated to the VO_{2max} in RS (r=0.86, P<0.05). No significant correlation was found between SpO_{2max} in the maximal effort and VO_{2max}, B_{Fmax}, V_{Tmax}, VE_{max} or between VO_{2max} and B_{Fmax}, V_{Tmax}, VE_{max} (P>0.05 *vs.* all exercise modes).

Discussion

This study shows that EIH is more important in R compared to RS maximal exercises. This is associated with a greater VO_{2max} during R, whereas there is no difference between cardiorespiratory parameters.

EIH description

To our knowledge, only one study [17] measured O_2 desaturation during R and RS maximal exercises at

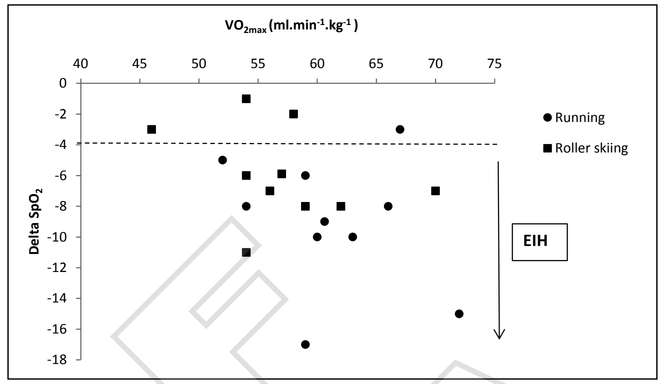

Figure 2.—Individual decrease in haemoglobin O_2 saturation (%) from baseline values (rest) during running and roller skiing at max.

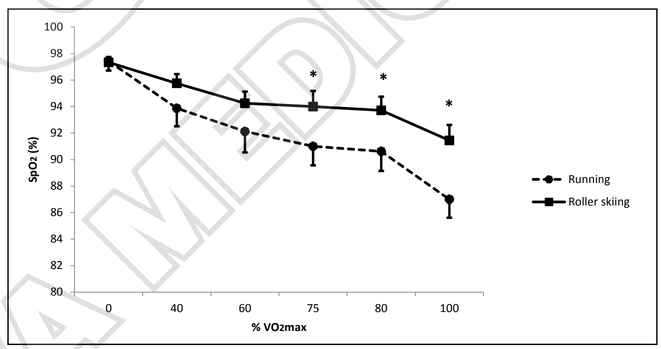

Figure 3.—Haemoglobin O_2 saturation (SpO_2) during rest and incremental maximal exercise under both experimental conditions.

sea level. At the end of tests O_2 saturation was ≈93% and delta of arterial O_2 saturation was ≈5 with no difference between 2 modes exercises. VO_{2max} values (≈6 L/min) were no great difference. Well there was no difference between cardiorespiratory parameters. In our study more subjects developed EIH and EIH severity was more important in R compared to RS maximal exercises. This phenomenon has been objectified by an O_2 desaturation between rest and maximal more important in R. More specifically EIH kinetic analyse showed that O_2 desaturation difference appeared from 75% of VO_{2max}. Yet this intensity matches with a specific stage of EIH. Indeed in EIH phenomena Durand *et al.*[3] and Prefaut *et al.*[15] identified two stages. The first, during submaximal exercise was called early stage. It has been consistently associated with a sluggish ventilatory response leading to decrease O_2 blood pressure (PaO_2) and O_2

arterial saturation (SaO_2). If the first stage is subsequent to high endurance training cardio muscular adaptation, the second is specific to EIH phenomena. This late stage starts from ≈75% VO_{2max} until VO_{2max}. A gas exchange alteration was signalled by a widening in alveolar-arterial PO_2 difference which contributed to the hypoxemia increased: the fall of PaO_2 and SaO_2 continued to increase. In our study a difference between RS and R occurs in the second stage suggesting that in R gas exchange abnormality could be increased and/or that another mechanism could be present. Several hypothesis have been proposed to explain gas exchange abnormality in EIH: 1) reduced transit time; 2) ventilation to perfusion mismatching; 3) increased shunt; and 4) interstitial pulmonary oedema.[15] In addition our study was realized at moderate altitude and it is well proven that diffusion limitation becomes more pronounced in hypoxia at any given alveolar ventilation.

EIH explicative hypothesis

A part of this gas exchange alteration could be explained by a duration of haemoglobin O_2 reload not sufficient to maintain SpO_2.[9] It is also assumed by Holmberg *et al.*[17] when they reported a lower O_2 desaturation and VO_{2max} in double polling (upper body exercise) compared to R and RS exercises. They suggested that as there is a linear relationship between the VO2 and the cardiac output (Qc), the mean red cells transit time may be slightly longer during double polling. In our study O_2 desaturation was more important in R than in RS. Insofar as Qc was more important in R, the mean red cells transit time can be to faster to allow an optimal duration of haemoglobin O_2 reload. In line with this, if the Qc is higher during R test compared to RS test, lung blood pressures are more important causing higher alveolar capillaries stretching or/and break.[18] Indeed when the stress in the capillary walls rise to high levels, ultrastructure changes occur in the pulmonary gas-blood barrier, a condition known as stress failure. Several studies have been in evidence an excessive accumulation of extravascular lung water secondary to stress-induced failure of pulmonary capillaries, which may contribute to the impairment of pulmonary diffusion in response to high-intensity exercise.[18-20] As such, we would suggest that the higher O_2 desaturation in R can be explained by a greater O_2 diffusion limitation.

Differences of VO_{2max} and EIH relationship

It is well reported in literature that EIH induced a VO_{2max} decrease.[2] Whereas in this study EIH is linked in R exercise with a greater VO_{2max} compared to RS exercise. On the basis of the evidence presented here it appears that degree of hypoxemia is function of exercise mode. Exercise using upper body (like roller skiing) seems moderate VO_{2max} and limit the fall of SpO_2 compared to an exercise using lower body (like running). An explanation for the lower VO_{2max} during RS may be the greater [21] and faster [22] recruitment of type II muscle fibers. In fact some previous studies reported higher blood (lactate) during arm exercise and the authors have assumed that a greater contribution from anaerobic glycolysis to the total ATP turnover may have caused the lower VO_{2max}.[23, 24] So in this study the difference of VO_{2max} can be explained by a utilization of muscular fibers II more important during the RS exercise because of the upper body requested. Indeed previous works have implicated the importance of upper body aerobic and anaerobic power to ski performance.[25, 26] Kinematic analysis of elite skiers [27] and top junior skiers [28] has suggested that approximately 50% of effective forward propulsion during uphill ski skating can be attributed to poling. Or it is know that there are significant differences in the proportion of type I muscle fibers between the upper body (arms, chest and shoulder: typically ≈30% type I fibers) and lower body (legs and seat: typically ≈50% type I fibers) musculature.[29] This suggests that the peripheral extraction is decisive in EIH apparition and that EIH is greater when oxidative metabolism activation is higher. Another reason for the lower VO_{2max} observed during RS exercise could be related to a muscle-specific detraining effect after the competitive ski season is over. Rundell [30] found that high volume roller skiing during summer training results in similar peak VO_2 values between R and RS, although lower peak VO_2 values for RS were obtained during presummer testing. This implies that ski-specific training can attenuate the physiological differences between RS and R. The significant difference in VO_{2max} may be coincident with a low percentage of ski-specific training. It is apparent that VO_{2max} is compromised during RS in skiers who do not have a large base of ski-specific training.[30]

Implications for training

The effects of EIH are currently debated. Further investigations are needed to determine the long term consequences of repetitive hypoxemia in highly trained endurance athletes. EIH exhibited by endurance-trained subjects during high-intensity exercise has been shown to contribute significantly towards quadriceps muscle fatigue, diaphragmatic fatigue [31] and more generally a significant effect on the rate of development of locomotor muscle fatigue.[4] Moreover independent of the type of maximal exercise, an approximate 15% reduction in pulmonary diffusion takes place 2-3 hours postexercise, which normalizes during the following day of recovery has been reported.[20] So the first studies about the consequences of EIH have been demonstrated potential negative effects on the performance and may be on the health in long term. It seems to be more favourable for younger biathletes to practice less time as possible an exercise which develop a greater EIH. In the findings presented here it becomes clear that it is important taking into account exercise mode order in training regimen for athletes developing EIH. It is advisable to encourage RS specific training rather than R training during offseason. Further under our results we would suggest that supplemental RS specific upper body training should be incorporated in the training regimen of EIH athletes for try to master EIH and the reduction of the performance associated. This is an adequation with Rundell [30] who suggested a high percentage of off-season training time should be spent RS in order to 1) provide sufficient stimulus for optimal peripheral adaptations to occur in RS-specific muscles; and 2) promote RS-specific neural pathway development, which is probably important in skiing efficiency.

Conclusions

In summary, this study shows that prevalence and degree of EIH are more important in R compared to RS maximal exercises. Moreover young elite biathletes reach higher VO_{2max} in R test, in spite of similar HR_{max} and ventilatory functions. So our data supports the hypothesis that gas exchange abnormality can be more important in R but more investigations are necessary for explain exactly the origin of EIH differences between exercise modes. Based on these results, practical advice for biathletes and coaches would be to take into account exercise mode in training regimen for athletes developing EIH, and the importance of upper body training in order to limit the potentially deleterious effects of EIH on health and performance.

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