

Blood Lactate Kinetics during Incremental Treadmill vs. Prolonged Field Running in Cross-Country Skiers

Blutlaktatkinetik während eines Laufbandstufentests vs. längerer Geländeläufe bei Skilangläufern

Summary

- › **Purpose:** The aim of the present investigation was to compare the blood lactate concentration (BLC) vs. heart rate (HR) relationship of incremental treadmill (ITR) vs. prolonged field running (PFR) in order to provide a mathematical equation allowing to adjust HR-based intensity zones, derived from non-steady state ITR-exercise, to ensure their transposition to -and application for prolonged field running.
- › **Methods:** Sixteen junior elite cross-country (XC) skiers were examined in ITR and PFR, where subjects were instructed to complete four consecutive self-paced 2.500 m-runs in undulating terrain at different exercise intensities. BLC obtained from both settings were compared at given HR, obtained from each of the four loops during PFR.
- › **Results:** A two-way 4 x 2 repeated measures analysis of variance (ANOVA) showed a statistically significant main effect of stage ($p < .001$) and test protocol ($p < .001$), as well as a significant interaction effect between these two factors ($p < .001$). Post-hoc calculated paired-samples t-test showed significantly lower BLC from ITR compared to that obtained from PFR at any loop/HR level. Cohen's d revealed large effect sizes (loop 1: -; loop 2: 1.11 ± 0.23 vs. 1.64 ± 0.38 mmol l⁻¹, $p < .001$, $d = 1.71$; loop 3: 1.79 ± 0.38 vs. 4.21 ± 1.19 , $p < .001$, $d = 2.12$; loop 4: 3.08 ± 0.75 vs. 9.16 ± 1.67 , $p < .001$, $d = 3.99$).
- › **Conclusion:** For BLC-levels ranging from 1.5-6 mmol l⁻¹, coaches should subtract approx. 15 beats min⁻¹ from the HR obtained during a lab test identical to that used in the present study in order to exercise at comparable BLC during prolonged training in the field.

KEY WORDS:

Heart Rate, Training Zones, T-Test
Two-Way Measures Analysis of Variance (ANOVA),

Zusammenfassung

- › **Ziel:** Das Ziel der vorliegenden Untersuchung war es, die Blutlaktatkonzentration (BLC) vs. Herzfrequenz (HR)-Beziehung zwischen einem Stufentestprotokoll auf dem Laufband (ITR) und dem Laufen im Feld (PFR) zu untersuchen. Ausgehend davon sollte eine mathematische Formel bereitgestellt werden, die es ermöglicht, Herzfrequenz-basierte Intensitätszonen, abgeleitet aus der non-steady state Belastung des ITR, anzupassen, um ihre Anwendung für das Training im Feld sicherzustellen.
- › **Methodik:** 16 hochtrainierte Nachwuchs-Skilangläufer/-innen wurden in ITR und PFR untersucht. Im PFR sollten die Probanden vier aufeinanderfolgende 2.500 m-Läufe in hügeligem Gelände mit unterschiedlichen Trainingsintensitäten absolvieren. BLC beider Settings wurden an den HR der vier Stufen des PFR verglichen.
- › **Ergebnisse:** Eine zweifaktorielle 4 x 2 Varianzanalyse mit Messwiederholung (ANOVA) zeigte einen statistisch signifikanten Haupteffekt der Stufe ($p < .001$) und des Testprotokolls ($p < .001$), sowie einen signifikanten Interaktionseffekt zwischen beiden Faktoren ($p < .001$). Der post-hoc gerechnete T-Test bei verbundenen Stichproben zeigte signifikant niedrigere BLC aus dem ITR im Vergleich zu denen des PFR an jeder Stufe/Herzfrequenz. Cohen's d zeigte starke Effekte (Runde 1: -; Runde 2: 1.11 ± 0.23 vs. 1.64 ± 0.38 mmol l⁻¹, $p < .001$, $d = 1.71$; Runde 3: 1.79 ± 0.38 vs. 4.21 ± 1.19 , $p < .001$, $d = 2.12$; Runde 4: 3.08 ± 0.75 vs. 9.16 ± 1.67 , $p < .001$, $d = 3.99$).
- › **Fazit:** Für BLC im Bereich von 1.5-6 mmol l⁻¹ sollten Trainer ca. 15 Schläge min⁻¹ von der aus einem der vorliegenden Studie ähnlichen Labortest erhaltenen Herzfrequenz subtrahieren, wenn das Training im Feld bei einer ähnlichen BLC stattfinden soll, wie sie Athleten-individuell auf dem Laufband zu erkennen war.

SCHLÜSSELWÖRTER:

Herzfrequenz, Trainingszonen, T-Test
zweifaktorielle Varianzanalyse (ANOVA)

Introduction

Physiological testing is integral to the training process of elite endurance athletes (34). The analysis of measured maximal and submaximal physiological variables is essential for monitoring adaptations to training and the appropriate adjustment or design of upcoming training programmes (1, 15). In order to ensure an individual control of exercise intensity during future training periods, the athlete is usually provided with training

intensity prescriptions (TIP), in terms of heart rate (HR)-based training zones (14, 15, 39, 40), following diagnostics.

For this purpose, physiologists typically determine the relationship between athletes' HR and blood lactate concentration (BLC) in order to prescribe target HRs associated with BLC levels defining different training zones specified for the athlete (14, 15, 39, 40). This approach is particularly used for

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1. INSTITUTE OF APPLIED TRAINING SCIENCE, Department of Endurance Sports, Cross-Country Skiing Section, Leipzig, Germany
2. FRIEDRICH-SCHILLER-UNIVERSITY, Department of Sports Medicine and Health Promotion, Jena, Germany
3. INSTITUTE OF APPLIED TRAINING SCIENCE, Department of Sports Medicine, Leipzig, Germany
4. HUMBOLDT UNIVERSITY, Department of Sports Medicine, Berlin, Germany
5. CHARITÉ UNIVERSITY HOSPITAL, Department of Sports Medicine, Berlin, Germany



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CORRESPONDING ADDRESS:

André Wilhelm; i. V. Dr. Axel Schürer
Department of Endurance Sports
Cross-Country Skiing Section
Institute of Applied Training Science
04109 Leipzig, Germany
✉: schuerer@iat.uni-leipzig.de

Table 1

Anthropometric and selected physiological parameters (mean \pm SD).

ANTHROPOMETRIC AND SELECTED PHYSIOLOGICAL PARAMETERS	
PARAMETER	ALL
N	16 (N (male) = 8; N (female) = 8)
Age (years)	17.8 \pm 1.6 (15-22)
Body mass (kg)	65.6 \pm 9.8 (51.6-84.4)
Body height (cm)	174 \pm 10 (161-187)
Maximum HR (beats min ⁻¹)	200 \pm 8 (185-214)
VO ₂ max (l min ⁻¹ kg ⁻¹)	66.0 \pm 7.0 (55.2 \pm 75.8)

sports such as cross-country (XC) skiing, as other types of intensity control, e.g. external intensity control based on running velocity or power output, are hindered by both permanently changing exercise modes (e. g. roller ski or running) and terrain (4, 14, 15, 29).

However, depending on the specifications of the test protocol used for diagnostics, such as the exercise mode (15, 21, 24, 39), the treadmill incline (12, 14), or the stage duration (7, 8, 9, 13, 14, 22, 35, 41), the BLC/HR relationship can vary significantly. This in turn can have considerable implications for derived HR-based training zones and their transposition to field setting, as demonstrated for example by the findings made by Vergès et al. (39). The authors compared the BLC/HR relationship from short stage duration (3 min) incremental treadmill running and prolonged field roller skiing (four 4 km loops at prescribed intensities) in well-trained male XC skiers. It was shown that at given HRs, BLC obtained from the field protocol was significantly higher compared to that obtained from treadmill running.

A wide range of literature provides plenty of insight into the metabolic behaviour of different muscle groups recruited during different training modes and illuminates the associated effect on the BLC/HR relationship (e.g. (15, 19, 20, 25, 38)). Further, previous literature shows that a 3 min stage, as applied during the above treadmill running, seems considerably too short to reveal a steady state condition in BLC (7, 8, 13), which is, however, given during prolonged exercising, as for example in case of the above field roller skiing.

Thus, the transposition and application of TIP derived from non-steady state lab tests typically used in sports medicine, is to be questioned for steady state field exercise, as this might result in athletes exercising at unintended intensities, which in worst case might lead to maladaptations and the emergence of overtraining (2, 3, 5, 16, 18).

Literature therefore proposes that lab tests should mimic real-life conditions in terms of emulated course profiles and prolonged exercising (14). However, short stage duration incremental treadmill tests are still attractive to both athletes and coaches for test economics and reproducibility. This is shown by the fact, that such protocols are preferably used in order to assess physiological variables of endurance athletes constantly exposed to prolonged exercise in daily training (11, 24, 34, 39). In this light, it can be of high practical relevance to provide guidance for coaches on how lab-based TIP have to be adjusted in order to account for the differences in exercise duration, ensuring their transposition to -and application for training in field. LaRoche et al. (14) presented a mathematical equation allowing coaches to alter target HRs, depending on whether athletes are either skiing in uphill or level terrain. This was based on a comparison of the BLC/HR relationship between graded and level roller skiing, both conducted on a treadmill (14).

However, this practical application does not account for the fundamental differences between lab tests and daily training conditions with regard to the exercise duration.

Hence, aiming for a practical application analogous to that of LaRoche et al. (14), which allows coaches to calculate the HR-shift when going from lab to field setting, the current study focused a comparison of the BLC/HR relationship of incremental treadmill vs. prolonged field running in a typical XC-skiing setting. By the example of this very specific environment, the present paper is to be seen as a proposal on how to approach the issue of adjusting lab-based TIP in order to apply them in a given field setting.

The methodological approach considers the suggestion that lab-based TIP should only be applied for the exercise mode by which they were established (15, 39, 42). The rationale for examining the exercise mode running is that skiers often use lab-based running protocols for their routinely performance diagnostics (24, 34, 40). Second, running takes an essential part of endurance training in XC-skiing (26, 29, 37). Thus, possible improper intensity control would have a large impact on an athletes' performance, emphasizing the high practical relevance of the aimed comparison.

Given the previously cited literature, it was hypothesized prior to the study that the BLC/HR relationship obtained from laboratory vs. field condition would differ from each other, in terms of a leftward shift of the BLC/HR curve from prolonged field running compared to that from lab running.

Methods and Data-Collection

Subjects

Sixteen junior elite XC skiers – eight of whom participated in the German national ski team (DSV) at the time of the study – were examined (characteristics see Table 1). All athletes were asked to reduce training intensity and volume for 48h before the tests. Furthermore, athletes were instructed to have their usual breakfast two hours prior to the tests. Before study participation, all subjects signed a written informed consent. The study was approved by the ethics committee (HU Berlin) and it conforms to the principles outlined in the declaration of Helsinki.

Overall Design

Subjects were tested in an incremental running test in both laboratory and field setting (see protocols below), at weekly intervals from the beginning of June until the beginning of July, which corresponds to the first stage of the preparation period. Since subjects participated in different training teams, the test days differed between some athletes. But the test interval of seven days was the same for all XC skiers. Each test on the h/p/cosmos saturn® 300/100 r treadmill (h/p/cosmos sports & medical GmbH, Nussdorf-Traunstein, Germany) took approximately 35 min. Ambient temperature was kept constant at 18.5°C. The field tests each took approximately 90 min. Testing here was conducted on two courses to which the athletes were randomly assigned. The courses naturally differed in the characteristic of the profile, whereby both the course length and the total climb were almost identical (course 1 – course length: 2.310 m, total climb: 51 m; course 2 – 2434 m, 53 m). The slight difference in the course length was not of relevance to the purpose of the study. Finally, the same investigator was present at every test.

The two-course testing was motivated by the main objective of the study, which was to provide a practical application allowing the transposition of TIP derived from the lab to field setting, without being valid only for a particular training location with a specific course characteristic.

Exercise Test-Protocols

Incremental treadmill running (ITR)

The initial running speed on the treadmill was 8 km h⁻¹ for female and 10 km h⁻¹ for male athletes, at a treadmill slope of 1%. The treadmill speed was then increased in steps of 1 km h⁻¹ every 3 min until the volitional exhaustion of the individual athlete. In between the stages, thirty seconds of rest were routinely used for measuring BLC from capillary blood samples taken from the earlobes.

Prolonged Field Running (PFR)

Following the methodological procedure of Vergès et al. (39), subjects were instructed to complete four consecutive self-paced 2.500 m-runs in undulating terrain at different exercise intensities, starting with a running speed corresponding to athletes-individual low-intensity training (LIT). Since XC-skiers realize a large amount of LIT sessions within their overall endurance training (26, 29, 37), each of the athletes examined has assigned a certain HR-range to this intensity during their participation in long-term training. Subjects were asked to complete the four loops in a way that, beginning with their respective LIT, a stepwise and distinct progression in exercise intensity was achieved, meaning that the mean HR should increase by at least 10-15 beats per loop. This corresponds approx. to the subjects' frequently applied intensities during long-term training, emphasizing that athletes were used to these various intensities. Due to previously described setting-related demands involved in XC-skiers' training, athletes were instructed not to focus solely on their appropriate HR in order to adjust running speed, but similar to daily training, on both effort perception and occasional HR-control. This is analogous to how XC skiers typically train, which is why they were accustomed to this method of intensity control, concurrently indicating that the above procedure best mimics real-life conditions. Ultimately, athletes started in individual trials at each of the four loops. According to the above specifications, the duration of each stage varied individually among subjects. Therefore, the duration of the pause also varied, since the next stage starts every 20 min. BLC was measured immediately after each stage from capillary blood samples taken from the earlobes.

Data-Recording

Using the Polar WearLink® transmitter, W.I.N.D.-technology and the polar RX800 HR monitor (Polar Electro GmbH, Büttelborn, Germany), the subjects' HR was measured during each protocol. During the laboratory test, HR was also recorded with a standard 12-lead surface ECG (custo cardio 100, custo med GmbH, Ottobrunn, Germany), as part of a routine health check. In the laboratory test, ventilation and gas exchange using breath-by-breath spirometry (Metalyzer® 3B R2, Cortex Biophysik GmbH, Leipzig, Germany) was measured, in order to determine the maximal aerobic capacity ($\dot{V}O_{2\max}$) of the athletes. This parameter was defined as the highest 21-breath moving $\dot{V}O_2$ average (17), obtained using MetaSoft® Studio 3.97 SR6. BLC was analyzed in a fully automated manner (SUPER GL, Dr. Müller Gerätebau GmbH, Freital, Germany). In the field test, BLC was assessed using the same equipment as was used during the laboratory test.

Data-Analyses

For analysing HR from PFR, the session goal approach was followed (30, 36), i.e. the average HR from every stage was taken. This is considered standard practice for mo-

nitoring and documenting training sessions in XC skiers and at the same time corresponds to the procedure of the investigation by Vergès et al. (39). From ITR, the averaged HR-value of the last 15 s of each stage was taken for further analyses.

For the comparison of the BLC/HR relationship obtained from different settings, BLC was compared at identical HRs. This procedure was oriented on that conducted by Vergès et al. (39). Athlete-individual average HRs, obtained from each of the four loops during PFR, were used to interpolate associated BLC from the ITR. This was conducted for each individual athlete using an exponential data fit by applying the software winlactat® (4.7.0.6; mesics GmbH, Münster, Germany). In order to get the best fit of the curve, the first BLC values were excluded from the analysis (outliers) if the lactate turn point was only reached after these stages.

Vice versa to the above procedure, predetermined BLCs (1.5, 2, 2.5, 3.0, 4.0, 5.0, 6.0 mmol l⁻¹), covering both the range of the BLC obtained from both ITR and PFR in all subjects and that of the typical five-zone intensity scale (32), were used to interpolate associated HR for both lab and field running. Means and standard deviations were plotted in a HR/BLC chart. According to the procedure of LaRoche et al. (14), a second order polynomial was fit to each curve and subsequently mathematically subtracted. Based on the resulting equation, the shift in HR at any BLC of the above range starting from 1.5 to 6.0 mmol l⁻¹ was calculated.

Owing to illness, two female athletes could not participate in the field test. In one male subject, a loss of HR-signal occurred, possibly caused by recording failure resulting from an improperly fitted chest strap. These three subjects therefore had to be completely excluded from the analyses, which is why Table 1 characterises sixteen subjects instead of the nineteen athletes originally participating in the study.

In one male and female athlete, the mean HR [%HR_{max}] of the first and second loop of PFR, respectively, had to be excluded from the analyses, owing to a loss of HR signal. Associated BLC were therefore not interpolated.

Statistical Analyses

Statistical analyses were performed using IBM® SPSS Statistics 23.0 (SPSS Inc., Chicago, Illinois). All parameters were tested for normal distribution with the Kolmogorov-Smirnov test. Descriptive statistics were calculated, showing means and standard deviations (SD) for HR [bpm], speed [km h⁻¹], time [s] and BLC [mmol l⁻¹]. A two-way 4 (HR-levels PFR) x 2 (test protocol) repeated measures analysis of variance (ANOVA) was calculated. A Greenhouse-Geisser-correction was applied if homogeneity of variances was violated. A p-value of <.05 was selected as the level of significance for all statistical analyses. When a statistically significant main effect of protocol was detected, a paired samples t-test or Wilcoxon-test (when normal distribution could not be shown) at each of the four stages was applied to test for simple effects. When statistically significant results could be shown, Cohen's d was run to look for the effect size.

Results

Due to the majority of measured HRs from the first loop of PFR were higher than for ITR, associated BLC was not interpolated. Consequently, data from loop 1 of PFR was removed from the ANOVA. In one female athlete, data from loop 2 was removed for the same reason. >

Table 2

Differences in blood lactate concentration (BLC) between incremental treadmill running (ITR) and prolonged field running (PFR). Values presented as means \pm standard deviation (SD) at four loops/heart rate (HR) levels obtained from PFR. Also depicted, speeds and associated time required by the athletes for each loop during PFR. F-values with degrees of freedom, p-values and Eta-squared (η^2) obtained from two-way 3 x 2 repeated-measures analyses of variance ANOVA*, showing possible main and interactive effects. T-values, corresponding p-values from the post-hoc paired-samples t-test and Cohen's d are presented if a statistically significant difference between PFR and ITR could be shown at any stage. *3 (loop) x 2 (test protocol) = loop 1 of PFR is not included due to the majority of measured HR from PFR were higher than for ITR implying that associated BLC were not interpolated); ^a main effect between stages; ^b Main effect between test protocols; ^c stages x test protocol interactive effect.

PARAMETER	FIRST LOOP/ HEART RATE		SECOND LOOP/ HEART RATE		THIRD LOOP/ HEART RATE		FOURTH LOOP/ HEART RATE		F-VALUE	P-VALUE	η^2
	PFR	ITR	PFR	ITR	PFR	ITR	PFR	ITR			
HR [BPM]	149 \pm 9		160 \pm 8		176 \pm 7		187 \pm 7		$F_{(2,26)}=180.4^a$	<.001	.933
SPEED [KM H ⁻¹]	11.21 \pm 0.78		12.50 \pm 0.89		14.99 \pm 1.20		16.52 \pm 1.47		$F_{(1,13)}=213.3^b$	<.001	.943
TIME [S]	806 \pm 57		707 \pm 51		604 \pm 49		550 \pm 52		$F_{(2,26)}=92.6^c$	<.001	.877
BLC [MMOL L ⁻¹]			1.64 \pm 0.38	1.11 \pm 0.23	4.21 \pm 1.19	1.79 \pm 0.38	9.16 \pm 1.67	3.08 \pm 0.75			
			N=14, $t_{(13)}=-6.4$, p<.001, d=1.71		N=16, $t_{(15)}=-8.5$, p<.001, d=2.12		N=16, $t_{(15)}=16.0$, p<.001, d=3.99				

A significant main effect of stage and test protocol (p<.001, resp.), as well as a significant interaction effect between both these factors was revealed (p<.001). Post-hoc calculated paired-samples t-test (normal distribution of BLC at any HR level could be shown for each test protocol) showed significantly lower BLC from ITR compared to those obtained from PFR at any loop/HR level (loop 1: HR: 149 \pm 9, BLC: -; loop 2: 160 \pm 8, 1.11 \pm 0.23 vs. 1.64 \pm 0.38, p<.001; loop 3: 176 \pm 7, 1.79 \pm 0.38 vs. 4.21 \pm 1.19, p<.001; loop 4: 187 \pm 7, 3.08 \pm 0.75 vs. 9.16 \pm 1.67, p<.001). Cohen's d each showed strong effects here (d=1.71, d=2.12, d=3.99) (see Table 2).

Second order polynomial regressions fit to the means of interpolated HRs at BLC of 1.5 mmol l⁻¹, 2.0, 2.5, 3.0, 4.0, 5.0 and 6.0 showed a distinct leftward shift of the BLC/HR relationship obtained from PFR compared to that obtained from ITR.

Discussion

Since the training load (TL) of elite XC skiers is quite high (26, 29, 32, 34, 37), there is a thin line between positive and negative training outcomes. It is therefore essential to prevent possible occurring training errors leading to the emergence of overtraining, such as failed compliance with session goals (6). The provision of TIP can make a significant contribution to this, by enabling the athlete to individually control his exercise intensity and ultimately match it with that specified by the coach. This can be particularly beneficial during the use of the predominant exercise modes, as these take up a large amount of training time. Besides roller skiing and skiing, running is considered one of these (26, 29, 37). Given, that i.) it is common to use short stage duration incremental treadmill tests in order to assess physiological variables of endurance athletes constantly exposed to prolonged exercise in daily training (11, 24, 34, 39), and ii.) XC skiers often use incremental treadmill running for their routinely performance diagnostics (24, 34, 40), there was a lack of information regarding the following. The extent of alteration in the BLC/HR relationship obtained from non-steady state lab vs. steady state field running and the associated consequences for the provision of HR-based training zones to be applicable for training in field.

The current study compared the BLC/HR relationship in identical exercise modes, while examined protocols differed markedly in their designs with regard to the number of stages,

the stage duration and the duration of the pause. The methodological procedure of a study by Vergès et al. (39) served as a model for the current investigation. Prior to the study, it was hypothesized that the BLC/HR relationship obtained from laboratory vs. field condition would differ from each other, in terms of a leftward shift of the BLC/HR curve from field running. According to the findings of the present study, the hypothesis is to be verified.

The results indicate that the difference in BLC between ITR and PFR, meaning higher BLC in PFR at given HRs, increased with increasing exercise intensity (see Table 2). This is in accordance with the findings made by Vergès et al. (39), which, however, compared the BLC/HR relationship obtained from different exercise modes, i.e. incremental treadmill running and prolonged field roller skiing. In the current study, though, the progressively greater differences in BLC were more pronounced than those found in the investigation by Vergès et al. (39) (percentage difference loop 2: 32.3% vs. 8.0%, loop 3: 57.5% vs. 28.2%, loop 4: 66.4% vs. 53.9%; differences are calculated based on the equation (value PFR - value ITR) / value PFR x 100). However, this comparison should be considered with caution, as the two studies differed with regard to exercise mode and course length (respectively -duration), which may affected the BLC responses accordingly. In addition, exercise intensities and associated HR levels of each loop may have had an influence, as they may have also been different between the two investigations.

Especially the distinct differences at HR-levels from loop 3 (176 \pm 7) and 4 (187 \pm 7) found in the present study may be of particular relevance for training practice. These intensities (88% of maximum HR (HR_{max}) and 93.5% HR_{max} , resp.) correspond approx. to the athletes' intensity zone 3 and 4 in the five-zone intensity scale (85-90% HR_{max} , 2.5-4 mmol l⁻¹ and 90-95% HR_{max} , 4.0-6.0 mmol l⁻¹, resp.) (32). Within the three-zone intensity scale, these would approx. correspond to the transition from zone 2 (moderate-intensity, MIT, 82-87% of maximum HR (HR_{max})) to zone 3 (high intensity, HIT, >87% HR_{max}) (33). Training in these zones, i.e. training around or above an intensity associated with the maximum BLC steady-state (≥ 4 mmol l⁻¹) (HIT) (31), plays an important role in the training regime of cross-country skiers throughout the entire training year (34, 37), as it is considered to be greatly effective in improving endurance performance (27, 28). Considering this, and given the discrepancies in BLC at given HR from loop 3 and 4 found in

the current study, it is imperative to adjust target HR when training in field, especially during sessions where the athlete is to exercise around or above the anaerobic threshold. Otherwise, athletes are at risk of exercising at unintended intensities leading to negative training outcomes and maladaptations, resulting in overtraining (2, 3, 5, 16, 18). This proposal is meant to account for the very different metabolic states evoked by lab and field conditions, already referred to at some point. During prolonged field running, where the observed exercise durations ranged from 550 ± 52 to 806 ± 57 seconds, the occurrence of a steady state condition in BLC can be assumed. This is substantiated by literature, as Foxdal et al. (8) proposed a stage duration of 8 min, if a steady-state condition in BLC is to be revealed. Consequently, a quite short stage duration of 3 min, typically applied in sports medicine diagnostics and used during treadmill running examined in the present study, is considerably too short to reveal such a metabolic state, as assumed at the outset. Vergès et al. (39) emphasized the same with regard to the laboratory protocol conducted in their study (3 min stage duration) and thus referred to Foxdal et al. (7), which in turn provide substantial explanations on this. First, the time dependent muscle-to-blood release of BLC, ii.) the also time dependent dilution effect while muscle-to-blood release of BLC and iii.) organs' and muscles' capacity for eliminating BLC. In this respect, the potential effect of nutrition and preloading on this parameter should also be considered. Although the present study attempted to mitigate the impact of these factors, the possibility of an influence cannot be ruled out.

The results of the current investigation are to be viewed with respect to the procedure of interpolating BLC from ITR at given HRs using an exponential fitting curve, while pointing to the sensitivity of BLC which may vary between subjects depending on individual BLC kinetics. Nevertheless, when analyzing the fits of each athlete in ITR, mean r^2 -values of 0.998 could be shown, with 0.996 being the lowest r^2 obtained. Exponential Data fits of PFR, conducted to interpolate HR at predetermined BLCs, as also performed for ITR, showed mean r^2 -values of 0.996, with 0.981 being the lowest r^2 .

Ultimately, some limitations of the study are to be considered and discussed hereafter. From PFR the average HR was analysed from each complete stage. This is not only a common practice for monitoring and documenting training sessions in German XC skiing, but also a frequently used method for quantifying training intensity, called "session goal approach" (30, 36). Furthermore, this procedure is consistent with that of the investigation by Vergès et al. (39), who plausibly discuss in detail as to why the mean BLC/HR relationship best mirrors the metabolic characteristics occurring in undulating field settings. Since latter colleagues conducted a similar test procedure in the field setting, the data analysis of the current study was oriented on their method. Second, according to the protocol spec-

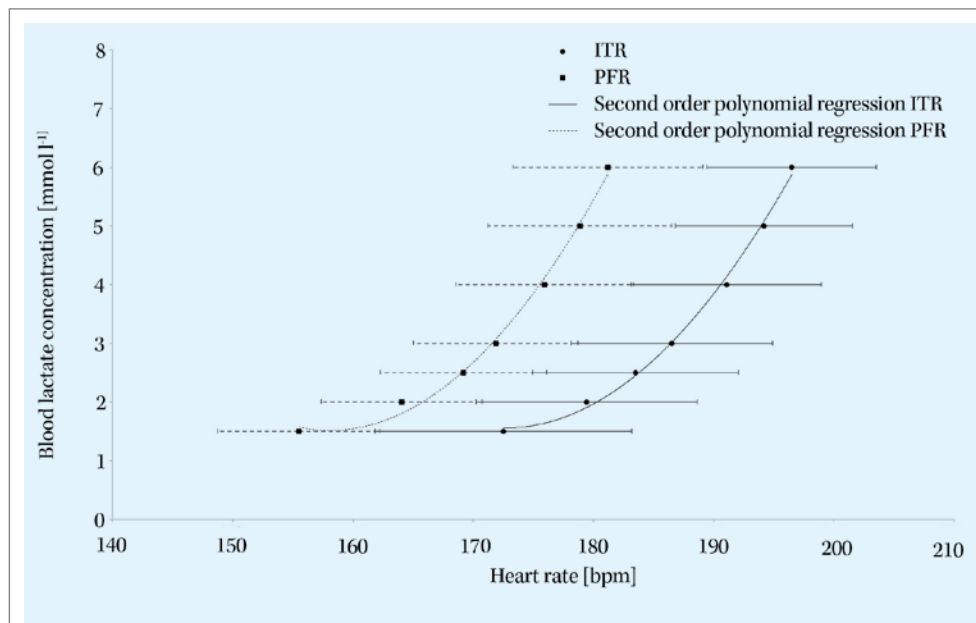


Figure 1

Differences in blood lactate concentration (BLC) vs. heart rate (HR) relationship between incremental treadmill running (ITR) and prolonged field running (PFR); Graph showing means \pm standard deviation (SD) of interpolated HR at BLC of 1.5 mmol l^{-1} , 2.0 , 2.5 , 3.0 , 4.0 , 5.0 and 6.0 .

ifications, HR from PFR was based on self-paced trials where athletes had to exercise at different intensities. Similar to the study of the above working group, subjects were asked to exercise at their proper intensities they are accustomed with from daily training. In case of the present study, however, the athlete was not to focus solely on its appropriate HR in order to adjust running speed, but similar to daily training, on both effort perception and occasional HR-control. As due to participating in long-term training, XC skiers are used to this method of intensity control during various intensities, the above procedure was intended to best mimic real-life conditions. As the objective was to compare BLC from the two protocols at an identical HR, whose amount is secondary, the precise and continuous compliance with a specific HR-zone was a priori not decisive for the purpose of the study. Rather, it was of relevance that subjects should produce a stepwise and distinct progression in exercise intensity. It was therefore tolerated if athletes HR varied with respect to terrain (uphill or downhill sections), as it is similar during daily training.

Accordingly, when interpreting the results, i. e. the significant differences in BLC between ITR and PFR, it must be considered that in PFR i.) athletes' HR during the stages may likely have been higher than at the end where it was measured and ii.) athletes' may not achieved an even pace, which however cannot be substantiated with data as no GPS recording was conducted. Taken together, in addition to the stage-duration-dependent increase in BLC, this may also have had an impact on BLC.

Finally, even though it was not monitored in the present study, it should be kept in mind that, besides the effects of varying terrain & self-pacing on HR, there are other factors that may have influenced HR responses, such as sleep behaviour or psychological stress (10, 23).

Practical Application

Based on the above findings, it is suggested to alter the HR at a given BLC when going from laboratory to field running in order to account for the differences in the stage duration. In the >

style of LaRoche et al. (14), an equation is provided by which coaches can calculate the number of heart beats (y) to be subtracted from the HR obtained during a lab test identical to that used in the present study in order to exercise at comparable BLC during training in field setting; $y = 0.283x^2 - 2.254x + 19.04$.

As variable x the desired BLC is entered, at which athletes are to train. Since 1.5–6 mmol l⁻¹ covers approx. each intensity zone of the typical five-zone scale (32), and at the same time the above analyses were conducted for this BLC-range, the equation presented should only be applied during this spectrum of intensities. However, it has to be emphasized that our results refer exclusively to XC skiers in this age group who are engaged in long-term training and should not be applied to other populations. Just as important, it has to be noted that the above practical application should only be applied for the exercise mode by which physiology was determined. Third, although the five-zone intensity scale suggests a direct relationship between BLC and HR based on empirical evidence, both parameters are still to be viewed as independent measures of intensity. Hence, it is not claimed that BLC might be a uniform measure of intensity. Note that the BLC/HR relationship may be different for each athlete. Accordingly, this practical application is to be seen against this background.

Finally, it is emphasized that the suggestions made here should be interpreted in the context of the main idea of this paper, which is to use the example of this very specific environment to address the issue of how lab-based TIP need to be adjusted in order to apply them in a given field setting. Accordingly, the reader is invited to consider and interpret the results in this context.

Conclusion

Within this investigation, the BLC/HR relationship of incremental treadmill vs. prolonged field running was compared. The methodological procedure of a previous study by Vergès et al. (39) served as a model on this. As assumed prior to the investigation, the BLC/HR relationship obtained from the different protocols differed markedly from each other. This was represented in an upward shifted BLC/HR curve from PFR, compared to ITR, as demonstrated by higher BLC values at given HRs. Accordingly, a distinct leftward shift of the BLC/HR curve from PFR compared to that obtained from ITR could be shown when plotted at given BLC.

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The second purpose of the current study was to provide guidance for coaches on how lab-based TIP have to be adjusted in order to account for the above differences in BLC kinetics between lab and field setting. Hence, the current paper provides a mathematical equation, allowing to shift HR-based intensity zones, derived from lab-based non-steady state exercise, to ensure their transposition to -and application for prolonged field exercise. For BLC-levels ranging from 1.5–6 mmol l⁻¹, coaches should subtract approx. 15 beats min⁻¹ when exercising at the same BLC during field training as obtained during lab testing.

Author Contributions

AW, BW & AS contributed conception and design of the study. AW, PR & CD contributed data collection. AW & CD performed data analyses and statistics. AW, MH & CD contributed to the interpretation of the results. AW wrote the first draft of the manuscript. MH contributed to the immediate revision of individual sections. All authors contributed to manuscript revision, read and approved the submitted version. ■

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Conflict of Interest

The authors have no conflict of interest.

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