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.

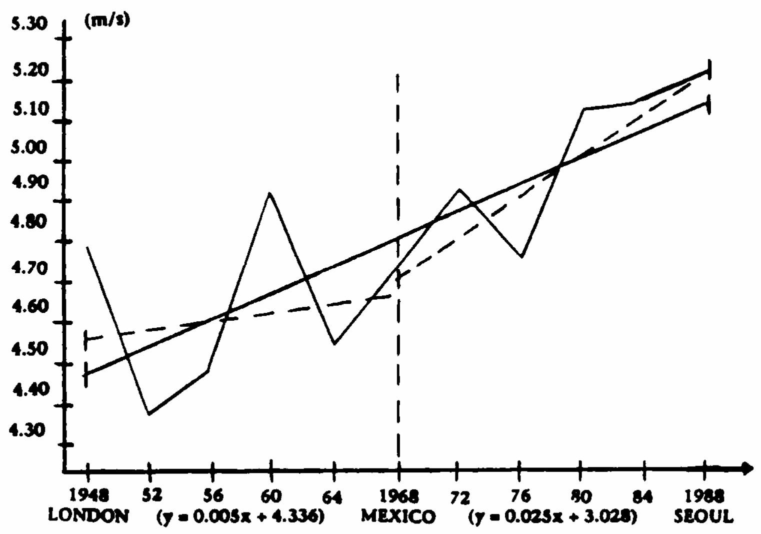
Question 1: How has race performance (boat speed, racing times) developed?

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 necessary at given stroke rate	1992	-3	-5	-3
	1996	-4	-4	-3
Extra distance needed per stroke (cm)	1992	12	18	15
	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

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