Determining the anaerobic threshold in finswimming

Busse M[1], Vogel Y, Tegtbur U[2], Thomas M[3]

Institute of Sports Medicine, University of Leipzig (Director: Prof. M. Busse, MD)
Center of Sports Medicine, Hannover Medical School[2] (Director: Dr. med. U. Tegtbur)
Orthopedic Clinic & Polyclinic, University of Leipzig[3] (Director: Prof. Dr. med. v. Salis-Soglio)

Abstract

Busse MW, Vogel Y, Tegtbur U, Thomas M. Determining the anaerobic threshold in finswimming. (CSMI) 2010, 4:19-28

Purpose:
To develop a field test for determining the anaerobic threshold in finswimming.
Methods:
An incremental swim test was carried out among 10 trained finswimmers after exercise-induced lactate acidosis (8 x 200 m increments with speed increases of 5-10 seconds per 200 m). During a 45-second rest period after each increment, blood was drawn to determine lactate levels and heart rate was measured. The lowest point of this curve is considered to be the steady state between enhanced lactate production and uptake and is therefore postulated as the anaerobic threshold (AT). To test this theory, constant load tests were subsequently carried out at three speeds: AT, AT + 5% and AT – 5%.
Results:
The symmetrical shape of the curve in the incremental exercise test shows that the speed increments used enable the enhanced lactate production and uptake kinetics to be determined. The lactate concentration at the lowest point of the curve is high enough to prevent artefacts at the onset of a steady state. The constant load tests demonstrate that finswimming in the area of AT speed leads to the rapid onset of a lactate steady state at a high level. A speed 5% above this results in a significantly delayed lactate steady state and produces very high lactate concentrations.
Conclusion:
The results prove the appropriateness of the method, which determines an individual's enhanced lactate production and uptake kinetics to establish the AT. Given the relationship between AT intensity and maximum speed and the very narrow area of the threshold, the use of a method such as this is of particular importance.
Key words:
lactate, anaerobic threshold, incremental exercise test, finswimming

Introduction:

Finswimming is a young, non-Olympic sport. The monofin dominates competition in the sport, as it enables faster swimming. The dolphin leg kick is used when swimming with a monofin. Finswimming can be practised both on the surface with a snorkel and underwater, either with or without breathing apparatus.

There is currently no accepted process for performance testing in the water.

The most successful process, commonly used for performance testing in endurance sports, is one that directly determines enhanced lactate production and uptake [1, 10]. This involves carrying out an incremental exercise test after maximal exercise-induced lactic acidosis. Initially, lactate is eliminated from the blood through light exercise and then accumulated by exercising above the anaerobic threshold (AT). According to this, the lowest point on the resulting lactate performance curve corresponds to the maximal dynamic steady state between lactate production and elimination. This method was proposed in 1989 by Tegtbur et al. [10] in the field of running and, in the same year, by Griess et al. [4, 5] in competitive swimming.

The current study tests the validity of this process, known as the "anaerobic threshold (AT) test", in finswimming.

Figure 3 illustrates the characteristic progression of enhanced lactate production and uptake kinetics. According to Braumann et al [1], the lowest point on the lactate performance curve corresponds to the AT (Fig. 3) and indicates the individual's critical power. This is the zone in which the maximal lactate steady state (MLSS) can only just be maintained between lactate production at the point of origin and lactate elimination from the lumen and there is no progressive accumulation of lactate in the blood.

To check whether the AT corresponds to the MLSS, constant load tests were carried out at different exercise intensities (v=AT, v=<5% AT, v=>5% AT), after determining the lowest point on the lactate performance curve (LPC). During this process there should be no appreciable increase or decrease in lactate concentration in the area of the lactate threshold. When carrying out a constant load test slightly above the balance between lactate production and elimination (AT + 5%), a significantly delayed lactate onset at a high level can be expected. Conversely, a constant load test slightly below the AT (AT -5%) should, after an initial accumulation stage, lead to a steady fall in concentration or a lactate steady state at a very low level.

Methods

Subjects: The test was carried out on five female and five male finswimmers as part of their routine performance testing. At the time of the study, all subjects were accomplished in this sport and were completing at least six training sessions per week. Depending on their age, the athletes were members of the A, B or C squad of the *Verband Deutscher Sporttaucher* or *VDST* (the German organization responsible for competitive finswimming).

The socio-demographic and anthropometric data on age, sex, body weight, height and number of training years can be found in Table 1 below.

Seven subjects trained as swimmers for several years before taking up finswimming and this is indicated in a further column.

The test was based on the current 200 m times from the Saxony championships, a competition that had taken place three weeks beforehand. Personal best 200 m times could not be used for this test, as, at the time of the study, the athletes were in the preparation stage of their training cycle, as defined by Matwejew [6]. Personal best times and current 200 m swim times can also be found in Table 1.

General provisions: Before the test, all subjects were informed about the way blood samples would be drawn from the ear to measure lactate levels during the studies, the purpose of the test and how it would be conducted, as well as about possible side effects. After receiving this information, the subjects gave their signed consent to taking part in the modified performance test. Parents' explicit permission was sought in the case of subjects who were minors.

The studies took place in a 50 metre pool at the University of Leipzig's swimming centre.

Table 1: Subjects' socio-demographic and anthropometric data, training years and best times.

Subject no.	Age in years	Sex	Weight in kg	Height in cm	No. of swimming training years	No. of finswimming training years	PB over 200 m in min	Current 200m times in min
1	15	F	63	168	7	1.5	01:52.34	01:55
2	16	M	57	170	6	2.5	01:34.05	01:36
3	14	M	68.5	171	3	2.5	01:53.07	01:57
4	18	F	62	176	6	5.5	01:47.08	01:52
5	23	F	55	171	8	8.5	01:47.80	01:50
6	18	F	68	164	2	4	01:56.36	01:58
7	29	M	72	186	7	16	01:33.52	01:36
8	31	M	75	182	0	21.5	01:39.05	01:46
9	23	M	83	186	0	12.5	01:37.02	01:40
10	24	F	62	173	15	3.5	01:37.94	01:43
Av	21.1	-	66.55	174.7	5.4	7.8	01:43.82	01:47.2
SD	5.859	-	8.539	7.617	4.477	6.763	8.479	8.404

Preparation: There was at least one rest day before the AT test and no high-intensity swim training was to take place in the two days before the test. The constant load tests took place on three consecutive days, one week after the AT test. Before the first constant load test, one training session was completed that included some anaerobic zone exercise. The order of the tests was determined by drawing lots on the day of the AT test. The pre-test warm-up took place on an individual basis at a low level of effort.

Determining the swim speed: The swim speed for the incremental exercise tests and the constant load tests was signalled aurally. The signals were executed via hand taps, through hammer blows on a set of breathing apparatus. While this was happening, the breathing apparatus was half-immersed in the water in order to ensure the sound carried through the water. When the signal was given, the swimmers had to be at the 50 m or 100 m mark.

Figure 1 shows the test sequence.

Carrying out the AT test: In the first part of the AT test the subjects swam 2 x 100 m at maximum speed with a two-minute recovery interval. They could choose to start the 100 m intervals either from the starting block or in the water. The majority chose to start in the water.

Directly after the maximum effort there was a seven-minute rest period. The blood samples were drawn during this time, in order to observe the peak of the blood lactate curve and how it developed during the period after effort. During the rest period the subjects were able to take the pressure off their foot muscles and joints and choose a less powerful fin.

Subsequently the incremental exercise test took place, consisting of eight increments each of 200 m. The speed increments and speed difference were in accordance with the modified Pansold test [7, 8]. This was also the same as the test carried out in the national team training course, in which the recovery intervals were universally set at 45 seconds.

Study conditions: The data regarding external conditions on the day of the AT test, such as room and water temperature, chlorine and pH levels can be found in Table 2

Table 2: Data regarding study conditions on the day of the AT test. Room and water temperatures and pool chlorine and pH levels.

Room temperature in °C	Water temperature in °C	Chlorine level	pH level
28.5	27.5	0.59-0.6	7.34

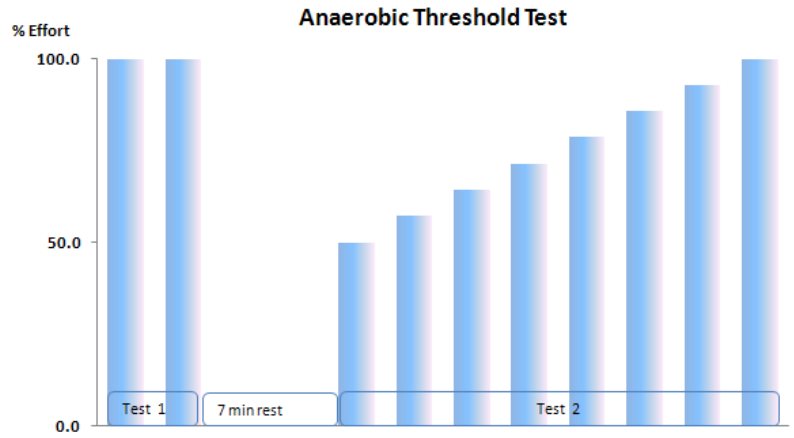

Figure 1: AT test 1 consisted of 2 x 100 m at maximum speed with a two-minute recovery interval. Test 2 was an incremental test of 8 x 200 m with 45-second recovery intervals.

Time points when blood samples were drawn: The first blood sample was drawn directly before the test, but no earlier than five minutes after the warm-up swim. Further blood samples were drawn immediately after the maximum effort, in the third and sixth minutes of the seven-minute rest period that followed, as well as in the 45-second recovery intervals after every incremental effort and in the first and third minute of the warm-down stage of the incremental test.

Constant load test: One week after the AT test, a constant load test was swum on each of three consecutive days. This comprised two sets of 3 x 400 m at the speed of V_{AT}, as well as 5% over and under this speed. The rest period between the two sets lasted four minutes, with 45-second recovery intervals between repetitions. In the rest period between sets, the swimmers were able to take off the fin and relax their feet.

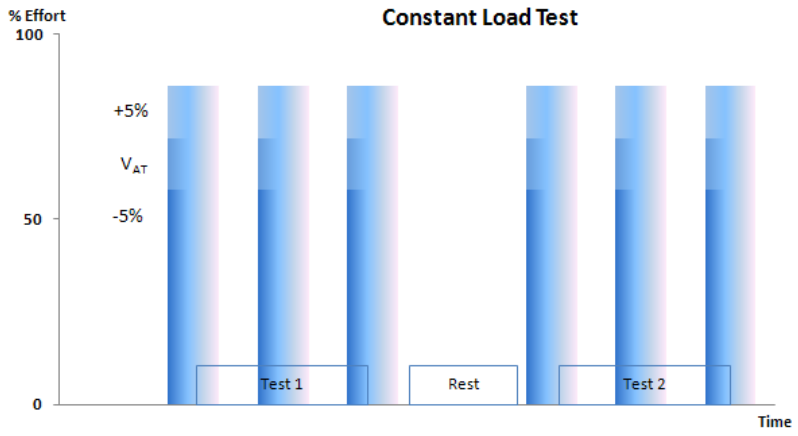

Figure 2: Constant load test structure. Set 1 and Set 2 each consisted of 3 x 400 m. The rest period between the two sets lasted four minutes, with 45-second recovery intervals between repetitions.

Table 3: Modified 8 x 200m incremental exercise test from Riemann (1995). The first column is for girls (G), the second for boys (B) and women (W), the third column for the top boys, women swimming with breathing apparatus and men (M). The fourth column is for men and top women swimming with breathing apparatus, the fifth for top men swimming with breathing apparatus.

Increment	01:48-01:55 min (G)	current 200m best times of approx. 01:43-01:48 min (B/W)	01:38-01:43 min (B/W/M)	01:33-01:38 min (M/W)	01:28-01:33 min (M)	Rest period	Blood sample drawn
1	02:35	02:30	02:25	02:20	02:15	40 sec	at once
2	02:25	02:20	02:15	02:10	02:05	40 sec	at once
3	02:15	02:10	02:05	02:00	01:55	40 sec	at once
4	02:10	02:05	02:00	01:55	01:50	40 sec	at once
5	02:05	02:00	01:55	01:50	01:45	90 sec	1 min
6	02:00	01:55	01:50	01:45	01:40	4 min	2 min
7	01:55	01:50	01:45	01:40	01:35	4 min	3 min
8	01:50	01:45	01:40	01:35	01:30	-	4. + 7. min

Time points when blood samples were drawn: The first blood sample was also drawn directly before this test, but no earlier than five minutes after the warm-up swim. Further blood samples were drawn from the swimmers after each 400 m, as well as in the four-minute rest period directly before the second 3 x 400 m and in the first and third minutes of the warm-down stage of the constant load test.

Determining the AT speed: On a graph, swim speeds in m/sec were plotted on the x-axis and blood lactate concentrations in mmol/L on the y-axis. The result was a parabolic curve and the speed representing V_{AT} could be read off at the lowest point of this curve.

Heart rate: Heart rate (HR) was measured using a POLAR brand heart rate monitor. The transmitter was fixed by a chest strap at the level of the xiphoid process and telemetrically linked to the receiver (a wrist watch). As the equipment was waterproof, the athlete wore it during the tests. When test subjects found the wrist watch to be a hindrance, the receiver was placed on the poolside, where it could be seen. If no measurement signal was received by the watch, the subject determined their heart rate manually, which was something they were familiar doing during daily training.

Timekeeping: The swim and rest times were measured manually by a helper with a digital stopwatch. Additionally, the helper informed the test subjects of their swim times, the difference compared to their target time and the rest time remaining between repetitions and sets.

Drawing blood samples: For the lactate analysis, whole blood was drawn from capillaries in the subjects' earlobes. After the warm-up swim, Finalgon® cream was applied to the ear lobes as a vasodilating agent. The cream was thoroughly removed after application. Each sample consisted of 20 µl of capillary blood, was collected in a single-use pipette and then transferred into the Eppendorf sample vial filled with 1 ml of system solution. The sample vial was sealed, shaken and kept cool in an Eppendorf rack until measurements were taken. During the test, ears were thoroughly dried with tissues before each sample was drawn.

Lactate analysis: After the test, the sample vials were kept in the Eppendorf rack in the refrigerator until analysis took place. This occurred within 24 hours of the test and was done in the laboratory, using a Diagnostic Systems DiaSys Super G Analyzer.

Results

AT Test

As there were ten test subjects, there was a corresponding number of AT tests available for further evaluation. After the maximum effort, none of the test subjects swam the entire incremental exercise test of 8 x 200 m. Due to physical exhaustion, two of the ten athletes abandoned the test after the fifth increment (subjects 3 and 6), five after the sixth (subjects 1, 2, 4, 8 and 10) and three after the seventh.

Table 4 shows the differences in time between the target and actual speeds in the incremental exercise test. From this it can be seen that the subjects had great difficulty in maintaining the target time, particularly in the two first and two last increments. The time difference at the end of the incremental exercise test was due to physical exhaustion on the part of the test subjects

The average lactate [lac] values at the times the individual samples were taken are summarised in Table 5 and Figure 3.

The two maximum efforts of 2 x 100 m resulted in maximum values between 10.6 and 16.9 mmol/L. In the AT zone, lactate values were significantly above 4 mmol/L at, on average, around 7 mmol/L. Figure 3 shows average [lac] values. It can be seen from Figure 4 that the lactate threshold was reached at, on average, around 90% of maximum effort.

Table 4: Differences in time (Δt) between target and actual speed for the incremental test section of the AT test.

Subjects	Δt in sec for individual increments							
	1	2	3	4	5	6	7	8
1	+3.00	-0.08	-3.06	-4.44	-7.83	-8.26	-	-
2	+1.5	+1.8	+2.21	+4.1	+2.8	-3.64	-	-
3	-0.85	+2.94	-1.84	-2.70	-6.91	-	-	-
4	+7.24	+2.0	-1.24	-1.46	-3.11	-5.5	-	-
5	+16.17	+5.2	+0.87	+0.58	+3.07	+1.08	-2.95	-
6	+0.61	-1.61	-5.45	-3.77	-6.36	-	-	-
7	-2.89	-1.86	-1.48	+1.08	+0.42	+1.78	-1.11	-
8	-6.04	-3.92	-6.09	+1.99	-1.51	-10.26	-	-
9	+14.4	+8.99	-0.54	+2.82	+2.23	+1.91	-1.32	-
10	+2.08	+4.08	+2.23	+1.44	-0.1	+1.39	-	-
Av	3.52	1.75	-1.44	-0.04	-1.73	-2.69	-1.79	-
SD	7.14	3.82	2.86	2.90	4.14	4.92	1.01	-

Table 5: Average lactate [lac] values and standard deviations in the AT test (N = 10).

	Rest	Maximum effort		Rest period in mins		Increments in the incremental exercise test								Warm-down in mins	
		1100m	2100m	3	6	1	2	3	4	5	6	7	8	1	3
Av	1.38	-	14.53	14.48	13.52	11.01	8.64	7.45	7.62	8.67	10.29	13.87	-	10.77	10.25
SD	0.69	-	1.86	1.91	2.02	2.18	2.18	1.96	1.98	2.36	3.64	1.55	-	3.16	3.27
N	10	0	10	10	10	10	10	10	10	10	8	3	0	10	10

Heart rate: The shape of the heart rate curves is generally very similar. Heart rate (HR) rose sharply during maximum effort and fell in the seven-minute rest period. During the subsequent incremental exercise test, heart rate rose again until the test was terminated.

In the maximum test, average heart rates were 174 ± 13.7 beats per minute (bpm) after 1100 m and 184 ± 13.2 bpm after 2100 m. The maximum rate at the end of the incremental exercise test was 186 ± 7.5 bpm.

Determining the AT speed: The AT speed was determined graphically by hand, according to the formula described elsewhere. Table 6 shows the lactate threshold (lowest point) determined for all subjects.

The average [lac] lowest point among the subjects was 3.72 (± 0.49) and was determined graphically. The swim speed at the curve's lowest point, V_{AT}, was determined as being 1.57 m/s, and, within this, differences between individuals of 1.42 to 1.73 m/s could be seen. The exact AT speeds and the speeds calculated respectively for 5% over and under the AT can be found in Tables 20 to 29. The corresponding heart rate was 177 (± 11.9) bpm, or 95% of maximum rate.

The subjects' average critical power stood at 90.3% of the maximum speed reached in the incremental exercise test (Fig. 4). It should be pointed out here that the subjects began the first increment having reached, on average, 80.95% of the maximum increment speed. The first increment acted as a compensator.

Constant Load Test

To examine the question as to whether the lowest point on the lactate curve corresponds to the AT, a total of 29 constant load tests were carried out, each of 2 x 3 x 400 m. The test subjects swam the constant load test at the speed V_{AT} and V_{AT} ± 5%. Subject 2 could not take part in the constant load test V_{AT} + 5% due to a sudden illness.

Constant Load Test at V_{AT}

All ten subjects each swam a constant load test at V_{AT}. Table 7 shows the corresponding average [lac] values and standard deviations. Figure 5 also shows average values.

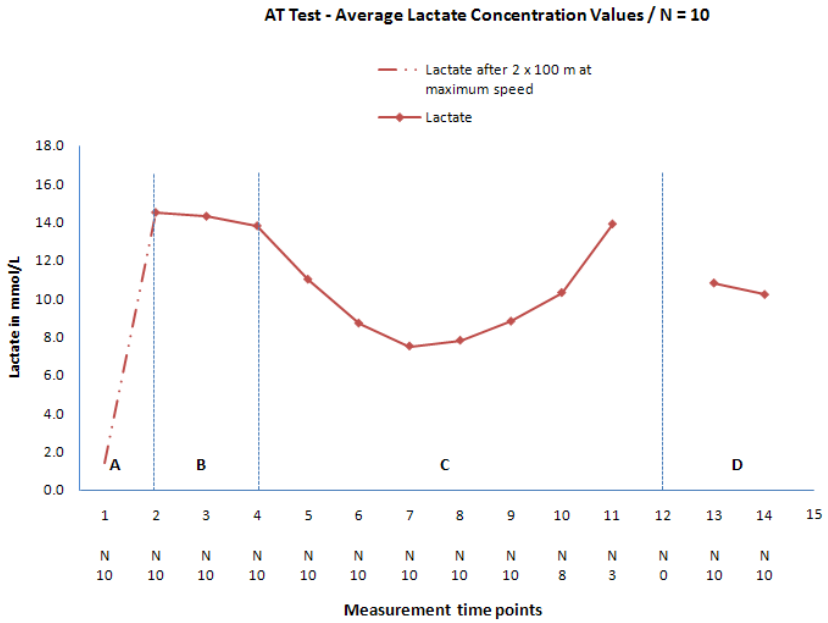

Figure 3: Average [lac] values in the AT test (N = 10). After 2 x 100 m at maximum speed (A) there was a seven-minute rest period (B) and an incremental exercise test of 8 x 200 m (C). Section D shows the warm-down stage.

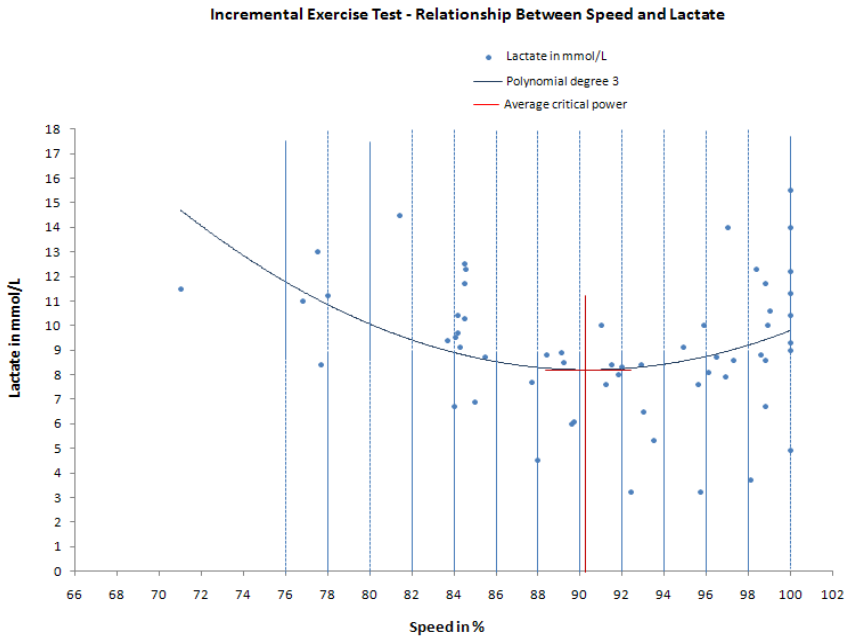

Figure 4: Relationship between speed and lactate during effort in the incremental exercise test with existing lactic acidosis.

Table 6: Lactate threshold time for all subjects determined graphically.

	Subjects											
	1	2	3	4	5	6	7	8	9	10	Av	SD
Time of lactate threshold in increment	4.2	3.5	2.9	4.0	4.0	3.0	4.1	3.7	4.3	3.5	3.72	0.49

Table 7: Average lactate values and SD in the constant load test at V_{AT}

	Rest	1400 m	2400 m	3400 m	Rest period in mins 3	4400 m	5400 m	6400 m	Warm-down in mins 1	3
Av	1.68	5.68	5.63	5.63	4.66	5.24	5.23	5.23	5.03	4.67
SD	0.82	1.28	1.68	1.98	1.89	2.06	2.09	2.30	2.40	2.30
N	10	10	10	10	10	10	10	10	10	10

In essence, there were only slight deviations in adhering to target speed in the individual 400 m intervals, as the athletes, with the exception of subjects 3, 4 and 5, were able to achieve the targets with a tolerance of ± 2 seconds. At the end of the first endurance stage (3400 m), heart rate was 168 ± 14.4 bpm. At the end of the second endurance stage (6400 m) it was 170 ± 15.4 bpm.

Constant Load Test at V_{AT} + 5%

Due to subject 2 becoming suddenly ill, results are only available for nine of the constant load tests. Subject 9 terminated the constant load test after the fifth repetition due to physical exhaustion. Table 8 shows the average values and standard deviations. Figure 5 presents the average values graphically.

Several subjects had great difficulty in keeping to the faster target speeds. In general, speeds were often too low, particularly towards the end of the second set. Subjects 1 and 6 swam on average five to ten seconds more slowly, subject 8 swam eight to thirteen seconds more slowly and subjects 9 and 10 five to eight seconds more slowly. Subject 4 was nine seconds slower on the first 400 m and seven seconds slower on the second 400 m. On the other hand, subject 3 was four seconds faster on the first 400 m and six seconds faster on the second 400 m. After 3400 m, heart rate was 179 ± 13.5 bpm and after 6400 m it was 180 ± 15.6 bpm.

Table 8: Average lactate values and SD in the constant load test at V_{AT} + 5%.

	Rest	1400 m	2400 m	3400 m	Rest period in min 3	4400 m	5400 m	6400 m	Warm-down in min 1	3
Av	1.59	7.81	9.12	9.42	8.17	8.90	9.10	8.54	8.87	8.42
SD	0.69	2.08	2.60	2.73	2.65	2.73	3.03	2.65	3.01	3.17
N	9	9	9	9	9	9	9	8	9	9

Constant Load Test at V_{AT} - 5%

In this instance, the results of ten constant load tests at a speed of V_{AT} -5% were also available for evaluation, corresponding to the number of subjects. Table 9 shows the average values and ± standard deviation each time the samples were drawn. Figure 5 shows average [lac] values.

Table 9: Average lactate values and SD in the constant load test at V_{AT} - 5%.

	Rest	1400 m	2400 m	3400 m	Rest period in mins 3	4400 m	5400 m	6400 m	Warm-down in mins 1	3
Av	1.21	4.00	3.30	3.08	2.47	2.94	2.83	2.76	2.63	2.42
SD	0.44	1.13	1.13	1.08	0.95	1.22	1.02	1.02	0.99	0.88
N	10	10	10	10	10	10	10	10	10	10

Overall, subjects adhered well to the target speeds for the individual 400 m intervals. Only subjects 1 and 3 swam the first 400 m three seconds faster. Athlete 5 was on average two to four seconds quicker over the whole test. After 3400 m, heart rate was 156 ± 15.5 bpm, after 6400 m it was 155 ± 16 bpm.

Comparing the constant load tests

A steep rise in [lac] from rest can be noted after the first 400 m interval among all athletes tested and in all three constant load tests. As the tests progressed through the 3 x 400 m (Test 1), the four-minute rest period and the second 3 x 400 m (Test 2), differences in [lac] levels could be determined according to the effort intensity.

Figure 5 summarizes the average [lac] values from all three constant load tests. It is clear that swimming at AT speed led to the onset of a lactate steady state at a high level (approx. 5.5 mmol/L) within approximately 6.24 ± 3.5 minutes. At AT speed + 5% it lasted until the onset of a steady state, on average at 10.08 ± 3.06 mins, when the lactate value was approximately 9.5 mmol/L. At AT speed – 5%, the highest lactate value (4 mmol/L) was reached after approximately 4.27 ± 0.16 mins. Lactate then decreased steadily to 3 mmol/L. The relationships were similar in each of the second sets of the constant load test. In the constant load tests, heart rates differed overall in a highly significant way. The differences after 3400 m were, in each case, approximately 11 beats over (V_{AT} + 5%) or under (V_{AT} - 5%) the AT rate.

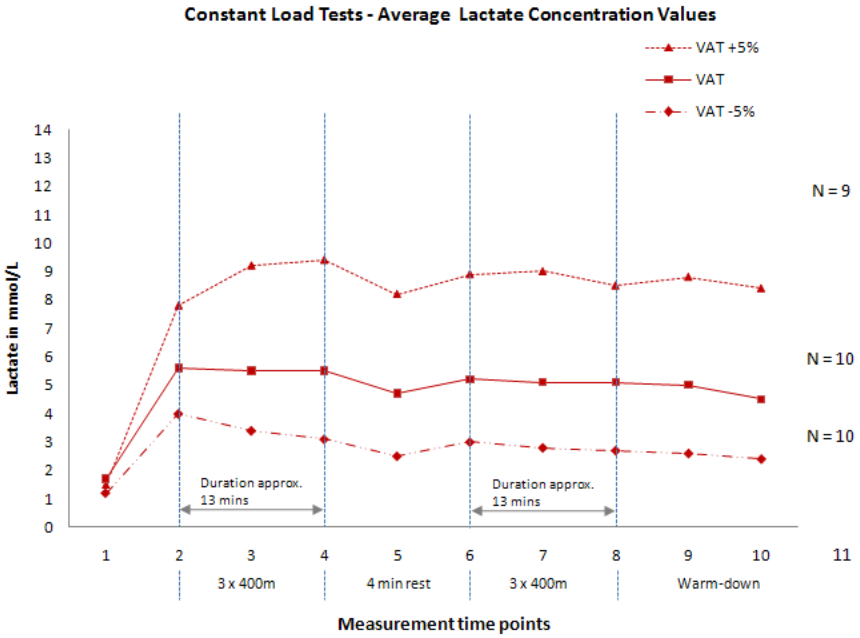

Figure 5: Average lactate values over all three constant load tests

Discussion

Blood lactate concentration is dependent on lactate production, muscle lactate release and vascular lactate uptake (lactate transport), as well as lactate elimination by means of oxidation and gluconeogenesis.

The resulting [lac] level in the cell and in the blood and, therefore, also the shape of the lactate performance curve (LPC) are dependent on various factors. Thus glycolysis and gluconeogenesis have a crucial influence on [lac]. Moreover, lactate is a valuable carbohydrate metabolite, which functions in many body cells to enable oxidative energy production. A raised dietary level of carbohydrate can raise the blood lactate level by 2-4 mmol/L [2, 3].

The activation time for glycolysis until pyruvate is formed is much shorter during physical effort than the activation time for oxidative phosphorylation [9]. As a result, there is a build up of pyruvate, NADH + H^+ ions and, due to the law of mass action, lactate is created.

Lactate transport: Lactate is produced in the cell cytoplasm by means of glycolysis or glycogenolysis. But, when determining lactate levels, it is blood [lac] rather than cell [lac] that is measured.

A lactate concentration gradient arises between muscle and blood as a result of physical effort and increases according to the level of effort intensity. During maximum effort, muscle cell [lac] peaks. On the other hand, blood [lac] peaks only after a period of maximum effort. The difference persists for a few minutes [11, 12] and decreases after it has reached a steady state in both compartments.

Muscle lactate release is dependent on intracellular and extracellular [lac], the degree of dissociation of lactic acid and the pH balance. Facilitated lactate transport occurs in the cell membrane.

Lactate elimination: [Lac] is not only influenced by lactate production and release, but also by lactate elimination. As this is particularly dependent on training status, it must be considered when determining the AT. According to [2], oxidative elimination occurs predominantly in red muscle fibres and in the heart muscle. Lactate is eliminated not only at rest, but also during effort. The re-metabolization of lactate to pyruvate is effected by LDH isoenzymes 1 and 2. LDH isoenzyme activity is dependent on intracellular pH and cytosolic and

mitochondrial NAD+/NADH quotients. There is high LDH isoenzyme 1 and 2 activity in the heart and it is this that encourages the oxidation of lactate to pyruvate. Consequently, the heart muscle and red skeletal muscle are able to metabolize 100% of the peripheral lactate.

It is known that the muscular system removes lactate from the blood during effort, in order to meet energy requirements, although, at the same time, large amounts of lactate are released from the working muscle. In particular, endurance status is reflected by lactate uptake.
With regard to measuring lactate levels during the constant load test, the following apply from a pharmacokinetic perspective:

- Enhanced lactate production ("invasion") leads to higher lactate values when the speed of onset of a steady state does not change;
- Enhanced lactate uptake in the muscles ("evasion constant") leads to the accelerated onset of a steady state.

A critical evaluation criterion for attaining or exceeding the anaerobic threshold is, therefore, the onset time of a steady state. A significant delay in this indicates a status of being "beyond the threshold". In general, this corresponds to a time > 7-10 minutes.
Consequently, a "maximal lactate steady state" ("maxLASS") is not possible from a pharmacokinetic perspective. However, the onset of a steady state can fail to occur due to the fact that it is not possible to maintain the effort until onset occurs.

Test evaluation

In this study, ten athletes swam the constant load test at V_{AT}. In 70% of cases the [lac] could be held constant from the outset after a slight fall following the initial accumulation stage. In this constant load test, [lac] was in the region of 2.0 to 9.4 mmol/L for all test subjects. Like many earlier studies, this wide distribution shows that a universal absolute lactate threshold of, for example, 4 mmol/L does not exist.
Nine athletes completed the constant load test at V_{AT} + 5%, during which subject 9 abandoned the test prematurely due to physical exhaustion. The considerable delay in the onset of a lactate steady state was particularly evident, as was the high average lactate concentration.
All ten test subjects swam the constant load test at V_{AT} -5%. In 80% of cases there was a decrease in [lac] or the concentration could be held constant after a slight decrease. The wide distribution in lactate concentration was also noticeable here. It can be seen that there was no steady state present in the constant load test at V_{AT} -5%, as the [lac] declined or adjusted to a value that corresponded approximately to the value at rest before the test. Furthermore, it can be seen from the results among one group of athletes, that [lac] was held constant both in the V_{AT} and the V_{AT} + 5% tests. In any case, a steady state is to be expected based on the distribution kinetics. Lactate elimination is a crucial factor for determining the rate of onset of a steady state. The current study shows that the onset of a steady state was, on average, significantly delayed (>7 mins) and was unrelated to the absolute lactate concentration. In contrast, the onset at V_{AT} -5% was very quick or, after the initial distribution stage, there was a decline in lactate.

In summary, it can be established that:

- The swim speed specified in the AT test is closely linked to the fast onset of a lactate steady state at a high level.
- A swim speed only 5% faster, i.e. almost in the area of onset, leads to the considerably delayed onset of a steady state at a level (> 9 mmol/L) that no longer permits intensive endurance effort.
- A swim speed of 5% below AT speed causes, on average, a decline in lactate which indicates, at best, an extensive endurance effort below the AT. This follows a short rise in the curve that is conditional on distribution.
- The AT for fin swimmers is, on average, at approximately 90% of the individual's maximum speed.
- The heart rate corresponding to the AT is approximately 95% of the individual's maximum rate.

Using the method shown, for the first time a specific method for finswimmers can be proved that determines the AT in a kinetically-distributed manner. The method is based on known pharmokinetic facts. As a result, it is, therefore, possible to specify the AT for finswimmers within a very narrow band of speed. This permits, firstly, exact statements to be made about the individual's exercise metabolism and, at the same time, relevant training ranges to be precisely established.
The particular implication of an exact method for determining the AT, such as this, is that the AT and the corresponding heart rate are near to the individual's maximum values at the time. Exceeding the "threshold value" only slightly must, therefore, rapidly lead to exhaustion due to effort.

References

1. **Braumann, K.M., Tegtbur, U., Busse, M.W. & Maassen, N., (1991).** Die „Laktaksenke": Eine Methode zur Ermittlung der individuellen Dauerleistungsgrenze. *Deutsche Zeitschrift für Sportmedizin*. **42**, 240-246.
2. **Brooks, G.A., (1986).** The lactate shuttle during exercise and recovery. *Medicine and science in sports and exercise.* **18** (3), 360-368.
3. **Brooks, G.A., (1991).** Current concepts in lactate exchange. *Medicine and science in sports and exercise.* **23** (8), 895-906.

4. **Griess, M., (1992).** *Der Senkentest eine neue Methode zur Bestimmung der Dauerleistungsfähigkeit im Schwimmen.* Dissertation, Medizinische Hochschule Hannover.
5. **Griess, M., Tegtbur, U., Braumann, K.M., Busse, M.W. & Maassen, N., (1989).** Eine neue Methode zur Ermittlung der Dauerleistungsgrenze im Schwimmsport. In: Böning, D., Braumann, K.M., Busse, M.W., Maassen, N. & Schmidt, W., (eds.) *Sport – Rettung oder Risiko für die Gesundheit?* Cologne: Deutscher Ärzte-Verlag, pp.418-422.
6. **Matwejew, L.P., (1981).** *Grundlagen des sportlichen Trainings.* Berlin : Sportverlag.
7. **Pansold, B. (1985).** *Untersuchungen zur komplexen Leistungsbewertung unter Berücksichtigung der Spezifität des Testverfahrens an ausgewählten Gruppen and Probanden von Leistungssportlern.* Dissertation B, Greifswald.
8. **Pansold, B., Roth, W., Zinner, J., Hasart, E. & Gabriel, B. (1982).** Die Laktat-Leistungs-Kurve – ein Grundprinzip sportmedizinischer Leistungdiagnostik. *Med. u. Sport.* **22** (4), 107-112.
9. **Stainsby, W.N., (1986).** Biochemical and physiological bases for lactate production. *Medicine and science in sports and exercise.* **18** (3), 341-343.
10. **Tegtbur, U., Griess, M., Braumann, K.M., Busse, M.W. & Maassen, N., (1989).** Eine neue Methode zur Ermittlung der Dauerleistungsgrenze bei Mittel- und Langstrecklern. In: Böning, D., Braumann, K.M., Busse, M.W., Maassen, N. & Schmidt, W., (eds) *Sport – Rettung oder Risiko für die Gesundheit?* Cologne: Deutscher Ärzte-Verlag, pp.463-466.
11. **Zouloumian, P. & Freund, H., (1981a).** Lactate after exercise in man, II: mathematic model. *European Journal of Applied Physiology.* **46,** 135-147.
12. **Zouloumian, P. & Freund, H., (1981b).** Lactate after exercise in man, III: properties of the compartment model. *European Journal of Applied Physiology.* **46**, 149-160.

Correspondence: Prof. M. Busse, MD
Institute of Sports Medicine
Marschnerstrasse 29
04109 Leipzig
Germany

Email: busse@rz.uni-leipzig.de