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Comparison of Maximum Lactate Formation Rates in Ergometer Sprint and Maximum Strength Loads

Vergleich der maximalen Laktatbildungsrate zwischen Radergometersprint und maximalen Kraftbelastungen

ORIGINALIA

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Summary

- **Background:** Intensive muscular performance depends on the anaerobic capacity and performance of the alactic and lactic energy metabolism. Until now, short running and bicycle-ergometer tests have been used to measure anaerobic performance. Local muscle performance in isokinetic force tests correlates to the sprint performance on a bicycle-ergometer.
- **Aim:** Aim of the study was to compare parameters of the anaerobic energy metabolism between an isokinetic force test and an ergometer sprint test. 14 subjects completed a unilateral isokinetic force test (10 REP/180°s^{-1}) and a bicycle-ergometer sprint test (15s/130rpm).
- **Results:** Maximum lactate (La_{max}), time to maximum lactate (tLa_{max}), alactic time (t_{alac}), maximum power (P_{max}) and the maximum rate of lactate production ($\dot{V}La_{max}$) differed significantly between the two tests ($p<0.05$). The relative maximum rate of lactate production ($_{rel}\dot{V}La_{max}$) between these tests showed comparable values ($p>0.05$). The $\dot{V}La_{max}$ and $_{rel}\dot{V}La_{max}$ showed a correlation of r=0.42 respectively r=0.43 ($p>0.05$) with an SEE of 0.22mmol*l^{-1}*s^{-1}*$kg^{-1}{}_{M}$ between the two tests.
- **Conclusion:** It should be noted that a prediction of the individual anaerobic performance with the $\dot{V}La_{max}$ by means of the ergometer sprint test to the local isokinetic force test is impossible. Valid statements about the local anaerobic performance of the muscles should be determined by local loads.

Zusammenfassung

- **Hintergrund:** Die Leistungsfähigkeit der Muskulatur bei intensiven Kraftbelastungen hängt von der alaktaziden und laktaziden Kapazität und Leistungsfähigkeit des muskulären Energiestoffwechsels ab. In der Vergangenheit wurden Laufsprinttests sowie Radsprinttests zur Bestimmung der anaeroben Leistungsfähigkeit herangezogen. Untersuchungen zur lokalen Leistungsfähigkeit der Muskulatur mittels isokinetischen Krafttest zeigten Zusammenhänge zur Leistung im Radsprint.
- **Ziel:** Die Studie hatte zum Ziel, physiologische Größen des anaeroben Energiestoffwechsels zwischen Krafttest und Radsprint zu vergleichen. 14 Probanden absolvierten einen unilateralen isokinetischen Krafttest mit 10 Wiederholungen (180°s^{-1}) und einen Radsprint über 15 Sekunden (Trittfrequenz 130min^{-1}).
- **Ergebnisse:** Die Parameter maximale Laktatkonzentration (La_{max}), Zeit bis zur maximalen Laktatkonzentration (tLa_{max}), alaktazider Zeitraum (t_{alak}), maximale Leistung (Pmax) und die maximale Laktatbildungsrate ($\dot{V}La_{max}$) unterschieden sich signifikant zwischen beiden Tests ($p<0,05$). Die relative maximale Laktatbildungsrate ($_{relV}\dot{}La_{max}$) zeigte vergleichbare Werte zwischen beiden Tests ($p>0,05$). Die $\dot{V}La_{max}$ sowie die $_{rel}\dot{V}La_{max}$ zeigten eine Korrelation von r=0,42 sowie r=0,43 ($p>0,05$) mit einem SEE von 0,22mmol*l^{-1}*s^{-1}*$kg^{-1}{}_{M}$ zwischen beiden Tests.
- **Fazit:** Es ist festzuhalten, dass mittels eines Radsprinttest eine Vorhersage der individuellen anaeroben Leistungsfähigkeit anhand der Laktatbildungsrate einer maximalen lokalen Kraftbelastung nicht möglich ist. Zuverlässige Aussagen zur lokalen anaeroben Leistungsfähigkeit der Muskulatur sollten durch spezifische lokale Belastungen ermittelt werden.

KEY WORDS:
Lactate Formation Rate, Strength Loads, Anaerobic Performance

SCHLÜSSELWÖRTER:
Laktatbildungsrate, Kraftbelastungen, anaerobe Leistungsfähigkeit

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Introduction

The performance capacity of the musculature under intensive exercise depends essentially on the anaerobic capacity and performance of muscular energy metabolism. Anaerobic energy metabolism consists of alactic and lactic components. Muscular adenosintriphosphate-(ATP) and creatinphosphate concentration (PCr) are mainly decisive for the alactic component. In the so-called Lohmann Reaction, ATP is formed with the help of creatinkinase from adenosindiphosphate (ADP) and PCr. The myokinase reaction, in which an ATP is resynthesized by the accumulation of (ADP) from two ADP, is quantitatively less important. The AMP thus formed is, in turn, is deaminated to inosinmonophosphate (IMP), forming irreversible ammonia (29). The performance capacity of the lactic component depends essentially on the content of glycolysis enzymes like phosphofructokinase (PFK) (23). Minimally-invasive determination and evaluation of the individual components of anaerobic energy metabolism is only indirectly possible (19). In the past, various running sprint tests, stair-ergometric tests and cycle ergometic sprint tests have been developed to determine anaerobic performance (1, 3, 10, 11, 24, 28, 31, 33). The exercise times vary in the test protocols from 6 to 60 seconds.

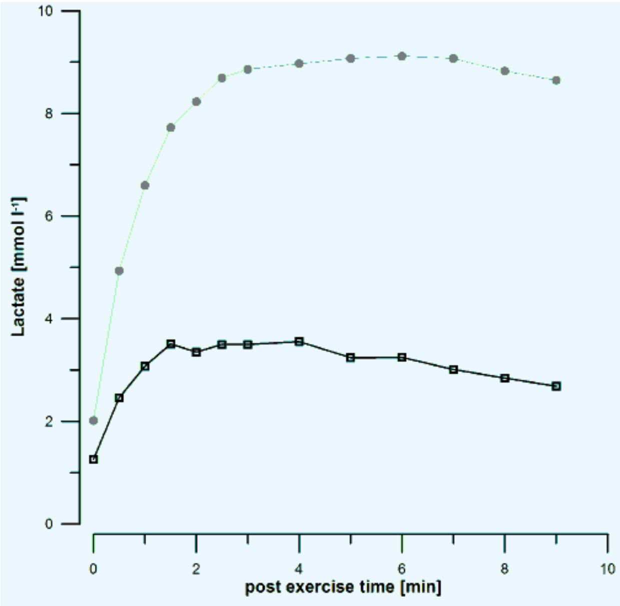

Figure 1

Course of post-exercise lactate (□ isokinetic force test, • isokinetic cycle sprint).

Anaerobic lactic performance capacity can be estimated using the metabolite lactate and the maximum work load achieved (19). For this, the lactate accumulation in dependence on time is used. This is determined from the maximum lactate difference before and after exercise and the difference between exercise time and alactic time span (22). Under maximal exercise, alactic ATP consumption is 3-6mmol kg^{-1} s^{-1}. At a capacity of ca. 20-25mmol kg^{-1} ATP in the muscle wet-weight, ATP is available primarily via glycolysis after just a few seconds. A fall in performance occurs due to the somewhat lower performance capacity of glycolysis of 1.5-3mmol $kg^{-1}s^{-1}$ ATP (18). In numerous studies, the anaerobic lactic performance capacity has thus been determined using cycle ergometric tests (1, 4, 15, 16). Adam et al. (1) could demonstrate a high reliability of the lactate formation rate in blood for ergometric cycle sprint. The performance capacity of glycolysis appears to be dependent on the sport-type specific load profile and the test time applied in the anaerobic test (4, 14, 26). Since sports with high strength demands (such as wrestling, sprinting, apparatus gymnastics) on the muscles involved, contraction velocities and exercise time vary greatly, cycle sprints and running sprint tests can hardly depict the performance capacity of the local muscle segments. In this connection, a study on game athletes showed only slight connections between performances of the various tests between running and cycle sprint (11).

Overall, there are only some single tests which determine the anaerobic performance capacity in the context of a special, sport-type-specific exercise requirement. In addition to comparisons with jumping tests, isolated strength tests have been performed on the Isokinet (6, 7, 8, 27). At significant differences in performance, a positive relationship could be determined between the performance on the Isokinet and the cycle ergometer (7). Performance of the leg musculature in the isokinetic force test is primarily associated thereby with the anaerobic performance capacity (8). Quantification of the anaerobic performance capacity in isokinetic force tests is, however, missing in studies to date. In order to evaluate the two tests based on energy supply, the objective of this study was to compare the performance capacity of the anaerobic lactic energy supply during isokinetic cycle sprints with that in isokinetic force tests.

Methods

14 trained subjects (7 game athletes, 2 cyclists, 1 material art athlete, 1 runner, 2 gymnasts, 1 racket sport athlete) performed two maximal exercise tests in a predefined sequence (Table 1). The tests were 5-7 days apart. The training scope of the 4 weeks immediately prior to the test was 4.8±2 hours per week. Test 1 consisted of an isokinetic force test (Con-Trex MJ), in which 10 unilateral leg flexing and contracting movements were performed, seated (left leg) at 180°s^{-1}. The maximal performances of the flexing and extending movement in the individual repeats were determined. The resultant mean maximal performance was used for the assessment. Test 2 was performed on a cycle ergometer (Lode Excalibur Sport) in isokinetic mode for 15 seconds (s), at a cadence rate of 130rpm. The maximal performance attained within the test period was used for the assessment. To determine the blood lactate concentration (BLC), capillary blood (20µl) was drawn directly prior to the exercise test and immediately at the end of exercise (within 10s) at 30-s intervals until the end of the third minute post-exercise (PEM). After that, capillary blood was drawn every minute until the 9th PEM (1, 16). Local warm-up of the leg muscles (moderate stretching) was performed prior to each test.

Calculation of the maximal lactate formation rate ($\dot{V}La_{max}$) was made according to Mader (22) (Equation 1). The maximal BLC in the post-exercise time (La_{max}), the BLC pre-exercise ($La_{prä}$), the test time (t_{test}) and the lactate-free time interval (t_{alak}) were used for the determination (19). The term t_{alak} is taken as the period from test begin to the time at which the maximal performance (P_{max}) has fallen by 3.5% (1, 16). The $\dot{V}La_{max}$ was also set in relation to the active proportion of the working musculature ($_{rel}\dot{V}La_{max}$ [mmol l^{-1} s^{-1} kg_M^{-1}]). Assuming a 44% skeletal muscle proportion in body weight, in cycle sprint at ca. 80% active muscle proportion, 35% mus-

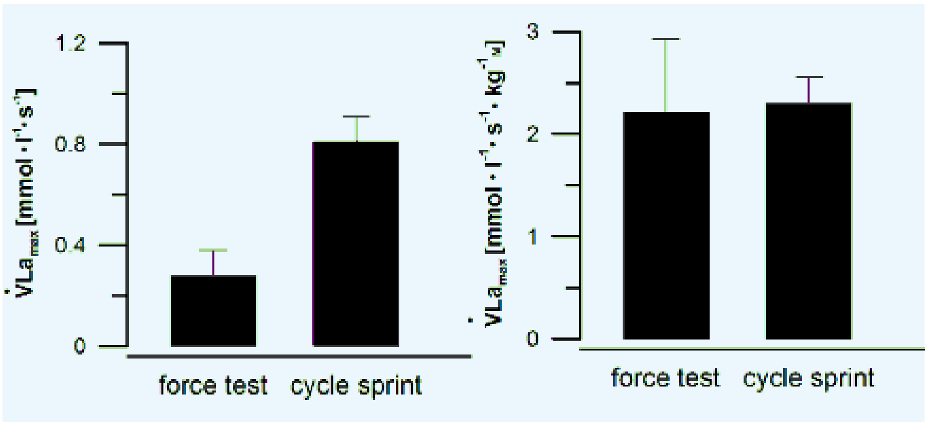

Figure 2

Depiction of the mean maximal lactate formation rate and the mean relative maximal lactate formation rate with standard deviation.

cle proportion of body weight is assumed. For the calculation of the relative formation rate ($_{rel}\dot{V}La_{max}$), a correction factor of 100/35 = 2.85 (22) for the conversion of blood value to active muscle mass in cycle sprinting was determined. Both in cycle sprinting and the isokinetic force test, segments of the torso musculature are active in addition to the lower extremities. In the isokinetic force test, the work is performed primarily by the thigh musculature. Due to the negligible lower-leg and hip musculature, 25% less active muscle mass can be assumed (32). Thus, the active muscle mass lies at assumed 26% active muscle mass of body weight. Due to the unilateral load, 13% of body weight is taken here as active muscle proportion. This results in a correction factor of 100/13=7.69. Using these two correction factors, the blood-related lactate formation rates were corrected to active muscle proportion. Calculation of the Fatigue Index (FI) was made based on the performance decrease of P_{max} to performance at the end of exercise Pend (FI=(P_{max}–P_{end}/P_{max}) 100) (5, 19).

Equation 1: maximal lactate formation rate: $\dot{V}La_{max}=(La_{maxPost}-La_{prä})/(t_{test}-t_{alak})$

All data were checked for normal distribution using the Shapiro-Wilk Test. The paired t-test was used to check for significant differences. Not-normally distributed data were checked with the Wilcoxon Test. Relationships of the test parameters between the two tests were checked with Pearson's correlation. In order to enable individual predictability, the linear regression of standard estimation error (SEE) was determined from the residuals. Statistical calculation was made using SPSS 16.0. Charts were created in Grapher 4.0.

Results

There were no significant differences in test time or resting lactate (p>0.05). The parameters La_{max}, tLa_{max}, t_{alak}, P_{max}, and $\dot{V}La_{max}$ differed significantly between the two tests (Table 2: Results). The parameters tLa_{max}, P_{max}, and $\dot{V}La_{max}$ in cycle sprints were well above those in the isokinetic force tests. The t_{alak} was significantly lower in cycle sprints (p<0.05). There were clear differences in the course of the BLC between the force tests and cycle sprints (Fig. 1). For the $_{rel}\dot{V}La_{max}$ in relation to the muscle proportion exercised, comparable values could be calculated in the isokinetic cycle sprints and the isokinetic force tests (p>0.05) (Fig. 2). There was a highly-significant relationship of the maximal performance between the isokinetic force tests and cycle sprints (r=0.94, p<0.00) (Fig. 3). The $\dot{V}La_{max}$ and the $_{rel}\dot{V}La_{max}$ showed a correlation between the two tests of r=0.42 and r=0.43 (p>0.05). The SEE at 0.22mmol l^{-1} s^{-1} revealed thereby a high deviation of the $_{rel}\dot{V}La_{max}$ between the two tests (Fig. 4). The time interval to the onset of maximal post-exercise lactate (PEL) correlated between the two tests with r=0.61 (p=0.02). In cycle sprints, there was a highly-significant correlation of r=0.81 (p<0.01) between t_{alak} and P_{max}. In the isokinetic force test, these parameters were not correlated (r=0.28; p>0.05). No relationship could be determined between P_{max} and $\dot{V}La_{max}$ in the two tests (r<0.1; p>0.05). The values of FI differed significantly between the two tests (p<0.01). There was no relationship between the FI of the two tests (r=-0.150, p>0.05).

Discussion

The involved muscle proportion of total body weight is about 35% in the diagnostics of anaerobic work capacity in high-intensity cycle ergometry tests (22). Due to the high proportion of active muscle mass performance readiness, only limited statements are possible concerning the local anaerobic work capacity of a single muscle group. The objective of the present study was to compare an isokinetic force test with an isokinetic cycle sprint test for parameters of anaerobic metabolism, performance and the FI. The relative lactate formation rates of the two anaerobic tests showed that, on average, there was hardly any difference, but the high SEE indicates marked intraindividual deviations. Thus, especially for athletes whose types of sport primarily require acyclic and local load in the lower extremities, it must be initially assumed that a cycle ergometer sprint does not depict the local anaerobic work capacity in the individual case.

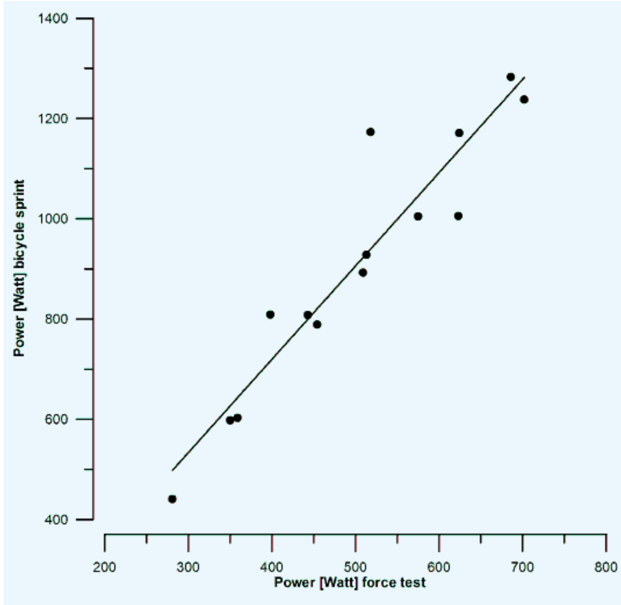

Figure 3

Linear correlation between performance of the isokinetic cycle sprint and the isokinetic force test.

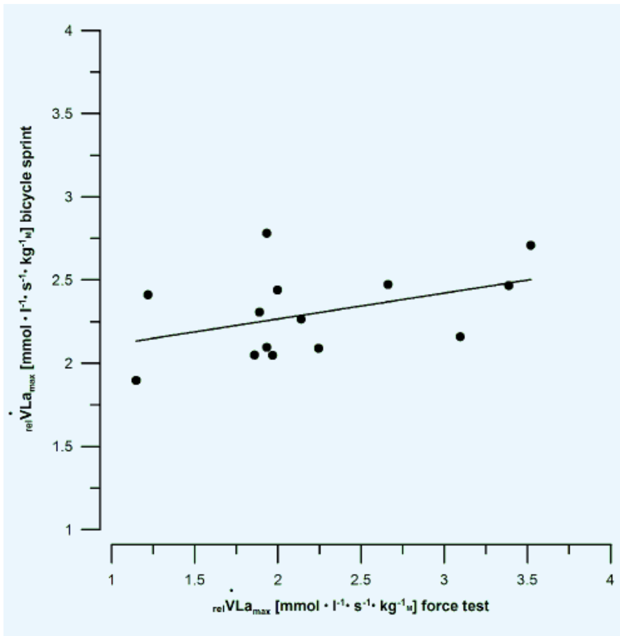

Figure 4

Linear correlation of the relative lactate formation rate of the isokinetic cycle sprint and the isokinetic force test.

Table 1

Anthropometric data of the subjects.

N=14	AGE (YEARS)	HEIGHT (CM)	WEIGHT (KG)	BMI (KG/M2)
MW±SD	24,6±2,4	180,2±11,08	77,47±15,45	23,3±2,4
Min	22	160	53	20,1
Max	31	193	103	30,1

Despite the different extent of the physiological values, marked relationships in performance can be determined between the two tests. Bosquet et al. (8) observed somewhat less relationship in performance between tests on the cycle ergometer and tests on the Isokinet. Thereby, moderate correlations of r=0.65 were determined between work in the Wingate Test and work in the unilateral isokinetic force test in the thigh. The test time was double (30 s vs. 15 s). The energy-supplying metabolic systems were, however, not taken into account. The greater muscle proportion used in cycle sprinting leads in this connection to higher performance and BLC and thus also to a higher $\dot{V}La_{max}$ than in the isokinetic force test. In relativizing the $\dot{V}La_{max}$ to the assumed active muscle proportion, there were hardly any differences in the means. In the correlation analysis, however, high individual deviations were observed in the $_{rel}\dot{V}La_{max}$ between Test 1 and 2 (Fig. 4). To calculate the correction factors of the $\dot{V}La_{max}$ assumptions were made concerning the active proportion of the musculature. For cycle sprinting, reference could be made to conclusions drawn by Mader (22). In the isokinetic force test, the estimate was based on muscle weights (32). Other assumptions would likely lead to different values.

Hauser et al. (15, 16) were able to demonstrate that the lactate formation rate depended clearly on the test time in the determination methods used. Despite comparable mean work time, scattering could be observed in test time of the isokinetic force test over 10 repeats. While there was fluid transition between movement cycles in cycle sprinting, there was a complete reversal of movement direction after each extensor and flexor movement in the isokinetic force test. Delayed reversal of movement led here to increased test time. Dependency of the t_{alak} on the duration of load, as calculated by Heck and Schulz for various running distances (19), were not to be expected due to the "all out"-strategy of the test. Nevertheless, higher t_{alak} (Difference >1s) were determined in the isokinetic force test. The performance maximum and performance fall (by 3.5%) were reached later in the force test and thus t_{alak} was longer. The considerably lower FI compared to cycle sprint confirms this assumption. The subjects did not necessarily show prolonged time to P_{max}, but possibly also a later decrease in performance. The decrease in performance can be explained by the marked decrease in PCr determined in the studies. This is associated with lactate accumulation and the related decrease in pH values (20). Since P_{max} was considerably higher in cycle sprint, the decrease is faster. Due to this, a lower t_{alak} was calculated in the isokinetic cycle sprint. In addition, an altered lactate accumulation can be observed due to the different muscle proportions of active muscle mass and the distribution space (Fig. 1). In the isokinetic force test, this possible source of error could be minimized by assuming a fixed t_{alak} for the calculation of $\dot{V}La_{max}$. Unlike for cycle sprint exercise, in which t_{alak} has been calculated (19), no empirical data are available for isokinetic force exercise.

Whereas in cycle sprint there is a brief co-contraction of the thigh musculature , there is a constant switch from contraction and relaxation of the knee extensors and flexors in the isokinetic force test. In the resultant longer relaxation phases, a short greater perfusion of the musculature than in cycle sprinting is to be expected. It was determined in earlier studies that the uninvolved musculature contributed to lactate elimination (12). In addition, the lactate formed in the cytoplasm is distributed via cell-cell shuttle within the muscle even before transposition to the blood (9, 13). The BLC thus only depict a net lactate accumulation. It is therefore to be assumed that less-involved muscle proportions in the isokinetic force test produce greater elimination even during the test and therefore different lactate kinetics must be assumed. Differences in lactate accumulation are also to be sought in the differing number of muscle actions. In the one-leg isokinetic force test, there are 10 extensor and 10 flexor movements. In cycle sprint, up to 32 step cycles per leg can be assumed at a step rate of 130rpm.

It must be taken into account that an uncontrolled energy uptake might have influenced the $\dot{V}La_{max}$. Reduced La_{max} due to glycogen depletion or elevated lactate values due to high-carbohydrate uptake prior to the test could be the result (17, 21, 25). Moreover, the individual exercise profile of the subject could have an influence on lactate production via differing extents of muscle fibre and cause the scattering in lactate accumulation (14, 26). In particular, the performance decrease during the test is dependent on the form of training. Thus, clear differences in muscle fatigue in isokinetic leg extension tasks could be demonstrated between strength-trained and active athletes (2). With respect to the effect of the fibre spectrum on maximal torque, Bagley et al. (2) reported different results than those of Thorstensson and Karlsson (30). All of the factors considered here can have considerable influence on the calculation of the $\dot{V}La_{max}$ and result in over- or underestimation.

The low correlations between the P_{max} and the $\dot{V}La_{max}$ may be based on the one hand on the small and heterogeneous sample (16); on the other hand, they indicate at the same time a problematic relevant for practice. Since the P_{max} depends decisively on the anaerobic alactic work capacity, a significant

Table 2

Results.

PARAMETER	ISOKINETIC FORCE TEST	ISOKINETIC CYCLE SPRINT	P-VALUE
Test time (s)	16.1±2.0 (14.5-21.2)	15	0.061
Resting lactate (mmol l^{-1})	1.28±0.61 (0.50-2.44)	1.48±0.32 (0.74-1.99)	0.159
$Lactate_{max}$ (mmol l^{-1})	3.75±0.61 (2.51-4.32)	8.98±1.10 (7.68-10.9)	<0.001
tLa_{max} (s)	138.4±42.2 (54.7-204.1)	247.2±45.6 (180.1-335.4)	<0.001
t_{alak} (s)	6.7±2.0 (3.8-11.4)	5.3±0.9 (4.1-7.4)	0.043
P_{max} (Watt)	502.5±129.5 (281.0-702.0)	910.4±255.6 (441.0-1283.0)	<0.001
$\dot{V}La_{max}$ (mmol l^{-1} s^{-1})	0.28±0.09 (0.15-0.46)	0.81±0.09 (0.67-0.98)	<0.001
$_{rel}\dot{V}La_{max}$ (mmol l^{-1} s^{-1} kg_M^{-1})	2.21±0.71 (1.14-3.52)	2.29±0.26 (1.89-2.78)	0.681
FI	14.05±3.71 (4.80-18.47)	46.69±5.04 (38.49-55.09)	<0.001

relationship need not necessarily be expected here. With low intraindividual variability in $\dot{V}La_{max}$, P_{max} and t_{alak} (VK=6.3%; 4.5%; 5.8%) in repeated tests on the cycle ergometer (1), it appears much more likely that the interindividual variability of P_{max} and $\dot{V}La_{max}$ are decisive. With respect to external validation, there are presently no studies between the lactate formation rate of anaerobic tests and the specific (competition) performance in individual types of sports. This would be desirable in the future, especially in sports in which the anaerobic energy metabolism is an important component in performance structure.

It must be noted that prediction of the individual anaerobic work capacity based on the $\dot{V}La_{max}$ of a maximal local work load is not possible by means of a cycle sprint test. Reliable statements on local anaerobic work capacity of the musculature should be determined by specific local exercise. ■

Conflict of Interest

The authors have no conflict of interest.

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