Introduction to the Biomechanics of Rowing

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When two coaches observe a crew rowing, each will have a different frame of reference. One coach likes to observe the teamwork while the other watches for the power application by the rowers. What is the reason that the two coaches have different points on which to focus?

It may be that the two coaches have different concepts of what is the correct technique. It may also be the way the coaches look at the movements. One looks for the movement of the bodies while the other observes the movement of the blades. It could also be that the movements are just too quick and the coaches have no real point of reference.

One can learn to see a movement but the question really is which pattern of movement is the correct one? Which parts should be watched in which order and with what emphasis? Can one say that the faster rower utilises the best technique? Questions such as these are fundamental and apply directly to biomechanics. Biomechanics is the science that explores the human patterns of movement with application to physics.

Analysis based on physical laws as well as exact measurements have helped develop a stable base of biomechanical knowledge on rowing technique. It is relatively easy to acquire the basic knowledge necessary in biomechanics and be able to describe the biomechanical connections that the rowers can use in rowing practices. This article presents an overview of the biomechanics of rowing and provides suggestions to the coach to apply this information in practices.

The Tasks of Biomechanics in Rowing

The goal in rowing is to make the unit (the rowers and the boat) cover the distance as fast as possible from the start to the finish. Physical performance is necessary to achieve this basic goal and the muscles of the human body produce the necessary energy. Biomechanics is interested in how the rower converts this physiological capacity into moving the boat. Biomechanics describes the movements first and then explains the movements; more specifically, which muscles and joints the rower uses and which forces have an effect on the body and to propel the boat.

There is a vast range of research in this field. The development of photography and video cameras have brought with them great progress in biomechanics. The coach now does not need to rely on his or her eyes only. In this way comparisons with other teams are now possible.

From simple analysis of photographs, the next level of rowing technique analysis can be reached with an improved means of filming, i.e., use of the video camera. Angles and lengths can be measured using sharply defined pictures from special viewpoints (90 degrees to the side or from above). Time can be very accurately measured by using advanced filming techniques. Careful identification of the joints of the body through a series of pictures can provide effective analysis. By

taking each of these frames (pictures) and analysing them separately, you can calculate the actual change in the angles of the major body parts (see figure 1).

Figure 1: Determination of the important joints in several phases during the drive phase (please note the angle of the knee and the back).
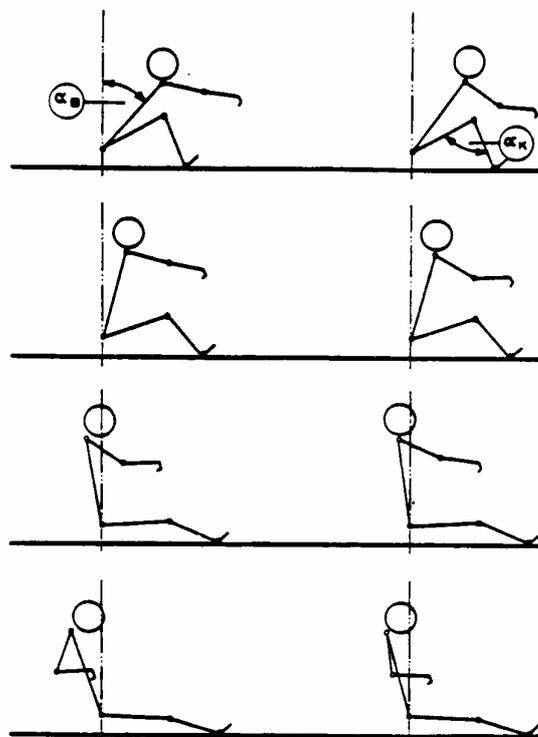
The position of the oars and the blades provides another means of analysis. From the side of the crew, you can analyse the distance of the blade to the water at any point in the stroke (especially at the entry). Another popular type of analysis is to observe the position of the oar relative to the boat. By filming from a bridge, you can calculate the length of the stroke at the entry and the finish of the stroke and compare it to the orthogonal or perpendicular line to the boat (see figure 2). The centre of gravity (CG) can be calculated by analysing the sequence of the movement of the body joints. The movement of the CG horizontally and vertically during the stroke cycle is important for the forces exerted by the rower (see figure 3).

With somewhat more sophisticated equipment you can measure the forces on various parts of the boat, such as on the oarlock, on the footstretchers and on the blade (see figure 4). Great progress has been made in this means of analysis over the past several years.

Figure 2: Measurement of the length of the stroke from pictures made looking down from a bridge.
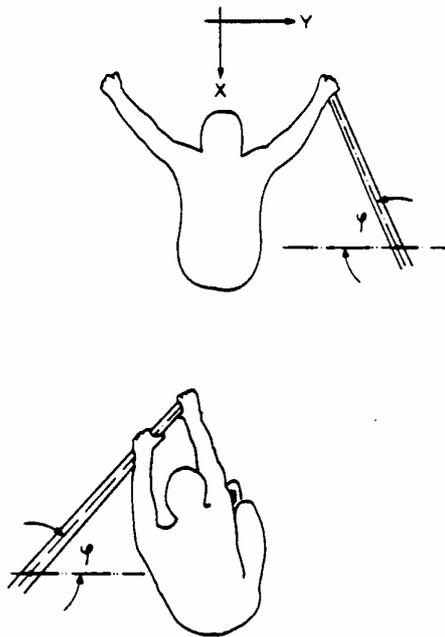

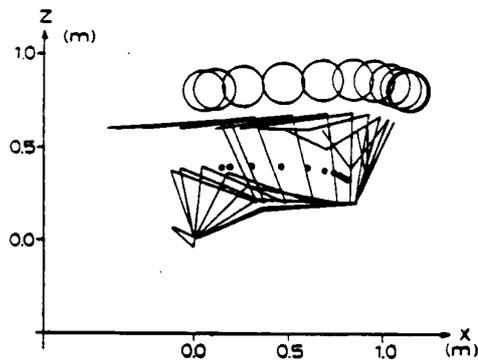*Figure 3: The movement of the centre of gravity (CG) during the recovery phase.*
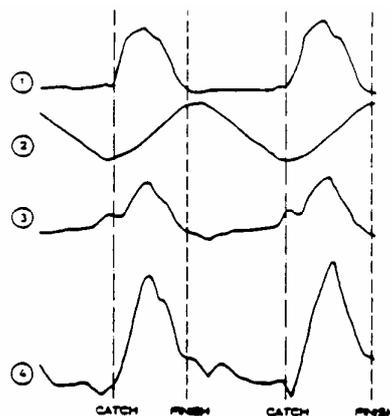

Figure 4: Measurement of parameters on the oarlock and on the footstretcher as viewed from the starboard side (from Haynes, 1988, p. 67).

1. orthogonal force to the oarlock

2. angle of the oar

3. footstretcher force in the vertical direction

4. footstretcher force in the rowing direction

Previously a coach could only rely on trial and error to apply rigging changes and the effects, if incorrectly applied, could ultimately hinder the rowers' performances during the year. Now the biomechanist can analyse these changes. Biomechanical research has also helped to eliminate the negative mechanical influences on the stroke. This allows analysis of the effects of CG movement by making changes in rigging (see figure 5). For example, how does lowering the height of the oarlock change the length of the stroke? The efficiency of drills and exercises for improving technique and the effectiveness of fitness training can also be analysed.

Beyond improvement in performance, biomechanic research has been able to analyse the loss of load to the human body. This research brought prophylaxis, or analysis to preserve health, to our attention. The load on the bones, tendons, ligaments and muscles can now be determined. Movements and techniques can be identified that do not injure the rowers. This is particularly true in the sport of gymnastics in recent years. Functional gymnastics refers to exercises that are adapted to the human body and its parts. This has shown not only that the position of the joints should receive attention but that the velocity of certain movements greatly influences the way the muscles and ligaments are loaded and, therefore, can respond in the correct manner.

Figure 5: The influence of the height of the oarlock (vertical distance between the oarlock and the seat) on the length of the stroke; a longer stroke (S1) using a higher oarlock and the same slide length.
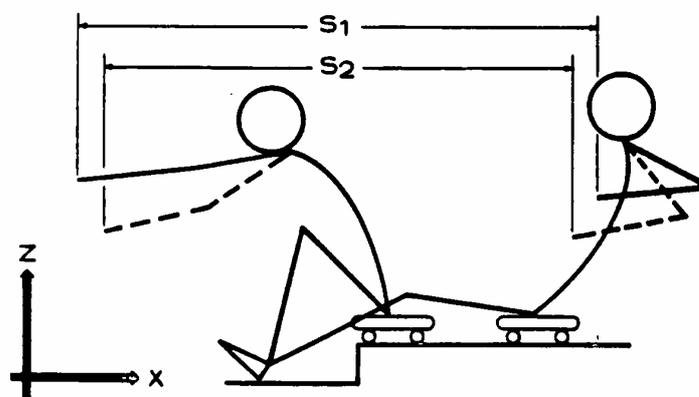
Biomechanics research has found certain indicators that are essential to reach high levels of performance. As with other sports, rowing has certain basic body requirements which are necessary for high performance (i.e., body height, arm length, lean body mass, etc.). Such anthropomorphic analysis is made in countries where it is possible to select athletes for sports at an early age.

Practical Biomechanical Applications

The most important applications for the rowing coach in biomechanics are found in the biomechanics principles. They are the bases for the daily instruction by the coach. They determine the rowing technique that will help rowers attain the common goal of rowing faster. The latest research in the biomechanics of rowing follows.

The biomechanical principles show the complete framework for rowing technique. Nevertheless it is obvious that the coach has to adapt these principles to the particular situation, perhaps with the assistance of a biomechanist. Because principles are comprehensive laws, they apply to tall rowers as well as not so tall rowers, single scullers as well as for the sweep rower in the eight.

Principle Number 1

All movements have to be performed in a way that the rower is able to transfer his/her physiological performance into optimal propulsion.

With this first principle it becomes clear that, for rowing technique, only functional considerations have value. There is no need that the pattern of rowing be "beautiful." The rower must be able to 1.) produce the highest physiological performance and 2.) transform this performance into the best propulsion possible.

Principle Number 2

The long stroke is necessary to produce a high level of rowing performance.

The long stroke length, on the outboard of the oar, creates a large reaction force with the water on the blade and, thus, enables the rower to produce his/her best performance on the inboard portion of the oar. The following factors restrict the practical application on the length of the stroke: 1.) the physiological ability of the rower (the more powerful the rower is, the longer the stroke can be), 2.) the velocity of the boat (the faster the type of boat and the higher the level of proficiency, the longer the stroke can be), and 3.) the functional capability of the rower (depending on the body height of the rower and the geometry of the boat).

To produce a high level of performance means to generate a large force over a long distance in as little time as possible. This is a law of physics. In rowing there is a double relationship between performance and the necessary distances: 1.) within the boat, the rower can only attain his/her maximal physiological performance using as long a stroke as possible with the inboard portion of the oar; and 2.) outside of the boat, the necessary force, on the outboard portion of the oar, can only be generated through a long stroke length. A blade without movement relative to the water does not create any reaction force with the water. A common myth among coaches is that the blade is relatively fixed or "sticks" in the water. Research shows that the blade does move through the water more than commonly thought, similar to the hand of a swimmer moving through the water. This movement creates the force to propel the boat.

Research has shown that for all rowers the angle of the oar at the finish is very similar (Nolte, 1982). It is interesting to note that the body height does not matter in this case. Only the body width and the geometry of the boat can cause small differences. Therefore you can influence the length of the stroke only with the variation of the angle of the oar at the entry. In this situation it is important to know that, contrary to popular opinion, the most effective use of the rower's strength is in the early drive phase of the stroke, the angle created before the perpendicular point to the boat (Affeld, 1985, 2.4.4.). In short, the second principle says that a long stroke is important for high performance and this length is most effective in the early drive phase of the stroke (see figure 6).

*Figure 6: The ideal course of the pull force of the rower (F = force, t = time) (Nolte, 1984, p. 203).*
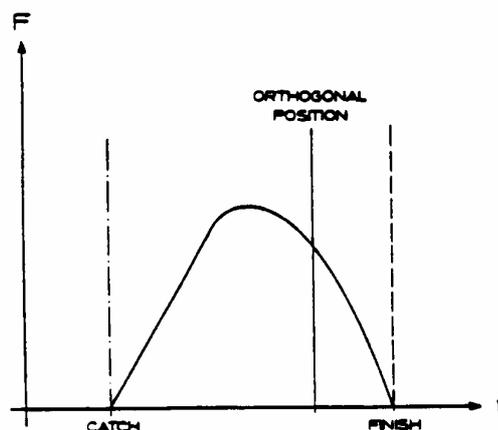
To produce force on the inboard section of the oar, the rower has to move his/her body weight. A considerable amount of power is necessary for this movement. From the total production of the physiological performance of the rower, the following has been determined: 1.) approximately 75 percent is used to pull the oar; 2.) approximately 9 percent is used to support the horizontal movement of the body weight; and 3.) approximately 16 percent of the whole performance is used for the vertical movement of the body (Nolte, 1984, p. 174).

Performance capacity that is used to move the body cannot propel the boat. These biomechanical reflections created the next two principles.

Principle Number 3

The movement of the rower has to be as horizontal as possible so that the vertical displacement of the centre of gravity is minimised without losing length in the stroke.

Figure 7: Comparison of the vertical displacement of the centre of gravity (CG) with the correct (the more horizontal CG - solid line) and incorrect (the CG that has vertical movement - dotted line) technique.
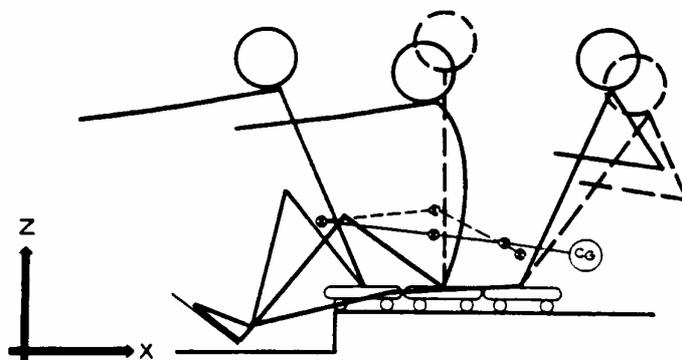
The flexion and extension of the legs, the swing of the upper body from the hips and the vertical movement of the hands and arms cause certain vertical displacements of body parts. With functional co-ordination and avoidance of

unnecessary movements, the vertical displacement can be minimised. Biomechanical research shows clear evidence of this principle. The upper body leaning too far back and straightening up during the early drive are major errors. On the contrary, a position with a naturally round back along with minimal vertical movement by the hands are signs of a physically correct technique (see figure 7).

Principle Number 4

The horizontal velocity of the rower relative to the boat should be as small as possible. Ex: The displacement of the centre of gravity in the horizontal plane should be minimised without losing length in the stroke and there should be no lost time with stops or pauses.

This consideration can be followed in two main steps: 1.) the horizontal distance of the CG has to be minimised and 2.) the horizontal movements have to be performed with minimal changes in acceleration. Figure 8 shows schematically that you can have the same length of stroke with different horizontal movements by the CG. It is evident that the so-called Karl Adam technique which uses the extended tracks (Klavora, 1977) is incorrect.

Figure 8: Schematic representation of how to shorten the horizontal movement of the centre of gravity (S1 vs. S2) with slide length where the length of the stroke stays the same.
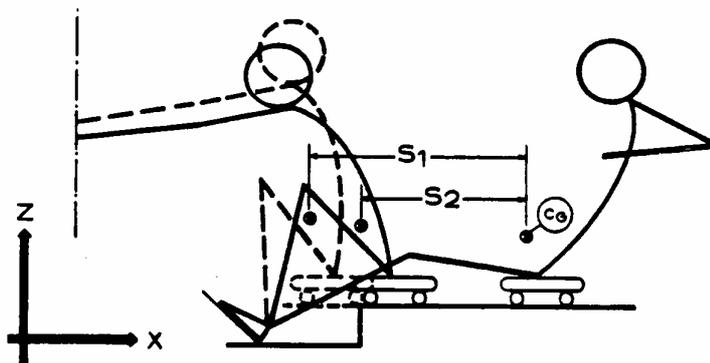
To this point we have only considered the performance effect the rower has on propelling the boat. This refers to the rower's effect to overcome the water resistance of the shell (not to mention the air resistance and elements of friction such as the wheels of the sliding seat). The water resistance of the boat grows proportionally with the square of the velocity. The changes of the velocity of the boat are considerable because of the differences in the stroke and recovery phases as well as the movements of the bodies of the rowers. Because of these changes in boat velocity, the resistance of a rowing boat is much greater than for a boat of constant speed. To show this, let's consider the following example:

A shell with a constant velocity of 5 meters per second (a men's pair with coxswain) produces a resistance of 100 Newtons. If the velocity is changed so that the boat goes the same average speed but spends approximately half the time at 4 m/sec and the other half at 6 m/sec, it has a 4 % greater resistance.

Normally the changes in boat velocity produced by the rowing stroke are even greater. Therefore it is quite important to consider anything that can reduce these

changes. By selecting a rowing technique that minimises changes in boat velocity, the rower can be much more effective in moving the boat. The importance of principles 3 and 4 becomes even greater when you can save performance capacity by minimising the resistance of the boat.

Vertical movement of the centre of gravity produces a dipping of the boat and creates even greater resistance. Large and fast changes in the horizontal movement of body weight also increase the changes in the velocity of the boat. Attention to these principles in boat velocity movements in selecting a rowing technique will have positive effects on the performance of the crew.

Biomechanical Applications in Rowing Training

We have seen that the racing times in international competition for all boat classes have decreased in recent years. The physiological capacity of the rowers has not increased as much as have the improvements in times. Therefore, the development of rowing technique is considered one of the major reasons for this success and biomechanical analysis has assisted this development. The women's pair without coxswain from West Germany who won at the l990 World Championships is an example of a crew whose technique closely followed the principles of biomechanics. Their technique did not emphasise the excessive layback at the finish as employed by the Romanian women's crews, the previous winners of the event. Biomechanical principles applied by a larger group, such as an entire national rowing federation, can provide big advantages to the rowers. Over a longer period, it is possible to create consistently successful big boats, like the Italian men's lightweight eight and the West German men's open eight.

It is possible to reach the top levels of world class rowing only if you employ a sound rowing technique. An outstanding example of this is the 1990 Australian men's four without coxswain. This boat defeated many excellent past champions by using superb rowing technique and, in doing so, in the extremely fast time of five minutes, 52 seconds.

Biomechanics in the Future

Research in biomechanics is not finished. Basic research in specific analysis of rowing technique is on going. For example, additional research is necessary to determine at which point the effectiveness of the angle of the oar at the entry decreases. The measurement tools and analysis methods will be developed so that they can be used by coaches at all levels. The efficiency of an individual rower in a crew can be increased with dynamic measurement devices, such as force transducers, in the boat. In the end, the practical education of biomechanical concepts and the simplification of scientific research into language that can be understood by the coaches and the rowers is our goal.

References

1. Affeld, A., K. Schichl: Untersuchungen der Kräfte am Ruderblatt mithilfe eines mechanischen Simulators. Bericht der Technischen Universitat Berlin, 1985.

2. Brüggemann, P.: Biomechanik des Sports. In: Carl, K. et al. (Hrsg.): Handbuch Sport, Bank 1. Düsseldorf (1984), p. 259-302.

3. Hänyes, B. et al.: Wenn jeder Schlag sitzen soll… In: Rudersport 3 (1988), p. 67-69.

4. Klavora, D.: Die wichtigstenbiomechanischen Unterschiede bei den heutigen Stilarten im internationalen Ruderwettkampf. In: Rudersport 33 (1977), p. VI-XI.

5. Nilsen, T.: Basic Rowing Technique. FISA Development Programme. Zürich, 1987.

6. Nilsen, T., V. Nolte: Basic Rigging. FISA Development Programme. Zürich, 1987.

7. Nolte, V.: Rudertechnik und ihre Analyse: Der Arbeitsbereich im Skullboot. In: Rudersport 20 (1982), p. 468-469.

8. Nolte, V.: Die Stemmbretteinstellung und der Ruderwinkel in der Rücklage. In: Rudersport 25 (1982), p. 544-545.

9. Nolte, V.: Die Effektivität des Ruderschlages. Berlin, 1984.

10. Nolte, V.: How the world class scullers scull their singles. In: Rowing 4 (1986), p. 16-18.

11. Nolte, V.: The inter-relationship between equipment and adjustment and efficient technique. In: Report 15/16. FISA Coaches Conference 1986/1987. Minden (1988), p. 153-175.

12. Schmidtbleicher, D.: Maximalkraft und Bewegungsschnelligkeit. In: Reider, H. (Hrsg.): Beiträge zur Bewegungsforschung im Sport. Bad Homburg, 1980.

13. Schneider, E.: Leistungsanalyse von Rennmannschaften. In: Grösing, S. (Hrsg.): Aus der Wissenschaft fuer die Praxis. Bad Homburg, 1980.

14. Willimczik, K. (Hrsg.): Biomechanik der Sportarten. Reinbek, 1989.

Applying Biomechanics to Improve Rowing Performance

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1. Improvement of Rowing Performance

Every rowing race has a winner. This winner - the individual or the crew - has rowed the racing distance in the fastest time with the highest average boat speed. The final performances by rowers in the finals of the top international competitions (World Championships and Olympic Games) are the result of important and complex efforts by the rowers and the coaches.

The results make it possible to evaluate, among other things, the effectiveness of the training, the creatively efficient effort of the athlete during training and competition, and the development of modern materials for the production of boats, oars and other equipment. In order to draw conclusions about future success in competitive rowing, it is important to have a general idea of the trends in racing times in the finals of previous top international competitions. If this is regarded as a benchmark for the development of performance requirements in rowing, it is important to emphasise that performance is influenced by two factors: The *human* factors (personal abilities, fitness, rowing technique, etc.) and the *non-human* factors (boat equipment, weather, regatta course, etc.).

Three questions about the development of performance will be addressed in this section. The answers to these questions are based on the following:

- the winning times of all boat classes for men in the World Championships and the Olympic Games; and

- the results of test races performed in measuring boats by FES-Berlin in co-operation with Humboldt University in Berlin.

Question 1: How has race performance (boat speed, racing times) developed?

Figure 1 shows the development of the boat speed of winners of the Olympic finals in all men's boat classes (average) from 1948 to 1988.

If you analyse the average boat speed of all winners of the men's Olympic finals (except the 4x) from 1948 (London) to 1988 (Seoul), it is clear that from one Olympic Games to the next, the average boat speed over the racing distance has increased by 1.3 percent.

It is interesting that the development in the average first-place time corresponds to the relative development in the single sculls. From this one can cautiously draw conclusions about the development of the individual performance.

Figure 1: Development of the boat speed of winners of the Olympic finals in all boat classes (average) from 1948 to 1988.
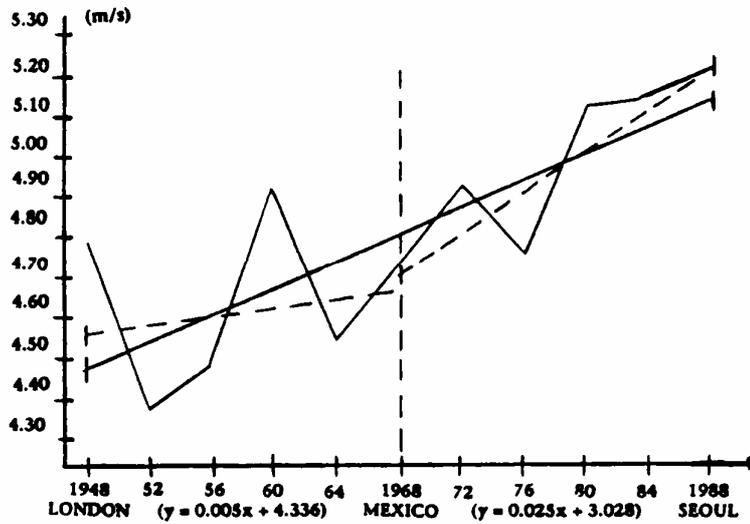
If this period of time is divided, then (see dotted lines in Figure 1) from 1948 (London) to 1968 (Mexico) the first-place time in an Olympic cycle improved by an average of **0.4 percent;** while from 1968 to 1988 (Seoul) the first-place time in an Olympic cycle improved on average **1.9 percent.** Winning times in the period since 1968 have improved at a rate greater than the previous period.

The result is that boat velocity, as a mean value for Olympic winners of all boat classes, has increased on average by 1.9 percent in an Olympic cycle. The relationships in velocity between boat classes (mean values) of the winners have stabilised (see Table 1).

Table 1: Speed relationships for men (winners in all World Championships and Olympic Games 1958-1989) as a percentage of the men's eight.

Boat Class	Scheyer 1958	Herberger 1970	Schwanitz 1985	Schwanitz 1989
2+	80	79	79	79.4
1x	82	83	80	80.3
2-	84	85	83	83.2
2x	89	89	87	87.1
4+	90	90	89	89.8
4-	92	93	92	92.3
4x	-	-	96	96.2
8+	100	100	100	100.0

Question 2: How are the racing performances in the Olympic cycles of 1992 and 1996 likely to develop?

Future increases in speed over 2,000 meters have been calculated based on improvements in performances. It should be noted that weather is included as an "average condition." Therefore, the expected improvements imply "average" weather conditions (i.e., calm, small waves, etc.). For example, for the three boat classes, 1x, 2- and 8+, the improvement in the racing times and the boat speed in the cycles of 1992 and 1996 are clear in Table 2.

Table 2: Mathematical adjustment of the improvement in boat speed from the World Championships and Olympic Games, 1974 to 1988, (winning performance) and concluding in 1992 and 1996.

	Year	1x	2-	8+
Velocity (m/s)	1988	4.81	5.04	5.98
	1992	4.88 (+1.5%)	5.14 (+2.0%)	6.06 (+1.4%)
	1996	4.96 (+1.6%)	5.26 (+2.3%)	6.16 (+1.7%)
Winning time (m/s)	1988	6:56	6:37	5:35
	1992	6:50	6:29	5:30
	1996	6:43	6:21	5:25

Question 3: How are the key technical parameters likely to change in the cycles of 1992 and 1996?

Assuming a constant stroke rate in the three selected boat classes, the Olympic winner in 1992 and 1996 will have to:

- reduce the total number of strokes in a race;

- increase the propulsion per stroke in comparison to the winners of 1988 and 1992 (see Tables 3 and 4).

Table 3: Increase in propulsion (cm) per stroke and reduction in the number of strokes (SZ) as a function of reduced racing times and constant stroke rate (1988, 1992, 1996).

Stroke rate in 1988	Year	32 (1x)	34 (2-)	38 (8+)
Reduced number of strokes	1992	-3	-5	-3
necessary at given stroke rate	1996	-4	-4	-3
Extra distance needed per stroke	1992	12	18	15
(cm)	1996	18	19	15

Table 4: Increase in the stroke rate as a function of reduced racing times and constant propulsion per stroke.

Stroke rate (strokes per minute)			
Year	1x	2-	8x
1988	32.0	34.0	38.0
1992	32.5	34.7	38.6
1996	33.0	35.4	39.2

Assuming constant propulsion in the three boat classes, stroke rates must increase.

Now it is interesting to see the consequences of the probable quantitative improvement of important rowing technique parameters and their relative percentage changes (see Table 5). These data were obtained from measurements of the former East German National Team.

Table 5: Empirical, mathematically based consequences of the improvement in boat speeds from 1974 to 1988 for the quantitative shaping of biomechanical parameters in a representative rowing cycle (X), (parameter as [power-] function of the boat speed).

	Year	1x	2-	8+
Stroke power (PIHZ) Watts	1988	576	559	591
	1992	602 (+4.5%)	597 (+6.8%)	619 (+4.7%)
	1996	632 (+5.0%)	646 (+8.2%)	656 (+6.0%)
Drive power (PIHEF) Watts	1988	1017	931	1186
	1992	1041 (+2.4%)	962 (+3.3%)	1221 (+3.0%)
	1996	1068 (+2.6%)	997 (+3.7%)	1267 (+3.7%)
Drive force (FIHEF) Newtons	1988	535	471	484
	1992	542 (+1.3%)	484 (+2.7%)	493 (+1.9%)
	1996	550 (+1.5%)	499 (+3.6%)	504 (+2.2%)
Drive speed (VIHEF) m/s	1988	1.95	2.21	2.46
	1992	1.97 (+1.0%)	2.24 (+1.5%)	2.49 (+1.2%)
	1996	2.00 (+1.5%)	2.29 (+2.2%)	2.53 (+1.6%)

PIHZ = power in the full rowing stroke, PIHEF = power in the effective drive portion, FIHEF = force on the inboard or inside lever, and VIHEF = velocity of the inboard or inside lever. P = mechanical performance, F = force, V = velocity, IH = inboard, and EF = effective drive ("work in the water").

In the three boat classes the highest percentage rates of increase in the realised average performance (P) on the inboard (PIH) are shown for:

- a rowing cycle (PIHZ);

- the effective drive (PIHEF) in the rowing cycle.

The product of the factors "force on the inboard or inside lever" (FIHEF) and "velocity of the inboard or inside lever" (VIHEF) with the mechanical performance of the inboard show a minor rate of increase within an Olympic cycle.

In general it should be noted that the increase in boat speed puts demands on the athlete to exert more power on the inboard and to attain a higher velocity on the inboard.

2. Applying Interdisciplinary Contributions to Improve Performance

The definition of biomechanics can be described as the effects of mechanical laws on and in the living organism and the mechanically measurable reactions of the organism to these effects.

Thus, biomechanics has its basis in both the physical and biological sciences. Therefore, one should not depend solely on mechanical findings to determine how to achieve competitive goals (victory, best possible result, "faster," etc.).

This knowledge must be translated for use in an interdisciplinary synthesis and an application oriented training plan. The following four questions and their answers attempt to substantiate this claim.

Question 1: What are the possibilities and limitations of the contributions of biomechanics to the sport of rowing?

The essential focus of biomechanics in rowing has and always will be rowing technique.

Most objectives of biomechanical research are to explain the propulsion-causing powers and accelerations of the rowing stroke during competition, both in theory and in practice. This research also tries to explain the effects of the development of equipment.

Theoretically explained biomechanical knowledge and the empirical findings that create successful rowers are the bases for forming a technical concept. The application of this concept has contributed to the improvement of rowing performance.

The biomechanics of athletic movements in the endurance sport of rowing can improve performance, especially if it considers biomechanical/energetic and biological/energetic interactions. The task in this connection is:

- to investigate the movement sequences during competition and training in order to explain those mechanical causes that influence the biological/conditional effects;

- to develop rowing technique as a biomechanical solution process that can be applied to the effective biological/energetic development in training as well as result in higher speed during races.

It is important to develop and identify rowing technique from a biomechanical perspective, which makes it possible for the athlete:

- to achieve the fastest racing times and the highest average boat speed over the rowing distance on the basis of his or her individually available energy potentials at the lowest possible external resistance;

- to achieve the fastest time over a given distance on the basis of his or her individually available biological energy potential and taking into account the biological/conditional objectives for the particular training areas at given resistance conditions (boat type, gearing, area of blade, etc.).

Question 2: What research could form the basis for the establishment of a rowing technique for training and competition?

In practice you can find different force/time-curves on the oarlock [F=f(t)] with an approximately equal impulse area. These can be classified as shown in Figure 2.

"A" emphasises the middle of the drive: Synchronous force of leg, upper body and arm musculature is dominant. "B" emphasises the end of the drive: Synchronous force of upper body and arms musculature is dominant. "C" emphasises the beginning of the drive: Synchronous force of leg and upper body musculature is dominant. "D" strongly emphasises the beginning of the drive with no emphasis on the remainder of the drive.

Figure 2: Schematic representation of different force/time-curves in rowing.

Figure 3: Schematic representation of typical curves as a function of distance with constant work (acc. Müller, 1962).

The strongly schematicised force/time-curves appear in rowers of all classes, including World and Olympic champions!

But which of these curves will now be useful? Trying to get the answer from the science of biomechanics alone wouldn't be enough. The following accounts should give some help in making decisions.

"The work is all the more inefficient the more tension there is in the muscles at the end of the effort, because the work is wasted isometrically, without producing any performance." *(Landois-Rosemann 1962, p. 504)*

"The force/distance-curves with a short steep rise to the peak of maximum force and a subsequent flatter fall off to the end of the work distance appears to be the most favourable. The effectiveness of the energy turnover for equal work is, in comparison to other curves, the highest, since the necessary energy turnover is the lowest." *(Landois-Rosemann, 1962)*

This information disqualifies an orientation toward hard pressure at the finish of the rowing stroke, and it highlights an emphasis on the beginning of the stroke.

"Equal work, realised through extreme tension of the different muscle groups, results in various local loads. The higher loads manifest themselves in the smaller muscle groups (i.e., the arms), and the lower loads in the larger muscle groups (i.e., the legs)." *(Hollmann/Hettinger, 1976)*

From this statement it makes sense to employ a synchronous whole-body effort of muscle potentials, taking into account the different force potentials of the leg, back and arm muscles. Emphasis on the finish of the stroke should be de-emphasised because of the high local load on the arm muscles.

"There are two alternative ways to increase performance (in the mechanical sense, as a product of force and movement velocity): you can increase *either* the force *or* the movement velocity. The physiological processes react more strongly to changes of movement velocity than to changes in force." *(Landois-Rosemann, 1962; Roth/Schwanitz/Körner, 1989)*

Thus, it makes more sense to improve the time of the movements during the drive where the body parts work synchronously. The necessary high velocity on the inboard can be carried out through the slower movements of the legs, upper body and arms while they work individually.

"A high force development in the beginning of the stroke seems to be the most effective with regard to the most favourable body position for a proportional development of the force potentials. The position of the body in the beginning of the drive can be compared to the position of a weightlifter at the beginning of the lifting process." *(Gjessing, 1979)*

In light of the previous statement, one should emphasise the beginning of the drive portion of the stroke. Empirical research carried out by this author has produced the following results:

- The average boat speed per stroke rose with the rower's increased force exertion on the inboard at the beginning of the drive.

- The increase in boat speed did not parallel the increase of average force past the 90-degree position of the oar relative to the splashboard.

- The recorded increase of inboard velocity in the area of the drive is therefore mostly a function of higher boat speed initiated by the higher inboard force at the beginning of the drive. *(Schwanitz, 1975)*

Therefore, one can justify an emphasis on the beginning of the drive as well as an orientation toward increasing the force in the middle of the drive and in the finish in order to make use of reserves. *(Schwanitz 1976)* In the discussion about the effectiveness of the rowing stroke, Nolte (1985) raised the aspect of the hydrodynamic lift, which supports the orientation toward the beginning of the drive.

3. Summary

From a biomechanical, biological and training method point of view, there are reasons for an efficient rowing technique that take into account the aspect of load as well as the propulsive effect during training and competition. The emphasis of the force on the inboard, in order to produce a powerful first part of the drive, characterises this rowing technique and should be encouraged.

In addition to the emphasis on the first part of the drive, the force on the inboard should be produced in the tangential direction to the inboard, especially before the 90-degree position. A common expression for this force application would be "row around the oarlock."

The intention of all training methods is to increase the individual performances in the drive phase. This also covers the common forms of diagnosis used in biomechanics, rowing technique and sports medicine. These usually show the effects of training under defined test conditions.

The increased force exertion and movement velocity as components of the mechanical performance are the correlated partners of the biological and mechanical criteria, with the drive given first priority. Here one should pay attention to the fact that the co-ordination requirements of the recovery phase are particularly high. In training it is important to carry out a conscious conditioning of the muscles used during the recovery at race intensity to counter conditionally caused co-ordination problems and to ensure the propulsive effect in the drive by paying special attention to the reversal movement into the entry.

Question 3: What should the coach and athlete know about rowing in different boat classes?

An analysis of training methods with the boat measurement technology of FES Berlin in 1978 gave results which, later, strengthened the considerations of the rowing federation of the former GDR with regards to decisions about loads. Rowing in different boat types will, under the same training conditions (distance, stroke rate), put different demands on the athlete and result in different loads. A comparative examination of inboard velocities in similar training load ranges gives the following results:

- Recovery: The profile of the inboard velocity and the time bases approximately match in the various boat classes.

- Drive: As the boat classes get bigger the acceleration on the inboard in the beginning of the stroke increases, and the drive time decreases considerably. (Refer to Table 6)

Table 6: Load relevant to aspects of changes in the mechanical work in rowing.

If rowing with the same load demands (Watts) and the same stroke rate		
in small boats	∧	in big boats
with high load	∧	with easier load
with big blades	∧	with small blades
with heavy resistance (ergometer)	∧	with light resistance (ergometer)

Then, in the direction of the ARROW:
- the amount of inboard power during the drive-phase decreases
- the inboard velocity during the drive-phase increases
- the time of the recovery increases

Question 4: How does the individual rower deal with the requirements of the specific boat classes?

The research in the biomechanically explained movements of the different boat classes made it possible to qualify the diagnostics of the measurement boats in such a way that the individual load requirements and effects during training could be clarified, along with the development of rowing technique. This led to an experiment in 1987 carried out by Körner (training methodology), Roth (performance physiology) and Schwanitz (biomechanics).

The object of the experiment was the rower's mastery of the boat type specific requirements. Four athletes each carried out the following tests in 1x, 2+ and 4+ measuring boats:

- a five-step test (one step: three min.);

- one unit of basic endurance training (90 min.; stroke rate = 20 to 22).

Inevitably, there were the same general requirements (stroke rate, boat velocity) for every step for the four rowers in 4+. However, every rower showed very different realisations of the demands of every load level from the biomechanical point of view. The analysis of the biomechanical parameters shows great dispersion among the rowers at the same load input (between 4 and 25 percent). It was striking that:

- the highest individual deviation in the load steps appeared at lower intensity;

- at all load levels the inboard velocity showed the smallest individual deviation, which is mechanically explainable.

The overall impression of a team is often formed by that which one can see, such as movements of the body parts relative to each other and to the boat as well as movements of the oars and the boat. In general, one can conclude that:

- The different load demands of each boat class and of each step in the test show very individual results in rowing technique and physiological load;

- In every load of the step test the performance on the inboard as the product of the inboard force and velocity shows particularly large differences for every rower in all boat classes;

- Performance, force, velocity, lactate and other biological parameters determined as a function of the load in the different boat classes by the same rowers confirm the necessity *and* the possibility of emphasising the individual control of performance development by means of biomechanical/rowing technique parameters and characteristics. (See an example of this analysis in Figure 4.)

Figure 4: Lactate as a function of the power of rowers of a 4+ in a measuring boat.

The results of this experiment were used to prepare the athletes of the rowing federation of the former GDR for the 1988 Olympic Games in Seoul. Early in 1988 the women's sweep rowing team was diagnosed according to this method and given training recommendations. Later in June selection tests were carried out to form the crews in the different boat types.

A basic-endurance load test of more than 90 minutes at the stroke rate 20 to 22 showed:

- large differences among rowers in performance, force and velocity on the inboard;

- different amounts of force and velocity among the rowers;

- different lactate concentrations that prevented at least one rower from reaching the biological/conditional training goal.

As the training progressed all four athletes tended to:

- decrease the inboard velocity during the drive;

- increase the inboard velocity during the recovery;

- reduce the force on the inboard;

- reduce the performance on the inboard during the drive.

The following facts can be applied to the examined boat classes:

- Depending on the length of time and intensity of the training session on the water, a relatively early tendency of decreased rowing technique was observed;

- The biggest deviations in the technical parameters from rower to rower happened under low intensity training.

These facts strongly support Roth's demands in 1987 for a transition from a methodology/biological training concept to a methodology/biomechanical training concept to improve the performance of the active rowers.

4. Conclusion

The previous improvements in the times and the average boat speed in the finals in top international competition are milestones in the development of rowing performances. They are the results of human factors, developed by training and experience, and influenced by non-human factors. In terms of Olympic cycles, the relative increases in the average boat speed of 1.5 percent to 2.0 percent are also likely in the future.

The biomechanics of athletic movements based on physical and biological sciences can improve rowing performance, especially in biomechanical/energetic and biological/energetic contexts.

The following two essential tasks should be emphasised:

- the improvement of rowing technique to help the biological/energetic development during training, which leads to a higher boat speed and faster times in competition;

- the examination of movement patterns during competition and training to explain the mechanical causes in biological/conditional effects.

From a biomechanical and biological point, there are reasons for adopting an efficient rowing technique, the most important characteristic of which is the emphasis on the first part of the drive.

In order to perfect the technique and fitness as a synthesis for further improvement in rowing performance, one should find and pay special attention to the specific aspects of each boat class and the individual use of these characteristics.

The conscious use of the boat characteristics depends on one's knowledge of rowing in big boats versus small boats. For example, when going from a small boat to a big boat, one experiences:

- reduced drive times;

- increased inboard velocity;

- increased emphasis on the first part of the drive;

- reduced drive phase proportion in comparison to the whole stroke cycle (changed rhythm relations);

- increased inboard velocity in the performance of the drive.

Knowing about the individual characteristics of a certain boat class, one will be able to prescribe the correct workload, and gear the athlete in training toward a successful performance.

Diagnostic methods to check certain abilities specific to rowing should allow a variation of the loads that will enable the athlete to reach the limits of his or her current individual ability. It is therefore possible to make low risk assessments of the training effectiveness, and to give recommendations more likely to succeed in the further development of performance.

A diagnosis of the rowing technique should be done along with keeping track of the rowing performance. For this reason it is recommended that you make a system of diagnoses (video analysis, dynamic-graphical measurements, individually or together):

- full stroke cycle and drive portion evaluations;

- competitive evaluations in test and regatta environments;

- workload evaluations.

Abbreviations

Variables:
- P = Performance
- F = Force
- V = Velocity
- T = Time
- S = Distance

Indices:
- B = Boat
- EF = Effective Drive
- IH = Inboard part of the oar
- FL = Recovery
- Z = Rowing Cycle

Example:
- $PIHZ$ = average performance (P) on the inboard (IH) of one rowing cycle (Z) in the rowing stroke.

Reference parameters:
- SF = Stroke Rate
- GA = Basic Endurance
- WSA = Specific Endurance necessary for Competition
- S = Sprint
- WK = Competition

References

1. Andrich, B., R. Buchmann, P. Schwanitz: Ansätze für die Erarbeitung biomechanischer Zweckmässigkeitskriterien sportlicher Bewegungshandlungen in Ausdauersportarten fur Wettkampf und Training. In: Theorie und Praxis der Korperkultur 38 (1989) 6, p. 420-422.

2. Gjessing, E.: Muskeltätigkeit und Bewegungs verlauf beim Rudern -eine Kraftanalyse. In: FISA Coaches Conference, 1976, p. 15-35.

3. Hollmann, W., T. Hettinger: Sportsmedizin - Arbeits - und Trainings-grundlage. Stuttgart, 1980.

4. Müller entnomment Landois-Rosemann: Lehrbuch der Physiologie des Menschen. Vol. 11, München - Berlin, 1962, p. 504

5. Nolte, V.: Die Effektivität des Ruderschlages. Berlin, 1985.

6. Roth, R., P. Schwanitz, T. Körner: Untersuchungen zum Freiwasser-Mehrstufentest in den Messbooten Vierer, Zweier, Einer in fünf Geschwindigkeitsstufen. DRSV-intern, Berlin, 1989.

7. Schwanitz, P.: Ruderspezifische Systembetrachtung und Analyse der Veränderungen Rudertechnischer Parameter in drei Geschwindigkeitsstufen. Dissertation, Humboldt-Universität in Berlin, 1976.

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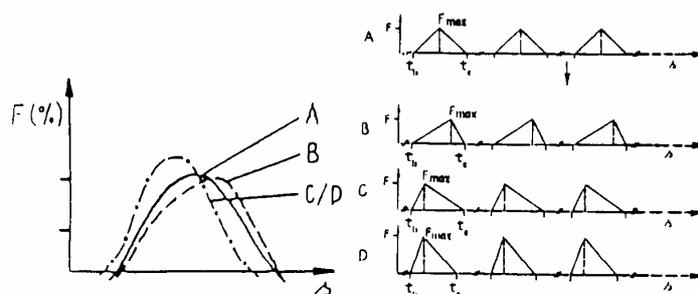
Abbreviations: F = Force, t = time, t_b and t_e = beginning and end of force impulse.
Left: Registration example of force/time-(top) and speed force/time-curves (bottom) measured with a measuring oarlock.
Right: Schematic presentation of the different types of force/time-curves.

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

106

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).
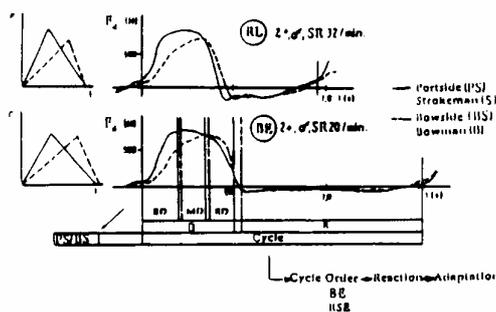
Left: Schematic presentation

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.

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.
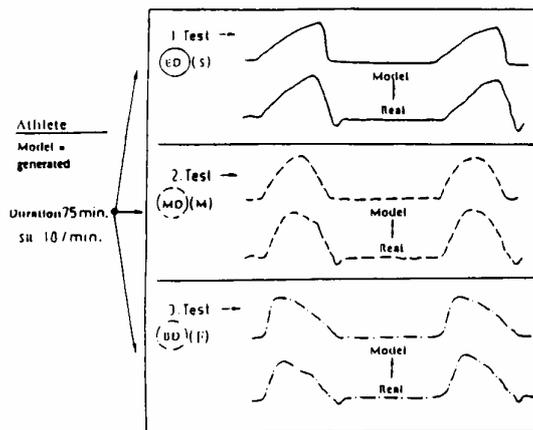
Diagrams of three different force/time-curves:

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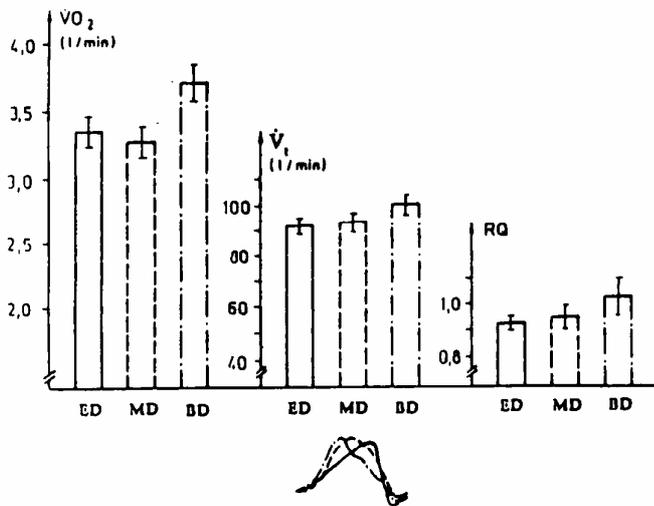
Reaction of O_2 - uptake (VO_2), minute ventilation (V), and respiratory quota (RQ) relative to the force/time-curve types (ED, MD, BD) under aerobic threshold endurance load on rowers (see legends in figure 3) (n = 10, average/mean value and standard deviation).

Figure 5
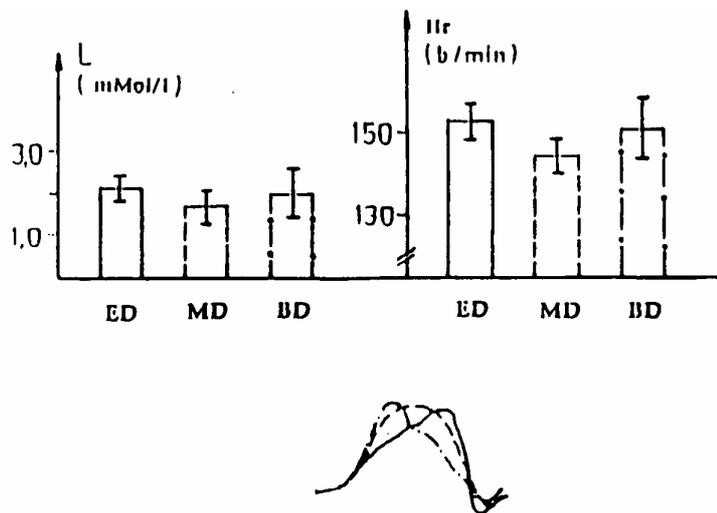
Reaction of lactic acid concentration (L) and heart rate (Hr) relative to the type of force/time-curve (ED, MD, BD) (see legend in fig. 4).

Figure 6
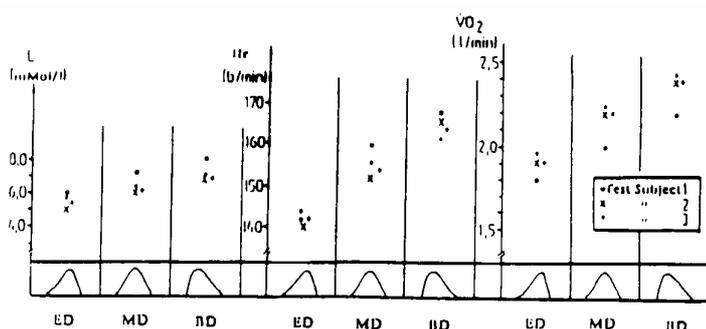
Reaction of lactic acid concentration in the blood (L), the heart rate (Hr) and the O_2 - uptake VO_2 in three test subjects relative to the type of force/time-curve under anaerobic threshold endurance load (Test subject 3 is a retest).

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

112

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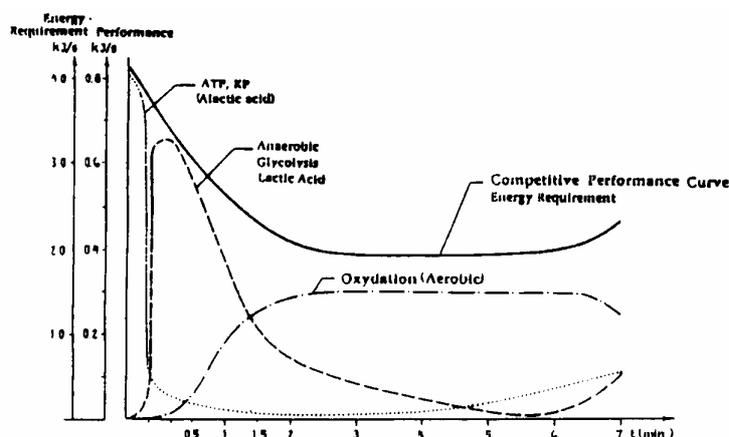
Quantitative, qualitative and chronological proportion of the three energy providing components of the metabolism (alactic, lactic and aerobic) for meeting energy requirements during simulated racing performance in a measuring ergometer (median value).

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:

114

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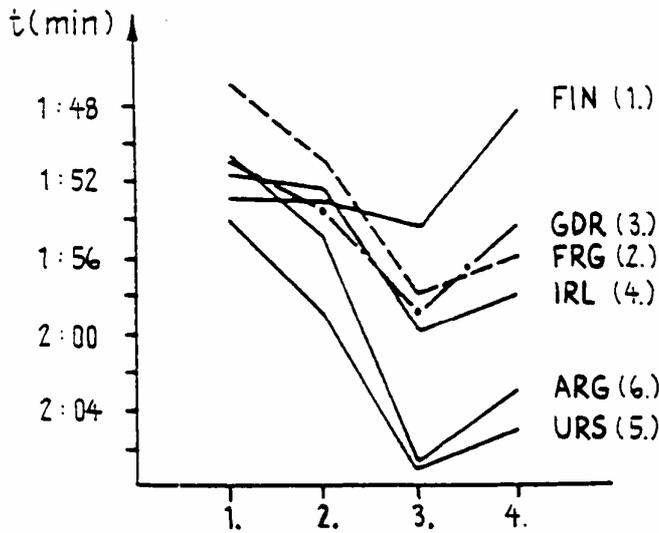
Racing profile of the men's single sculls race in the Olympic final 1976, 1. Karpinnen (FIN), 2. Kolbe (FRG), 3. Dreifker (GDR)

Figure 9
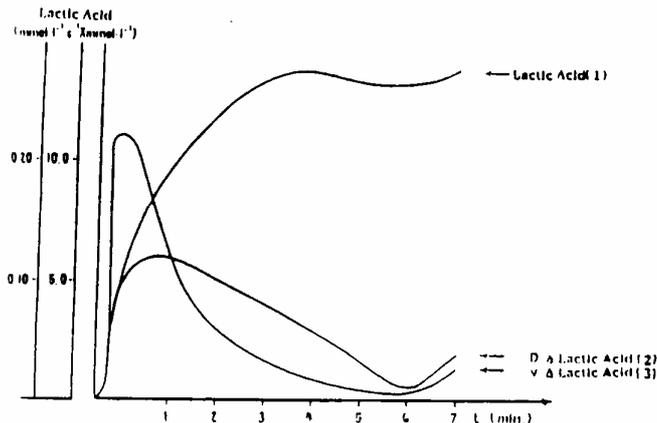
Reaction of lactic acid concentration in the blood and rate of lactic acid build-up under racing load (mean values, simulated racing performance in measuring tank).

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.

MF	Biology E S	Hr (b/min)	L (mmol/l)	KM/min	SR	TA	Predicted Velocity %	Biomechanics Rowing Stroke F/T - Curve	P = F • v	BC
FTF (STF)	an. (aer.) ~P/CH	≥180	≥6.0	n.125m	40	S	110			8 +
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			4 -
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			1 x

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.

116

- 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.

References

1.   Bergström, I.: Muscle electrolytes in man. Scand. J. Clin. Lab. Invest., Suppl. 68 (1962).

2.   Brzank, K.D., K.S. Pieper: Die Fasertypen im menschlichen Skelettmuskel - Basis für funktionalle Variabilität und energetische Effektivität in der Arbeitsweise des Muskels. Med. Sport, Berlin 25 (1985), 129-133.

3.   di Pampero, P.E.: Anaerobic Capacity and Power. In: Shephard, R.J. (Editor): Frontiers of fitness. Springfield, Illinois, 1971 and Med. Sport, Berlin 13 (1973), 1-13.

4.   Hagerman, F.C., M.C. Connors, J.A. Gult, G.R. Hagerman, W.J. Polinski: Energy expenditure during simulated rowing. J. Appl. Physiol. Respirat. Environ. Exercise Physiol. 45 (1978), 87-93.

5.   Hagerman, F.C., J.E. Falkel: Defining the Energy Systems. American Rowing 18, 5 (1986), 36-39.

6.   Ikai, M.: Trainings of Muscle Strength and Power in Athletes. Brit. J. Sports Med. 7 (1973), 43-47.

7.   Körner, T, P. Schwanitz (Editors): Rudern. Berlin, 1987 (2nd Edition).

8.   Roth, W.: Profil leistungsbestimmender Merkmale und muskelzelluläre Grundlagen der spezifischen Leistungsfähigkeit in der Sportart Rudern. Promotion, E.-M.-Arndt-Universität Greifswald, 1979.

9.   Roth, W., E. Hasart, W. Wolf, B. Pansold: Untersuchungen zur Dynamik der Energiebereitstellung während maximaler Mittelzeitausdauerbelastung. Med. Sport, Berlin 23 (1983), 107-111.

10.   Roth, W.: Bedeutung der energieliefernden Systeme (Energiekomponenten) für die Leistungsrealisierung von Wettkampf - und Trainingsbelastungen und ihre Beziehung zu ausgewählten leistungsbeschreibenden Parametern. In: Schriftenreihe des FKS Leipzig: Biomechanik in Ausdauer sportarten, Leipzig, 1986, 1-66.

11.   Roth, W., P. Schwanitz, P. Pas: Zum Einfluss definierter Kraft-Zeit-Verläufe im Training auf die muskelzelluläre Anpassung. Med. sport, Berlin 27 (1987), 166-169.

12.   Schwanitz, P.: Ruderspezifische Systembetrachtung und Analyse der Veränderungen rudertechnischer Parameter in drei Geschwindigkeitsstufen. Promotion, Humboldt-Universität zu Berlin, 1975.

13.   Schwanitz, P.: Biomechanische Untersuchungen ruderspezifischer Bewegungsstrukturen in den die Prognose einschließenden Belastungsbereichen des speziellen Trainings. Promotion, Humboldt-Universität zu Berlin, 1987.

14.   Schwanitz, P.: Grundorientierungen für die Ruderleistungs-und Fertigkeitsentwicklung 1991-1992 und Pognosekennziffern, Internes Material der Kooperationsforschung Rudern, Berlin, 1990.

15.   Secher, N.H.: The physiology of rowing. J. Sports Sci. 1 (1983), 23-53.

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