

Research article

A LABORATORY TEST FOR THE EXAMINATION OF ALACTIC RUNNING PERFORMANCE

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ABSTRACT

A new testing procedure is introduced to evaluate the alactic running performance in a 10s sprint task with near-maximal movement velocity. The test is performed on a motor-equipped treadmill with inverted polarity that increases mechanical resistance instead of driving the treadmill belt. As a result, a horizontal force has to be exerted against the treadmill surface in order to overcome the resistant force of the engine and to move the surface in a backward direction. For this task, subjects lean with their hands towards the front safety barrier of the treadmill railing with a slightly inclined body posture. The required skill resembles the pushing movement of bobsleigh pilots at the start of a race. Subjects are asked to overcome this mechanical resistance and to cover as much distance as possible within a time period of 10 seconds. Fifteen male students (age: 27.7 ± 4.1 years, body height: 1.82 ± 0.46 m, body mass: 78.3 ± 6.7 kg) participated in a study. As the resistance force was set to 134 N, subjects ran 35.4 ± 2.6 m on the average corresponding to a mean running velocity of 3.52 ± 0.25 m·s⁻¹. The validity of the new test was examined by statistical inference with various measures related to alactic performance including a metabolic equivalent to estimate alactic capacity (2892 ± 525 mL O₂), an estimate for the oxygen debt (2662 ± 315 ml), the step test by Margaria to estimate alactic energy flow (1691 ± 171 W), and a test to measure the maximal strength in the leg extensor muscles (2304 ± 351 N). The statistical evaluation showed that the new test is in good agreement with the theoretical assumptions for alactic performance. Significant correlation coefficients were found between the test criteria and the measures for alactic capacity ($r = 0.79$, $p < 0.01$) as well as alactic power ($r = 0.77$, $p < 0.01$). The testing procedure is easy to administer and it is best suited to evaluate the alactic capacity for bobsleigh pilots as well as for any other running discipline.

KEY WORDS: Alactic capacity, alactic power, metabolic cost, treadmill test, bobsleigh.

INTRODUCTION

Maximal performance in tasks with 10 to 15 seconds duration primarily depends on the energy flow of the alactic anaerobic metabolism (Green, 1995; Hultman et al., 1967; Karlsson et al., 1972; Keul et al., 1981). However, corresponding metabolic measures are very difficult to access. In the past, muscle biopsies and computerized nuclear magnetic resonance systems (McCully et al., 1988) as well as simplified metabolic models (Garvie, 1981; Mader et al., 1981;

Thomson and Serresse et al., 1988) have been used in order to evaluate the ATP- and CrP-content of the muscle tissue. In contrast to these costly and invasive systems, work and power values in various performance tests have been calculated as numerical estimates of the alactic energy supply (for a review, see Bouchard et al., 1991; Foster et al., 1995; Harman, 1995). It has been suggested that the work done within a period of time is used as an estimate for the capacity of an energy supply system and that the work per unit of time (equals the power) is used

as an estimate for the rate of energy flow within an energy supply system (Bouchard et al., 1991). However, it has to be kept in mind that those estimates do not correspond to one energy supply system only in a one-to-one relationship but rather to all of those systems working in concert with one specific system possibly contributing more energy than the others (Hill and Smith, 1989; Jacobs et al., 1983).

Although small amounts of oxygen are being consumed and muscle lactate concentration is slightly increased, maximal performance tests are denoted alactic if subjects cannot hold the given exercise intensity for more than 10 to 20 seconds due to a depletion of the muscular phosphagen stores (Cerretelli, 1992; Gatin, 2001; Keul et al., 1981). Due to the near-maximal exercise intensities, alactic tests in the laboratory should not require much intermuscular coordination and therefore, can only incorporate simple motor activities. Such tests are primarily administered on stationary cycle ergometers or on isokinetic strength measurement devices (Bouchard et al., 1991; Green, 1995; Harman, 1995). There are few studies reported in the literature with suggestions for alactic running tests, since near-maximal muscle activities should be required. To date, only two testing procedures are available for the evaluation of alactic running performance. In a study by DalMonte and coworkers (1978) subjects were required to push against force plates attached to the front safety railing of a treadmill with a very low treadmill velocity setting throughout the test. Using the force recordings in the horizontal plane and the treadmill velocity, DalMonte et al. calculated the average power for a 10 second testing period. Since subjects could not overcome the given treadmill velocity, near-maximal muscle activities were achieved by the exertion of near-maximal force levels. While the coordinative demands were low in the DalMonte et al. study, the required skill was somewhat different from running with a high movement frequency. In contrast, Lakomy (1984; 1987) reported a laboratory testing procedure with subjects running with near-maximal running speed. This author employed a small electrical generator, connected to a wheel of the treadmill, in conjunction with a load cell, which was attached waist-high behind the subject, for an evaluation of the horizontal propulsive power during sprint running on a non-motorized treadmill. The subjects, rather than the treadmill motor, propelled the treadmill surface. In order to keep the subject from accelerating horizontally, a strap connecting the runner to the load cell had to exert a horizontal force on the runner equal in magnitude to and opposite in direction from the force of the treadmill belt on the the runners feet. Horizontal power output

was calculated as the product of the force recordings registered by the load cell and the treadmill velocity. There are no reports, however, whether subjects were able to easily adjust to the required skill. Moreover, this task may be considered to match the maximal running speed in a 100 m dash when the runner has already accelerated his speed to its maximum. While the testing procedure by DalMonte and coworkers employed low movement frequencies and high force levels, the opposite was true for the Lakomy test. In the present paper, an alactic running test is introduced with requirements in running velocity and force exertion settled between the above two.

Our study aims to provide empirical evidence for the relationship between the BST and other tests on short term performance. Based on common physiological adaptations, BST values should correlate with values for maximal strength (Schmidtbleicher, 1985), with measures for alactic power (Margaria, 1966), and with metabolic measures for the alactic capacity in order to provide evidence for a construct validity. A metabolic model from Mader el. (1981) was used to show the assumed correspondence to the alactic capacity. Moreover, the observed variance in the BST values should be explained by the variances in the leg strength, the variance in an estimate of alactic power and in the variance in an estimate of alactic capacity. A multiple regression analysis was used to examine the assumed interrelations. In short, rather than expressing the external validity of the test by comparable values for mechanical power and work done during the test, we employed a correlational argument in order to provide evidence for a construct validity (Baumgartner et al., 2003; Thomas and Nelson, 2001) of our testing procedure.

METHODS

Ten male students majoring in sports science and five students majoring in other subjects were examined in the study. All participants were enrolled at the University of Freiburg, Germany (age: 27.7 ± 4.1 years, body height: 1.82 ± 0.46 m, body mass: 78.3 ± 6.7 kg). They reported to be physically active in various sports at least twice a week but they were not engaged in any kind of competitive sport. The tests were administered on different days in order to ensure that fatigue would not influence the test results. There was a time frame of twenty days for which all testing procedures were administered.

Bob start test

The bob start test can be executed with a slight modification in the electrical connection of a normal



Figure 1. Left: body posture while performing the Bob start test (BST). Further details are described in the text, right: photography showing the start of Swiss world class pilot Martin Annen and his team (Bobsleigh Worldcup in Cortina d'Ampezzo on Dec., 19th, 2004).

treadmill by inverting the polarity of the motor. The task resembles the requirements when pushing a small car in order to turn the engine without a starter. It is highly suitable for the examination of bobsleigh pilots for their starting performance (Figure 1). Therefore, the test will be denoted as bob start test (BST). While higher movement speeds than in the DalMonte et al. test are required, coordinative demands are much lower than in the Lakomy test. The BST is performed for 10 s in order to ensure that the alactic metabolism contributes the most energy for the work required.

In our study, a regular running treadmill (Woodway S1-25 $\text{m}\cdot\text{s}^{-1}$, Weil, Germany) was used for the BST. The polarity of the power supply was inverted in order to have the engine function as a brake rather than as an accelerator for the treadmill belt. A potentiometer was installed to regulate the resistant force of the treadmill motor. Horizontal forces beyond this resistant force will result in an acceleration of the treadmill belt. In a series of pre-tests, resistant forces between 90 and 150 N were evaluated in order to find a force setting - which would ensure fatigue after approximately 10 s with a running form close to normal. A suitable value was found at 134 N. Further tests were administered in order to provide evidence that differences in body weight and in treadmill velocity would not influence the resistant force. In these tests, an electronic motor (model: MT3-OU4 48 by EAT, Freiburg, Germany) was used to apply horizontal pulls (transducers type: U2A-1000kg by Hottinger-Baldwin, Darmstadt, Germany) upon the treadmill belt. Various pulling velocities and barbell loads (65 to 85 kg) were used in order to simulate running velocities. These tests did not show any systematic influence by weight or

treadmill velocity on pulling force due to a very good and near frictionless support system in the Woodway-treadmill. The maximal difference in horizontal force between the different settings was 2.9 N (< 1.7 percent of the pre-set resistant force).

For the BST, the testing procedure continued as follows: subjects were asked to warm up thoroughly. After warm-up, the front support bar at the treadmill railing was adjusted to body height so that subjects could push the support at a chest-high elevation (see Figure 1). In addition, the area for the first contact of the foot steps was marked on the body of the treadmill box right next to the treadmill belt. The elevation of the front support bar and the indication for the stepping area were matched to individual body height so that the direction of the resultant reaction force was similar for all subjects. The upper arms were aligned at the side of the trunk while the hands were held in front of the chest. At the start of the test, a resting position was required as in Figure 1. Before testing, all subjects were given enough time to adjust to the required task. After a preparatory vocal signal by the experimenter, the test was started with a beep by a computer analysis program. An A/D-converter interface (DT2821 - DATA Translation, USA) was used to record the velocity signal from the treadmill (frequency: 50 Hz). The test continued for 10 seconds and was terminated by another beep from the computer. Three test repetitions were administered with a 10-to-15 minute rest period between tests. The best trial was used for the subsequent statistical analysis. The running distance during the 10 second testing period (BST10) was used as the test criterion. In addition, the distance for the last three seconds (BST03) was evaluated as an indication for fatigue. Distance

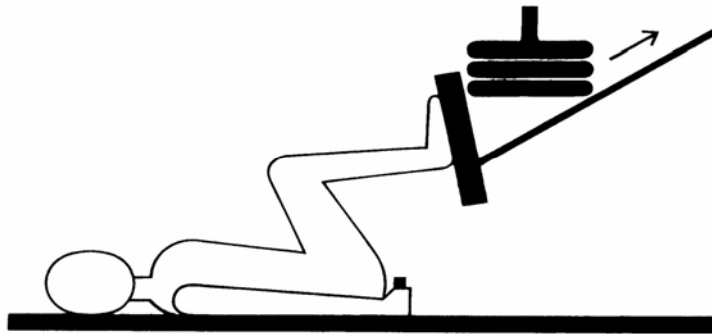


Figure 2. Leg press device for the analysis of leg extension strength performance (One-dimensional Kistler sensors are integrated in the foot plate).

values were calculated by an integration procedure (trapezoidal rule) on the velocity recording from the treadmill.

Leg extension strength test

The examination of the subjects' leg extension strength (LES) was achieved with a special leg press testing device developed at the University of Freiburg (Figure 2). Testing guidelines have been described in Schmidbleicher (1985). Maximal isometric contractions were evaluated for each leg separately in order to receive estimates for maximal strength. Three trials were evaluated for each leg. After warming up and stretching, subjects were comfortably positioned lying on their backs with hip and knee angles of approximately 80 degrees (see Figure 2). Following a preparatory signal from the experimenter, subjects were asked to exert as much force as possible while performing an explosive type of leg extension. The trial with the highest maximal force level was used for the statistical inference analysis. The values from all three trials were used for the reliability analysis. Force analysis was achieved by separate force plates for the left and right foot with four force sensors located in each corner (Kistler, Winthertur, Switzerland). Force signals were recorded through an A/D-converter (DT2821 - DATA Translation, USA) operating at 100 Hz input frequency. The maximal amplitude of the resulting force-time curves was evaluated for the maximal force level. The sum of the maximal forces in the right and in the left leg was used, for further statistical analysis.

Margaria step test

The Margaria Step Test (MST) is considered as a classical testing procedure for the examination of alactic power in the lower extremities (Bouchard et al., 1991; Harman, 1995). The test was developed by

Margaria et al. (1966) who demonstrated a strong correlation to alactic energy supply. For the examination of our subjects, we used a variation of the Margaria Step Test which was introduced by Kalamen (1968) and described by Fox and coworkers (1988). In this modification of the original test, subjects were asked to run up to a stair from a distance of 6 m. The task was to take three steps at a time as fast as possible. Switch mats were used on the third and ninth step in order to record the time necessary to elevate the body mass between these steps by 1.05 m. Three trials were examined and power was calculated by the following formula:

$$\text{MST} = m \cdot g \cdot h / T \quad (1)$$

with MST representing the power in the Margaria Step Test, m equals the body mass, g equals the constant of gravity, h equals the elevation measured (= 1.05 meters), and T equals the time necessary to elevate the body mass from the third to the ninth step. The testing protocol continued as follows: after thoroughly warming up and stretching, subjects were asked to practise the run-ups in order to become confident with the Step Test task. Three trials were administered for reliability analysis. The individually best trials were used for further statistical evaluations.

Alactic capacity estimated by a metabolic model

In the past, various metabolic models have been introduced by researchers in order to estimate the alactic capacity (Garvie, 1981; Mader et al., 1981; Thomson and Serresse et al., 1988). For this study, we adapted a model by Mader et al. (1981).

The basic idea was to examine an exhaustive run on a treadmill for which an estimate of the total energy demand was known and the metabolic subcomponents for the lactic system and the O₂-



| Estimated Energy Demand: | | |
|--|---|---------------------------------|
| $\text{VO}_2 (\text{ml/kg/min}) = 20 + 0.8 v^{2.35}$ | | |
| Alactic System: | Lactic System: | O₂-System: |
| calculated | 1 mmol/l lactate = 2.9 ml/kg O₂ | measured consumption |

Figure 3. Metabolic model for the estimation of the alactic capacity (details within the text). Alactic Capacity = Estimated Energy Demand – Energy Supply by the Lactic System – Energy supply by the O₂-System (mL O₂ Eq).

system were estimated by measurements. Since running intensities were limited because of coordinative demands for treadmill running, a running velocity and a running duration were required which would ensure a near maximal exhaustion of the alactic and the lactic energy supply and which was also feasible for a treadmill running test. We pre-tested for individual running velocities which subjects could tolerate for approximately 60 s. This work intensity was thought to exhaust the alactic energy supply (Cheatham et al., 1986; Karlsson et al., 1975; Katz et al., 1986; Sahlin, 1986; Withers et al., 1991) and to provide a maximum estimate of glycolytic metabolism. For each subject, a pre-test on an outdoor running track and two pre-tests on a treadmill were performed in order to discover the individual running velocity that could be tolerated for 60 s on a treadmill. For this running velocity, the energy demand (expressed by oxygen equivalents) was calculated by a method reported by Mader et al. (1981):

$$\text{VO}_2 (\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = 20 + 0.8 \cdot v^{2.35} \quad (2)$$

(v = running velocity in m·s⁻¹)

The formula was derived by Mader and co-workers according to preliminary work by other authors (Cavagna et al., 1965; Pugh, 1970; Saltin, 1967) and it estimates the total amount of energy per unit body mass (kg) which is necessary to run at a given velocity (mL O₂ Eq kg⁻¹).

For the estimation of the alactic capacity, energy fractions have to be subtracted from the estimated total energy demand - which are contributed by the O₂-system and by the lactate system (Figure 3). While measuring the O₂-consumption directly with an Oxycon Sigma System (Mijnhardt, Netherlands), we used maximal blood lactate concentrations to evaluate the lactate metabolism and we transferred the lactate values

into O₂-equivalents. We used a conversion rate of 2.9 mL O₂ per kg body mass for 1 mmol·L⁻¹ lactate as published by Margaria and co-workers (1966).

The 60 s exhaustive run was performed on a motor driven treadmill (Woodway, Model Weil, Germany) in the Department for Preventive and Rehabilitative Sportsmedicine at the University Hospital in Freiburg. After an intensive warm-up and stretching procedures, subjects were asked to perform a warm-up run at 8 km·h⁻¹ for two minutes. The last ten seconds were counted down before treadmill acceleration continued within 3 seconds to the individually determined running velocity. At the end of the run, subjects were asked to remain standing on the treadmill surface for one minute in order to take capillary blood samples from the ear lobe as well as to analyse their post-exercise oxygen consumption. For the next minute, subjects were allowed to slowly trot on the treadmill at a very low velocity. Finally, subjects were asked to sit down for another 20 minutes for further measurements.

Throughout the run, the oxygen consumption was measured by an Oxycon Sigma O₂-analysis system in the mixed chamber mode. The recordings for the oxygen consumption continued until one minute after the end of the run in order to examine the early component of the excess post-exercise oxygen consumption (eEPOC) as an indirect estimation for the phosphagen resynthesis, in other words, alactic capacity (Bangsbo et al., 1990; DiPrampero and Margaria 1968; Piiper et al., 1968). In the past, the term EPOC (for a recent review see Boersheim and Bahr, 2003) has been used in exchange of the expression “oxygen-debt”, the continued elevation of oxygen consumption after exercise, outlined by early muscle physiologists such as Hill (1924) or Margaria and co-workers (1933). Later on, the term “oxygen debt” received some critical appraisal (Brooks 1971; 1991; Gaesser and Brooks, 1984) and was dropped in favour of the

present denotation EPOC. The rationale of our measurement was based on the suggested half-time for this early component of EPOC in the order of 30 s (DiPrampo and Ferretti, 1999; Margaria et al., 1933).

The sampling frequency for the gas analysis was set to 200 cycles per second (with 12 bit resolution) with O₂-samples analyzed paramagnetically and corrected for breathing time, temperature, and barometric pressure. In order to correct the oxygen consumption during the running phase for the time-delay (Hughson and Morrissey, 1982) in the oxygen kinetic in the warm-up phase, the mean level for the oxygen consumption during warm-up was subtracted from each measurement during the running test (this point will be further outlined in the discussion). For the examination of the maximal blood lactate concentration, blood samples were taken at 1, 3, 5, 7, 10, 15, 20, 25 and 30 minutes after the end of the run. The lactate samples were immediately frozen and later analyzed by a photometric system (Boehringer, Germany). The corresponding lactate values were fed into a non-linear approximation algorithm (Procedure: Non-Linear Regression in SPSS-V12.0) in order to find the maximum of the fitting function $F(t)=a_1 \cdot (1-\exp(-k_1 \cdot t))+a_2 \cdot (1-\exp(-k_2 \cdot t))+a_0$. This function is related to a metabolic compartment-model developed by Freund and Zouloumian (Freund and Zouloumian, 1981; Zouloumian and Freund, 1981). For the calculation of the alactic capacity, values for the blood lactate concentration after warm-up were subtracted from the maximal values originating from the exhaustive run. Eventually, the oxygen consumption during the test as well as O₂-equivalents for the maximal blood lactate concentration were subtracted from the estimated total energy demand given by the formula from Mader et al. (1981). This value was used as an estimate for the alactic running capacity (mL O₂ Equivalents). As before, a conversion factor was used to calculate the CrP-concentration in the working muscles. An O₂-equivalent of 3.94 mL per mmol CrP was used for an estimated muscle mass of 44 percent of the total body mass - of which 80 percent of the latter is used for running (Mader et al., 1981). From the calculated O₂-equivalent 6 mL O₂ per kg muscle were subtracted to account for the stored O₂-reserve within the muscle (Jansson and Sylven, 1981). For the further analysis, this value was denoted as the model value for alactic capacity (AC).

Statistics

Mean values and standard deviations were calculated for descriptive statistics. Test on skewness and excess were used in order to examine

the normal distribution of the test values (Easy-Stat: Müller and Schweizer, Freiburg Germany). Intraclass correlations (r_{IC}) were calculated in order to examine the reliability of the test values. For this purpose, three test repetitions were analyzed. Best values were used for further tests on statistical inference by Pearson correlation coefficients (r). Multiple correlation coefficients (R) were calculated (SPSS-V12.0) in order to examine the amount of the explained criterion variance by the variances in the leg strength values, in the estimates for alactic power and for alactic capacity on the BST.

RESULTS

All the examined measures were normally distributed within the testing sample. The group mean value for BST10 in the best trials was 35.4 ± 2.6 m corresponding to a mean running velocity of 3.52 ± 0.25 m·s⁻¹. The group mean value for BST03 in the best trials was 12.9 ± 1.1 m. Intraclass correlations indicated high reliability with values $r_{IC} = 0.93$ for BST10 and $r_{IC} = 0.91$ for BST03. The group mean value for the maximal force level of the right leg was 1161 ± 179 N (intraclass correlation $r_{IC} = 0.97$) and for the left leg 1144 ± 186 N (intraclass correlation $r_{IC} = 0.95$). For the statistical analysis, the sum of right and left leg for maximal leg extension strength was used (LES with a group mean value: 2304 ± 351 N). For the MST, the group mean time in between the third and the ninth step was 469 ± 28 ms for the best trials resulting in an estimated power production of 1691 ± 171 W. The reliability analysis demonstrated an intraclass correlation $r_{IC} = 0.95$. For the 60 s exhaustive test, the group mean value for the total oxygen consumption was 3592 ± 490 mL. This value corresponded to 45.9 mL·kg⁻¹·min⁻¹. For an indirect estimation of phosphagen resynthesis, the early excess post-exercise oxygen consumption (eEPOC), related to phosphate resynthesis, resulted to a mean value of 2662 ± 315 ml. The group mean for the maximal lactate concentration was 12.6 ± 1.5 mmol·L⁻¹. The group mean for the alactic capacity in O₂-equivalents was 2892 ± 525 mL O₂. This value resulted in an estimated CrP-concentration of 26.6 ± 3.7 mmol per kg wet muscle and an estimated 25.0 ± 3.7 mmol CrP per kg wet muscle when corrected for stored O₂-reserves in the muscle.

Statistical inference tests served as the main tool to demonstrate the validity of the newly introduced laboratory test for alactic running performance. The Pearson correlation coefficients between the bob start test (BST10), the leg extension strength test (LES), the Margaria step test (MST), and the test for evaluating alactic capacity (AC) are

shown in Table 1. The level of significance for two-tailed testing with a sample size of $N = 15$ was $r = 0.51$ for $p = 0.05$, respectively $r = 0.63$ for $p = 0.01$. Significant and highly significant correlation coefficients were found among BST10, MST, AC, and eEPOC. Even higher correlations were observed between BST03 and MST ($r = 0.85$; $p < 0.01$) on one side and AC ($r = 0.90$; $p < 0.01$) on the other. The correlation coefficient for the relationship between BST10 and LES was found non-significant ($r = 0.41$, $p > 0.05$). However, significant correlations were found between the leg strength and the Margaria step test. The Margaria test also correlated with the measure for the alactic capacity ($\text{mL O}_2 \text{ Eq}$) and the early EPOC component.

Table 1. Bivariate correlations coefficients for bob start test (BST10), the leg extension strength (LES), the Margaria step test (MST), the early component for excess post-exercise oxygen consumption (eEPOC) and the test for evaluating alactic capacity (AC).

| | BST10 | LES | MST | eEPOC |
|-------|-------|-------|-------|-------|
| LES | .41 | - | - | - |
| MST | .77** | .71** | - | - |
| eEPOC | .61* | .28 | .59* | - |
| AC | .79** | .31 | .80** | .52* |

* $p < 0.05$, ** $p < 0.01$, for two-tailed testing.

Multiple correlations between the criterion value and two or more predictors did not prove to considerably increase the amount of explained variance above what was achieved by one single predictor only. At best, the multiple correlation between BST10 and combination of MST plus AC was found to be $R = 0.83$ with explained criterion variance as much as 68 percent (63 percent after correction for multiple predictors). For BST03, a multiple correlation coefficient of $R = 0.93$ was observed with 86 percent explained criterion variance (84 percent after correction for multiple predictors).

DISCUSSION

The goal of the present study was to introduce and evaluate a new laboratory test for alactic running performance. The correlations between the test measure (BST10) and other measures on alactic performance were found in very good agreement with the theoretical predictions on the relationship between the underlying physiological processes and capacities. In particular, a very close relationship was observed between the BST10 and the estimate for the alactic capacity, which was derived from the metabolic measures in an exhaustive 60 s run. This

relationship was even closer, when the distance run in the last third of the 10 s testing period was used as the test measure. Therefore, we conclude that the bob start test is a suitable procedure to evaluate alactic running performance. To our knowledge, there is no other laboratory running test which would stress the alactic capacity as well as require some coordinative skill for the running performance. While the aforementioned treadmill test by DalMonte and coworkers (1978) does not require normal running skill with close to normal running speed, other alactic tests are executed on stationary bicycles or on isokinetic devices (Bouchard et al., 1991). Therefore, the bob start test may be considered as a novel task to examine alactic running performance. Moreover, the validity of this test is based on the relationships between the testing outcome and various other short-term tests. However, one may object that our correlational data is a somewhat weak argument for the evaluation of a new test. In fact, our main point not only refers to one correlation but also to the very good agreement in the size of the different correlation coefficients in general. For the next part of the discussion, we will take a closer look at the correlational relationship of the bob start test which each of the other tests performed.

Testing for short-term performance should usually involve motor activities with near maximal muscle activation levels. Therefore, it was reasonable to expect a close relationship with measures for strength performance. Maximal isometric strength is considered a major testing parameter to examine an individual's strength abilities (Schmidtbleicher, 1985). However, the correlation between BST10 and LES was only moderate and failed to reach statistical significance. This moderate relationship may be explained by the different types of intermuscular and intramuscular coordination in the leg strength test as compared to the bob start test. It was Mueller (1987) who showed that the relationship between maximal isometric strength and values for dynamic strength performance decreases with a reduction of the load to be moved, while factors related to intermuscular coordination become more dominant. In contrast, a significant correlation was found between the leg strength and the Margaria step test. The near maximal movement speed in the step test with a very short duration (< 0.5 s) may have required muscle activation levels more related to maximal isometric strength than for the bob start test ($= 10$ s). In fact, strength related factors contributed to the performance in the Margaria step test independently from factors related to the alactic capacity. This conclusion may be derived from the partial correlation coefficient between MST and AC ($r_{pc} =$

0.87; $p < 0.01$) with LES as the control variable) which was found to be slightly larger than the bivariate Pearson correlation coefficient (see Table 1). In the literature, the step test by Margaria is considered a classical testing procedure for the evaluation of alactic power (in terms of energy flow per unit time). Since energy flow is also a crucial factor for the BST, the correlation with between MST verified the theoretical expectation. Moreover, a strong correlation between the estimate for the alactic capacity on the performance in the step test was found, indicating that the alactic energy supply would also influence the step test performance. Again, this relationship is in agreement with the theoretical considerations. Indeed, the most surprising result of our study was the strong correlation of the estimate for the alactic capacity with the two tests for alactic performance (bob start test and Margaria step test) as well as with the value for the early EPOC. Our estimate for the alactic capacity was derived from a metabolic model applied to an exhaustive 60 s running test, a task completely independent from either of the alactic performance tests. Nevertheless, highly significant correlations were found between this estimate and BST10 as well as BST03. Indeed, the strong correlation for BST03, rather than for BST10, makes the distance for the last third of the bob start test a very good predictor for alactic capacity. As much as 81 percent of the observed variance in AC may be explained by the variance in BST03. This strong, statistical relationship remains as well for the partial correlation coefficient ($r_{pc} = 0.80$; $p < 0.01$) with body weight as the control variable.

As for any other metabolic model, several assumptions were required which are commonly valid only to some degree. Nevertheless, the CrP-concentrations corresponding to the evaluated O_2 -equivalents were found in strong agreement with values derived from muscle biopsies between 20 and 30 mmol CrP per kg wet muscle weight as reported in the literature (Katz et al., 1986; Karlsson et al., 1975; Sahlin, 1986). A major objection to this result may relate to the evaluation of the oxygen consumed for the 60 s exhaustive test as well as to the maximal lactate concentration for the anaerobic energy supply. First, there is some controversy in the literature concerning the kinetics of oxygen consumption after a warm-up phase. While some authors (Hughson and Morrissey, 1982) claimed a time delay between the oxygen uptake in the muscle and the registered oxygen consumption, other researchers consider the oxygen uptake to be accelerated (Davies et al., 1972; DiPrampo et al. 1970) or unaffected (Margaria et al., 1965) by prior exercise. According to Hill and Smith (1992), a 3 percent error in the calculation of the total energy

consumption in a high-intensity 30 s cycle test would evolve if no time delay was accounted for the oxygen kinetic. In contrast, Morton (1987) concluded, that problems in methodology are the most likely cause for the contradictory results regarding the onset of oxygen consumption after warm-up. We have not found any indication for a delay in the oxygen consumption during our study. A close inspection of time markers, which were manually set through the computer evaluation program at the beginning and the end of the running period, did not exhibit any time lags. However, we had to correct the oxygen consumption data for the elevated values from the warm-up period. To solve this issue, we examined the oxygen kinetics in two subjects with and without a preceding warm-up phase. It has to be kept in mind that a sudden increase in running velocity from rest to near maximal is only possible with very experienced treadmill runners and after several practise trials. As a result of this comparison, we found that the oxygen consumed for the 60 s test may be estimated at best by subtracting the mean level of oxygen consumption during the last 30 s during the warm-up phase from each oxygen measurement during the exhaustive run (Figure 4, data based on $n = 2$).

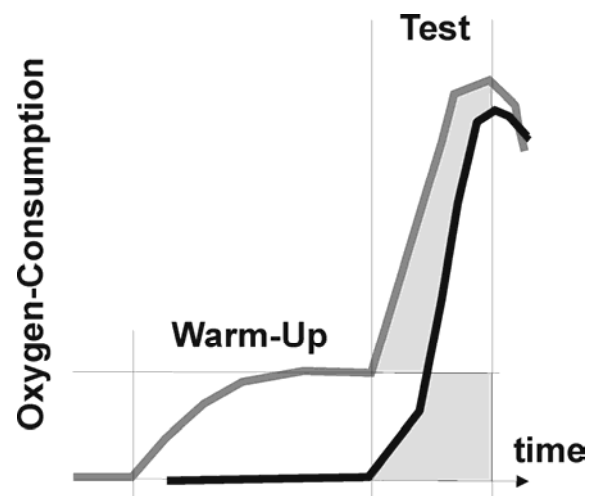


Figure 4. Prototypical oxygen consumption curves of one subject for two 60s exhaustive runs with and without a warm-up phase (grey trace: exhaustive run with warm-up, black trace: exhaustive run without warm-up). In order to justify the estimate for the corrected oxygen consumption in the 60s exhaustive run, which is subtracting the mean warm-values from the total oxygen consumption during the exhaustive run, both light grey areas should be approximately equal.

For the estimation of the lactate produced during the exhaustive run, lactate concentrations (mean value: $1.63 \pm 0.48 \text{ mmol} \cdot \text{L}^{-1}$) after an additionally performed two-minute warm-up run

were subtracted from the measured maximum in the post-exercise lactate kinetics for the 60 s exercise. The subtracted value was only slightly above the mean lactate concentrations at rest (1.11 ± 0.20 mmol·L⁻¹) indicating only small errors, if at all, through the applied data correction procedure. All in all, our model for the estimation of energy fractions among the different metabolic systems showed that alactic energy supply contributed 44 percent of the total energy in the exhaustive run. The translation of the corresponding O₂-equivalents into estimated muscle CrP-concentrations proved to be very close to corresponding value from muscle biopsies reported in the literature. However, we may have slightly overestimated the alactic capacity. While Luechtenberg (1982) has found an alactic energy fraction of 35 percent using the same metabolic model from Mader et al. (1981), authors like Serresse and co-workers (1988) found an alactic energy contribution of only 23 percent for 30 s exhaustive exercise. However, it is questionable whether the model by Serresse and coworkers may provide, in fact, comparable data at all. Translating their values for alactic energy supply (between 4 to 5 kJ) into a CrP-concentration, with the conversion factor used by Mader et al. (1981), a CrP-depletion of only 7 to 9 mmol per kg muscle mass would result. This value range is far below what is found in muscle biopsies in the literature (Katz et al., 1986; Karlsson et al., 1975; Sahlin, 1986). Nevertheless, our model may have somewhat underestimated the true amount of alactic energy consumed. This effect may have been produced by subtracting lactic and oxygen energy fractions from an estimated total energy demand higher than what was actually the case. In fact, we have assumed in our model that subjects would be running at the individually given velocity from the first second on while treadmill acceleration could only be achieved within 3 seconds. However, any overestimation or underestimation would be only effective for a correlational argument if it would have occurred in a non-systematic manner. All in all, the estimation of the alactic capacity provides some credible evidence for the amount of non-glycolytic energy that is stored in the muscle for short-term use. This conclusion is supported by the significant correlations with the early EPOC and the Margaria step test. Taken together, all correlational data is in very good agreement with the theoretical predictions on the contribution of the different metabolic systems for short-term performance. In particular, the results from the bob start test show strong correlations with all the tests that were examined, except for leg strength, where the level of statistical significance was not attained. While mostly correlational data was used to support our argument

for the validity of the bob start test, it has to be emphasized, that only randomly selected student subjects and no bobsleigh racers were investigated in our study.

CONCLUSIONS

In summary, the results show that the newly introduced bob start test may be a valuable alternative to other testing procedures on alactic performance and for alactic running performance in general. The test results show good statistical agreement with other tests on alactic capacity and alactic power. Moreover, athletes and coaches can easily understand the testing outcome which is given by a simple distance measure.

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KEY POINTS

- New testing procedure for the evaluation of alactic running performance.
- 10s treadmill sprint task with near-maximal movement velocity similar to a bob sleigh start.
- Treadmill motor is used with inverted polarity to establish mechanical resistance rather than acceleration.
- Highly significant correlations found between test criteria and alactic performance measures.