Physiological - Biomechanical Aspects of the Load Development and Force Implementation in Rowing

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1.0 Introduction

In rowing, as in other sports, physiology and biomechanics are key sciences to consider in training research and practice. There is a strong relationship between physiology and biomechanics. Because biomechanics is an element which determines the rowing technique used, there is an inner physiological adaptation created that relates to the training goal. Conversely, training based on physiological principles helps in the development of an optimal rowing technique. A one-sided approach to training based exclusively on physiological principles (e.g., lactate measurements or heart rates) or exclusively on biomechanical rowing technical criteria (e.g., emphasis on the beginning, middle or finish of the stroke) limits the potential for achieving the optimal rowing performance.

At today's level of rowing performance, deficiencies in rowing technique can no longer be compensated for by physiological superiority, nor can physiological deficiencies be compensated for by superior rowing technique. The optimisation of rowing technique and of its physiological, bioenergetic and neuromuscular bases is necessary for peak athletic performance. This demand can only be met through an application which unifies physiological and biomechanical principles in all areas of training.

The principle of unified training methods on the basis of the "energy phases concept" (3, 5, 7, 10) was successfully practised for the last 20 years in rowing within the former GDR. In recent years East German rowing worked increasingly on a transition for a unity of training theory, physiology and biomechanics (7, 10, 11). This article will present selected results from empirical and experimental studies on the relationship of physiology and biomechanics in rowing.

2.0 The Influence of the Force/Time-Curve Characterisation on Physiological Reaction and the Muscle Cell Adaptation

Coaches often observe that rowers show improvements, stagnation or sometimes even a worsening of performance under the same training program. Thus the same training program does not have the same effect on everyone. We see the causes of this phenomenon in:

1. the realisation of training load by different types of force/time-curves (see figure 1).

2. different biological function profiles in the training athletes (see table 1).

Table 1: The individual variation range of histomorphological parameters in the deltoid muscle of rowers. Muscle biopsy parameters:

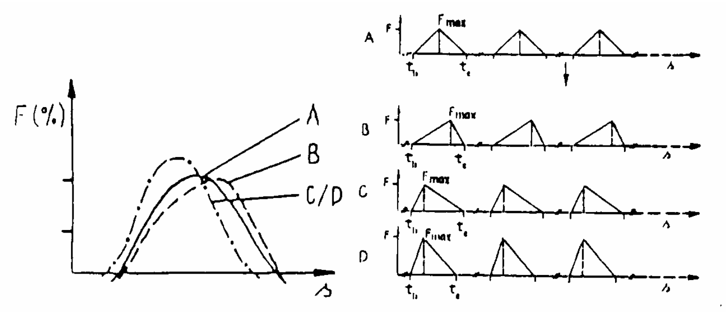
Parameter	Minimum	Maximum
Slow-twitch fibre (%)	46.0	92.0
Fast-twitch fibre (%)	54.0	8.0

Unequal progress in performance among rowers with the same physiological potential (e.g., fitness, distribution of muscle fibres) suggests that the reason will be found in the nature of the load as seen from training methods as well as biomechanics - especially in characterising the rowing stroke as a basic element of the total load (the cycle). Therefore we investigated the influence of different force/time-curve types on the physiological reaction and the muscle cell adaptation.

2.1 Empirical analysis of the force/time-curve parameters and muscle cell adaptation

Rowers who methodically practised the same special endurance and strength endurance training were classified according to the characteristics (figure 1), and their individually realised force/time-curves were analysed by means of a measuring boat (power exerted on the oar lock). The individual muscle cell adaptation in the musculature of the upper arm (deltoid muscle) was compared.

Figure 1: Illustration of different force/time-curves in rowing.



Abbreviations: F = Force, t = time, t_b and t_e = beginning and end of force impulse.
Left: Registration example of force/time-(top) and speed force/time-curves (bottom) measured with a measuring oarlock.
Right: Schematic presentation of the different types of force/time-curves.

Table 2 shows that different types of force/time-curves (type A/B as opposed to C/D from figure 1) in the stroke cycle occur among rowers with the same muscle fibre distribution. These rowers with similar muscle fibre makeup trained for a long time and developed different morphologic and bioenergetic adaptations. The force/time-curve type A/B has a physiologically emphasised aerobic adaptation tendency; conversely the C/D type has a considerably stronger anaerobic adaptation. The C/D type is, in comparison to the A/B type, characterised by a generally higher metabolic intensity.

Table 2: Impact of the different force/time-curves (FTC) on the muscle fibre adaptation in rowers.

Muscle biopsy parameters	Force/time-curve type	
	A/B	**C/D**
Slow-twitch fibre (%)	70.4	75.4
Fast-twitch fibre (%)	29.6	24.6

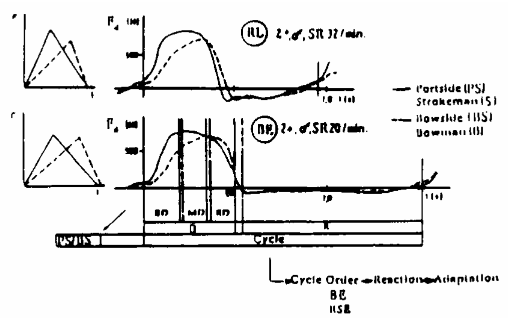
2.2 The influence of the force/time-curve on the physiological reaction in the stroke structure

Biomechanical rowing analyses have shown that bowmen and strokemen exercise different force/time-curves (figure 2) (12, 13). They differ from each other in the following ways:

1. The shape of the force/time-curve (strokemen: emphasis on the beginning and the middle of the stroke; bowmen: emphasis on the finish).

2. The biomechanical ranges of identification in strokemen, compared to bowmen, show an earlier and steeper power increase in the beginning of the stroke, a higher power value and a reduction of the time for the drive in the same time cycle, thereby increasing movement velocity and performance in the drive phase.

Figure 2: Force/time-curve of the strokeman (solid lines) and of the bowman (broken lines) in the pair with coxswain under racing load (RL) and during basic endurance training (BE).



Left: Schematic presentation

Right: Registration curves (curves of force on oarlock)

Abbreviations: F_d = Force in Drive; t = time in seconds; D = Drive; R = Recovery; RD = Beginning of Drive; MD = Middle Drive; ED = End of Drive; SR = Stroke Rate.

represent two different types of force/time curves. It is likely that the strokemen and the bowmen performing the same training will create different stroke patterns and, therefore, will also be subjected to different physiological demands.

We then examined the physiological reaction of the bowmen and the strokemen during special training (lactic acid concentration in the blood) after exposing them to training loads in varying degrees of intensity (measuring boats) and test loads (rowing tanks with measuring devices). We also examined the morphological muscle adaptation after extended periods of training (muscle biopsy during rest). The following occurred:

1. At the same training loads (same boat speed and most likely the same mechanical performance) in the pair with coxswain (2+), the strokemen show significantly higher lactic acid values in the blood when compared to the bowmen. Consequently, there is a more intensive metabolic demand on the strokemen, and a biologically different training intensity for each of the rowers in the pair with is necessary. We found that when performing basic endurance (BE) training, the strokemen worked at the anaerobic threshold while the bowmen worked at the aerobic threshold.

2. At test loads (standardised step tests in the rowing tank) with equal given and realised mechanical performance, the strokemen showed significantly higher lactic acid concentration than the bowmen on each step of the test load. The lactate performance curve of the strokemen moves to the left of the bowman, and ultimately performed significantly worse at lactic values from 2.0-4.0 mmol/l respectively (a lower aerobic and anaerobic threshold). Because of the individual force/time-curves, it appears that the strokeman shows a declined anaerobic fitness.

3. The biological difference in demand on the strokemen and the bowmen respectively becomes more pronounced with the increase of the load intensity.

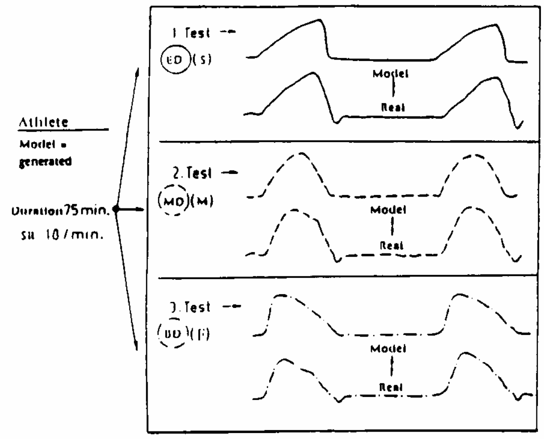
4. A high percentage of fast-twitch muscle fibres (FTF) and a respectively lower amount of slow-twitch muscle fibres (STF) in the deltoid muscle were found in the strokemen when compared with the bowmen. This difference in muscular structure should be the result of an empirical selection. A rower with predominantly more fast-twitch fibres is more fit for the stroke position, due to his muscles' ability to contract and also because of his biomechanical skills (figure 2).

In general, the strokemen, unlike the bowmen, seemed to possess a metabolically stronger glycolytic adaptation direction and a better adaptability to rapidness and speed strength. The findings should be observed in the individual training situation (duration of each training session, pauses, different use of the common means of training for strokemen and bowmen) and when assembling the rowers in the boats (aptitude of strokemen for big boats, aptitude of bowmen for small boats, etc.).

2.3 Model studies of the influence of different force/time-curves on the physiological reaction (tracking-dynamometrics)

The aim of these studies was to examine the physiological effect of three different structure types of the rowing stroke under constant external work conditions (stroke rate, duration of the power effort, maximum power). Three different types of force/time-curves were produced with a tracking-dynamometric procedure and were shown on a monitor (figure 3). These force/time-curves then served as a pattern for an athlete performing on a measuring tank (a rowing tank equipped with force/time impulse measuring devices). The force/time-curves illustrated: 1. a stroke with emphasis on the end of the drive (ED), 2. a stroke with emphasis on the mid-drive (MD), 3. a stroke with emphasis on the beginning of the drive (BD). Each of them had a flat, a medium and a steep power increase.

Figure 3: Methodical clarification of the tracking-dynamometric study.



Diagrams of three different force/time-curves:

1. **Emphasis on end of drive (ED) with slow power increase (S).**
2. **Emphasis on middle drive (MD) with medium power increase (M).**
3. **Emphasis on beginning of drive (BD) with fast power increase (F).**

Top curve: **Generated curve (model)**

Bottom curve: **Realized force curve measured on oarlock.**

The rowers were encouraged to produce force/time-curves (on the measuring oarlocks) to fit the model curves on the monitor. Figure 3 clarifies the experimental procedure. As the external working conditions were held constant, the form of the force/time-curves on the force-increase-gradient at the beginning of the stroke appeared to be the important biomechanical influence on the physiological demand. The tests were performed in two areas of intensity during endurance training:

1. Endurance training at an intensity equivalent to the aerobic threshold (lactic acid concentration approximately 2.0 mmol/1, stroke rate 18/min., duration 75 minutes).

2. Endurance training at an intensity equivalent to the anaerobic threshold (lactic acid concentration approximately 4.0 mmol/1, stroke rate 25/min., duration 10 minutes).

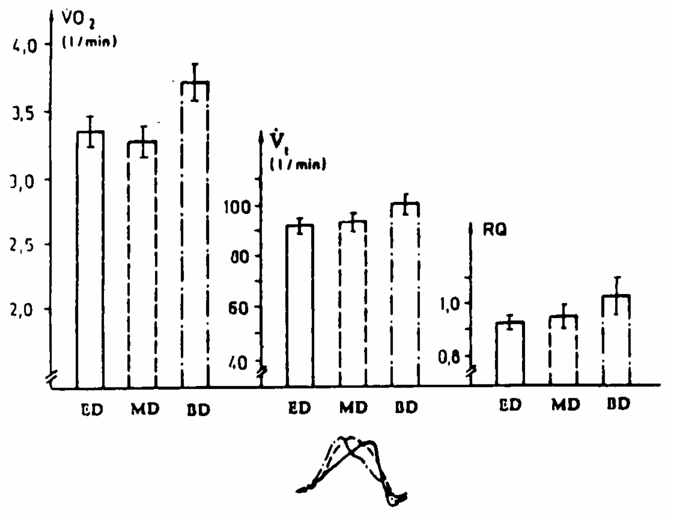
In order to characterise the physiological demand, the lactic acid concentration in the blood and the parameters of the oxygen transportation system were measured. The results in figures 4 to 6 demonstrate the following:

1. At the aerobic threshold endurance load (figure 4), there was a rise in the O_2-uptake curve (VO_2), the minute ventilation volume (V_1) and the respiratory quota (RQ) as the force/time-curve angle gets steeper (in the order ED, MD, BD), while maintaining a steady lactic acid concentration and heart rate (figure 5). The rise in the RQ points to the fact that, to produce the same mechanical performance, there will be an increasing utilisation of carbohydrate to fulfil the increased aerobic energy demand. Simply altering the pattern of the stroke causes a physiological change in the use of nutrients for aerobic energy. When using the BD stroke there will be a more intensive aerobic demand on the rower.

If training with an emphasis on the beginning of the drive is used, it is important to keep an eye on the duration of each training session and the recovery time (restoring the deposit of carbohydrate), because the storage of carbohydrates is limited. Simultaneously, from a physiological point of view these findings support the biomechanically based opinion that an emphasis toward pressure at the beginning of the drive is a recommended pattern for rowing technique. This kind of technique obviously demands, as a more physiologically effective stimulus, an adaptation to an energy supply based on carbohydrates whose level is a crucial biological precondition for high powered endurance performance.

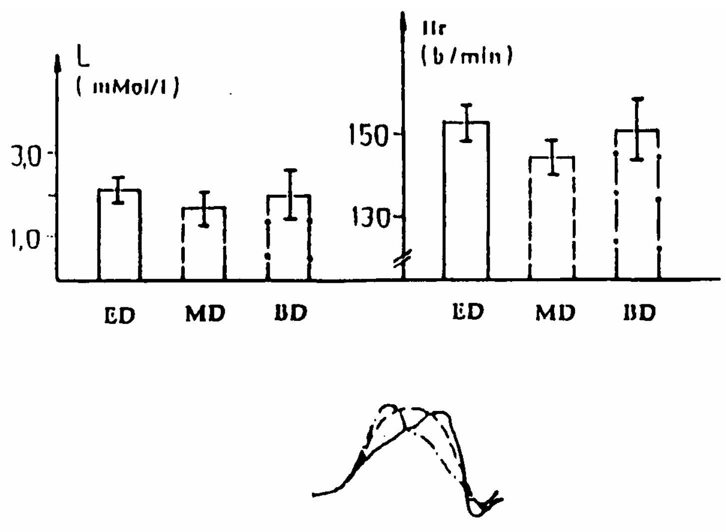
2. Contrary to the aerobic threshold intensity, the anaerobic threshold endurance load will cause dramatic changes in physiological demands as the force/time-curve steepens. In connection with the increased force (transition from ED stroke to BD stroke), there will be a significant rise in lactic acid concentration, heart rate and O_2-uptake (figure 6). The figure also shows that as the force curve in the beginning of the stroke steepens, the training criteria defined by training methods and biology for anaerobic threshold intensity training are being exceeded (lactic acid greater than 4.0 mmol/l), and the biomechanically based technique can lead to a mistaken physiological adaptation. Consequently, biomechanically based changes in rowing technique as a physiological stimulus for biological demands and their long term influences can have an effect on the biological adaptation. Since biological adaptation is the basis for fitness skills, there is a connection between the form of rowing technique (stroke pattern, force/time-curve) and fitness.

Figure 4



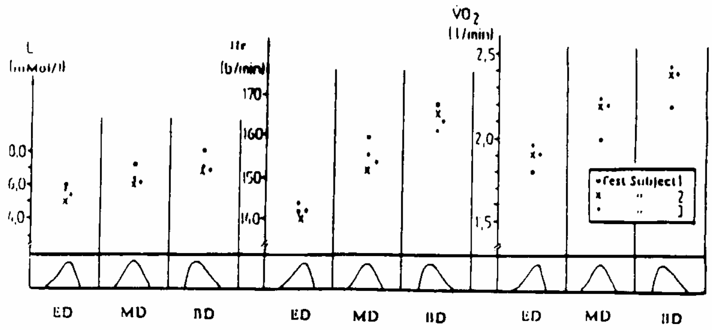
Reaction of O_2 - uptake (VO_2), minute ventilation (V), and respiratory quota (RQ) relative to the force/time-curve types (ED, MD, BD) under aerobic threshold endurance load on rowers (see legends in figure 3) (n = 10, average/mean value and standard deviation).

Figure 5



Reaction of lactic acid concentration (L) and heart rate (Hr) relative to the type of force/time-curve (ED, MD, BD) (see legend in fig. 4).

Figure 6



Reaction of lactic acid concentration in the blood (L), the heart rate (Hr) and the O_2 - uptake VO_2 in three test subjects relative to the type of force/time-curve under anaerobic threshold endurance load (Test subject 3 is a retest).

The following points should be considered as reasons for the physiologically more intense demand on the rower when performing the stroke pattern with a steep force increase:

1. As a deviation from the rowing technique model for body movements (BD: Legs and upper body, MD: Legs, upper body and arms, ED: Arms and upper body), a transition to a greater load on the whole body (legs, upper body, arms) is seen.

2. The increase in movement speed and the acceleration of larger body masses at the beginning of the drive and mid-drive of the stroke results in a decreasing effect and an increased energy requirement under the same demand for performance.

3. An increased need for rapid contraction of the muscles used in the beginning of the drive and the mid-drive possibly:

   a. slide into a more disadvantageous efficiency area of the recruited types of muscle fibres.

   b. recruit of FT fibres (especially when the demand on movement and contraction speed is very high).

2.4 The physiological effect of extreme force/time-curves in endurance training

When force/time-curves with extremely steep power increases are used, they can have catastrophic consequences for the planned endurance training and the direction of its biological effect. This kind of training often shows that an orientation toward fast power and propulsion in endurance training is realised through an over-emphasis in the beginning of the drive. The athletes did, in fact, propel the boat further per stroke and improve maximal performance over short and middle distances (for example, the start and the transition in a race). However, the endurance performance (the body of the race) remained static and sometimes even showed decreases.

The biomechanically demanded performance of a stroke pattern with extreme emphasis at the beginning of the drive is biologically realised predominantly from the FT fibres. The ST fibres that are essential for strength endurance are not affected. Additionally, there is a strong disproportion in the relation of the areas of ST fibres to FT fibres. This can be the cause for co-ordinative disturbances. The consequence is an impairment of the biological bases for a high loadbearing capacity, technical rowing stability and the specific performance ability. What must be remembered, however, is the proven positive relationship between the quantitative portion of the ST fibres, and the area of these fibres, with the performance at the lactic acid limit of 4.0 mmol/l (the anaerobic threshold), the performance in the body of the race relative to the general strength endurance ability.

2.5 Conclusions

- There is a relationship among the rowing techniques (pattern of the force/time-curve), its biological effect and fitness level.

- The biomechanical characteristic of the force/time-curves must be regarded as an important training methodological load factor and a biological factor of stimulus in training theory and practice.

- In basic endurance and strength endurance training, force/time-curves with an extreme power exertion at the beginning of the stroke should be avoided.

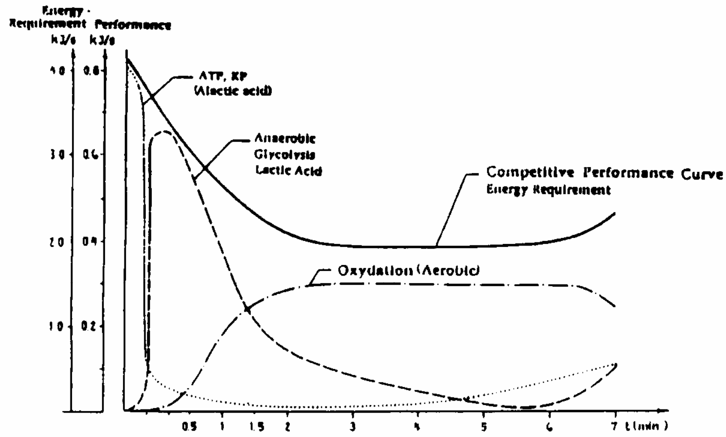
- The biological performance conditions characterised by a stroke pattern of initial strong power exertion are more suitable for 500 meter races than for 2,000 meter races.

- With biomechanically based changes in rowing technique toward a strong emphasis on the beginning of the stroke (short distance racing, specific to the boat class), the intensity, duration and frequency of each training session as well as the relationship between work load and recovery must all be adjusted according to biological demands (short training sessions, long rests).

3.0 The Connection Between Physiological Factors and the Stability of Rowing Technique: Race Performance Examples

In covering the energy need for the mechanical performance in a race (4, 7, 8, 9, 15) in the classic profile of start, transition, body of race and sprint, all three energy-providing mechanisms of the metabolism (energy components: alactic, lactic and aerobic) are involved chronologically, qualitatively and quantitatively in different relations (figure 7). There is a connection between the performance profile and the potential of the energy-providing processes. It should be noted that the individual energy components are characterised through specific features such as capacity and performance capability, and that there exists positive and negative interactions between these components (how long it takes to restore energy and recover). Attention should also be paid to the fact that between the energy components there is positive and negative interaction (2, 3, 5, 7, 10).

Figure 7



Quantitative, qualitative and chronological proportion of the three energy providing components of the metabolism (alactic, lactic and aerobic) for meeting energy requirements during simulated racing performance in a measuring ergometer (median value).

Quite often, international racing shows that favourites and top athletes who are supposed to be in optimal shape experience a decrease in performance and rowing technique in the last third of the race, after having delivered a high performance in the first part of the race. The final in the men's single (M1x) at the Olympic Games in 1976 (figure 8, P. Kolbe) and the women's coxless four (W4-) of the GDR at the World Championships in 1990 are good examples of the above. Other examples show that rowing teams have more success if they use a restrained performance in the first part of the race and exercise rowing technical stability in the last third of the race. The single scullers Jutta Behrendt, GDR (1988 Olympic Games), Birgit Peter, GDR (1990 World Championships) and the West German men's eight in 1990 are good examples of this. These findings can be explained by the chronologically, qualitatively and quantitatively different demands of each energy component and their interaction during a race. Therefore the lactic energy components and their final product, lactic acid, play a special role.

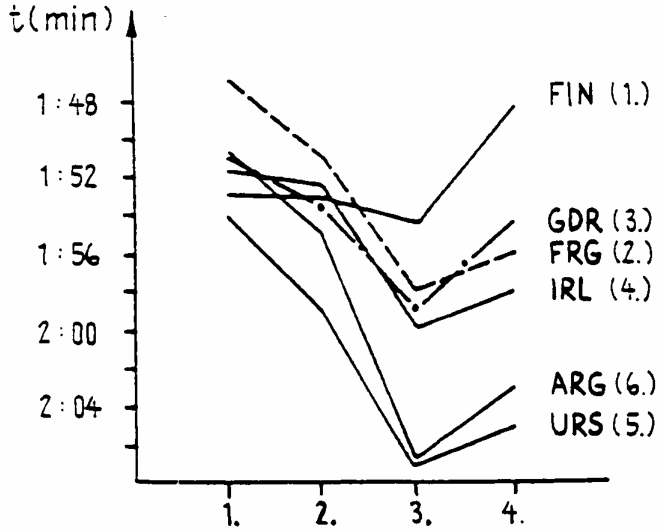
Figure 9 shows that in the classic performance profile the lactic acid build up occurs most likely at first in the start and transition phases. Research also has demonstrated that there is a connection between aerobic capability, the extent of lactic acid build up and the level of performance in racing, and that there is a negative relationship between lactic acid concentration in the first part of the race and mechanical performance in the last third of the race.

This demonstrates that rowers with a low aerobic capability, in comparison to well trained rowers, have a high start performance, an early high lactic acid build up and a worsening of performance at the end of the race. The same phenomenon would occur if a top athlete, as a consequence of a high and extended start performance, provokes high lactic acid concentration prematurely (figure 8). The decrease in performance during a race - especially in the last part of the race - for rowers in good as well as bad aerobic training condition can be attributed to the following:

1. Prematurely high lactic acid values with their negative consequences on all three energy providing metabolic systems and the process of muscular contractions.

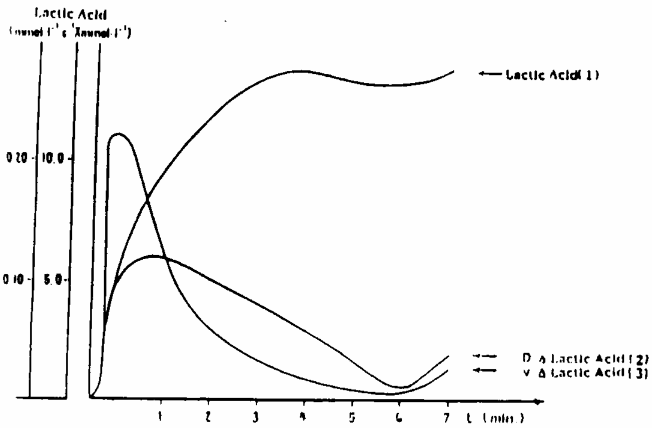
2. Lacking lactic performance reserves in the finishing sprint because of an almost complete use of the lactic energy supply at the beginning of the race.

Figure 8



Racing profile of the men's single sculls race in the Olympic final 1976, 1. Karpinnen (FIN), 2. Kolbe (FRG), 3. Dreifker (GDR)

Figure 9



Reaction of lactic acid concentration in the blood and rate of lactic acid build-up under racing load (mean values, simulated racing performance in measuring tank).

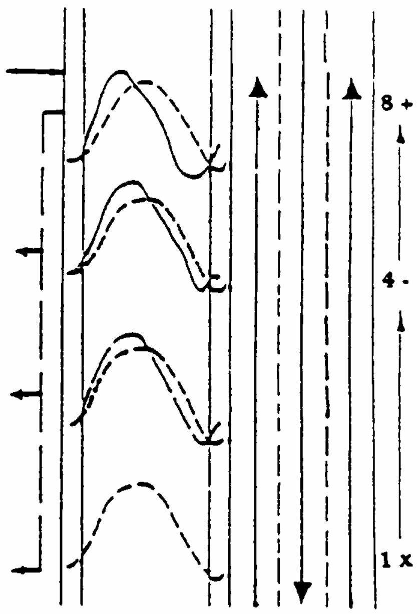
Curve 1: Absolute lactic acid concentration in blood (load value minus rest value).

Curve 2: Absolute lactic acid concentration between each time-section of the race.

Curve 3: Rate of lactic acid build-up in each time-section of the race.

Figure 10: Schematic table of standardised training methodological-biological-biomechanical concept of forming and managing training in rowing.

	Biology			Training Methods				Biomechanics		
MF	E S	Hr (b/min)	L (mmol/l)	KM/min	SR	TA	Predicted Velocity %	Rowing Stroke F/T - Curve	P = F • v	BC
FTF (STF)	an. (aer.) ~P/CH	≥180	≥6.0	n.125m	40	S	110			
FTF (STF)	an. (aer.) CH	≥180	≥15.0	n.1.5 km	32	SRE	103			
STF (FTF)	aer. (an.) CH/F	180	6.0-8.0 4.0-6.0	n.2.0 km 30 min	32 23	BE	90			
STF (FTF)	aer. (an.) CH/F	170	3.0-4.0	n.3.0 km 60 min	22	BED	85			
STF	aer. F(CH)	160	2.0-3.0	n.20 km 90 min	22	BE	80			
STF	aer. F	150	≤2.0	n.25 km 120 min	20 18	BEE	75			



Abbreviations:

Biology:

MF = Muscle fiber types, FTF = Fast-Twitch fiber,
STF = Slow-Twitch fiber, E = Energy provision, an. = anaerobic,
aer. = aerobic, S = Substrate, P = Phosphate rich in energy, CH = Carbohydrate, F = Fat, Hr = Heart rate, L = Lactate.

Training methodology:

TU = Training Unit, SR = Stroke Rate, TA = Training Area,
S = Speed, SRE = Specific Racing Endurance, BE = Basic Endurance, BED = Basic Endurance Development,
BEE = Basic Endurance Economy, Progn. = Boat velocity in % of the Prognosis.

Biomechanics:

FTC = Force/time-curve, P = Performance (W), F = Force, v = velocity, BC = Boat Class.

Conclusions

- The principles of bioenergetics (capabilities, interaction of the energy components) must be considered when fitness and technical rowing training as well as racing tactics are being planned.

- The development of high aerobic and alactic performance capabilities in training are crucial biological preconditions for race performance and a margin for racing tactics.

- The knowledge gained from racing experience should be transferred to training. High lactic acid values should be avoided in endurance training to secure the training goal, effectiveness and technically stable and quality rowing.

- Lactic acid concentration measured after a race gives no information about when it appeared in the race.

The problems described in this article point out the important practical connection between biomechanics (rowing technique, structure of movement), biology (energy components, structure of muscle fibres, training condition) and training methods (means of training, duration, intensity and frequency). They show that the previous practice of integrating training methodology and biology is no longer sufficient.

It is necessary to make the transition from the previous concept uniting training methodology and biology to the concept which unites training theory, biology and biomechanics. The need for this change is the result of improvement in the level of international rowing, the knowledge about specific boat classes and the requirements for individual training guidance.

The parameters in figure 10 attempt to clarify the training management through methodological, physiological and biomechanical dimensions. There is still some scientific research to be done to make the concept uniting training theory, physiology and biomechanics complete and more detailed.

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Translated from German by Lena Baden and Fred Kilgallin