Rowing Biomechanics: Technology and Technique

Contents

1. Introduction

I met rowing biomechanics for the first time when I was junior rower in 70-ties. A small men with big suitcase arrived to our training camp. He spent half a day with our boat and then we rowed with a thick cable, which hanged from a big fishing rod installed on the speedboat. I was a shocked when I saw my force curve for the first time in my life and when the man explained me my good things and mistakes. It is hard to say what was the reason, but we won FISA world junior championship that year.

A couple of years after that I was already in National squad and I've seen opposite example of implementing of rowing biomechanics. One day a big truck and a dozen of people arrived to our training camp. They spent half a day unloading the truck and more than a week crowding around the boat and walking between the boat and a room with big boxes, which were the first computers I've ever seen. We rowed a lot with heavy gear on the boat, but we didn't have any feedback during that camp. Those people visited us again a couple of times. Finally, they gave us some information, but it was so controversial that they even couldn't explain it. After that I said to myself that I hate sport science at all and rowing biomechanics in particular. But it appeared to be my destiny to spend my life with the rowing biomechanics trying to prove that it is useful and to find out how to use it in the best way.

How can sport science and biomechanics specifically help athletes and coaches achieve their best performance? What are the components and structure of sport science? How can we make it work more efficient? To answer these questions a methodological model of sport science will be defined. It has three main components (or levels): MEASUREMENT, ANALYSIS AND SYNTHESIS.

- MEASUREMENT is a basic component. It produces information and includes the selection and development of equipment, methods of data acquisition, processing, storage and visualization.

- ANALYSIS is a secondary component. It produces knowledge by collecting and studying the information from the measurement level and utilizing the knowledge of neighboring sciences.
- SYNTHESIS produces the expertise or know-how, i.e. in our case, the system of tools and methods, which are used for the rowing technique improvement.

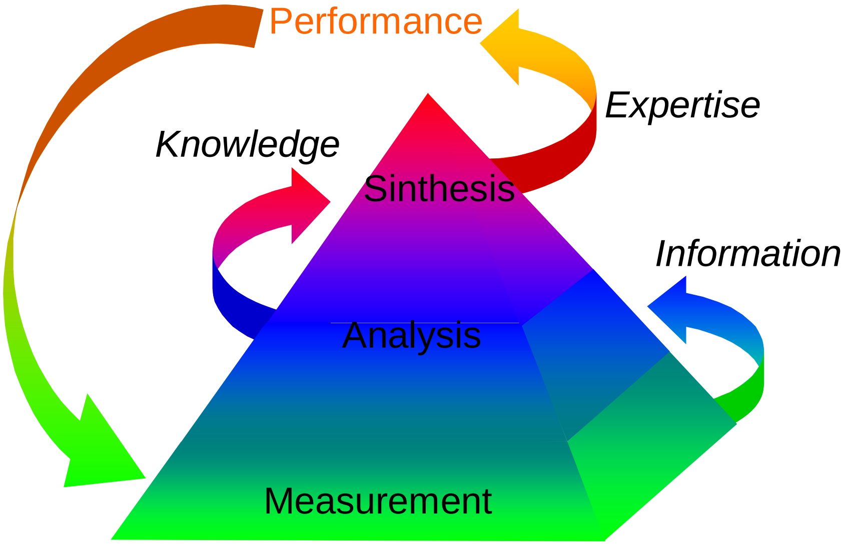


Figure 1. Methodological "Pyramid model" of applied science.

All three components are presented in the "Pyramid Model" to illustrate its structure (Figure 1), which can be useful not only for rowing biomechanics, but for any other applied science for this matter. Here we will try to describe the present and the future of the rowing biomechanics following the structure of the Pyramid Model.

2. Biomechanical measurements

Biomechanical measurements can be classified in categories of their mechanical area (kinematics, kinetics, and hydrodynamics) or their applied methods (contact and non-contact). Kinematical parameters in rowing (angle, velocity, acceleration) can be measured using both contact and non-contact methods, while kinetic parameters (force, momentum) can be better measured via contact methods.

The contact methods employ different sorts of transducers, which are placed at the measured object. Telemetry systems and data logger are used in rowing to collect the data acquired with transducers. Contact methods usually require significant time for setting-up and can irritate rowers, but the data processing is much quicker and the data is more accurate.

Non-contact methods usually use cine or video imaging and image digitizing for data acquisition. Also, radar guns, light gates and GPS systems can be used for measurements of the position and velocity of an object. Non-contact methods are usually the only way to acquire data during competitions, but they require more complicated and time-consuming data processing.

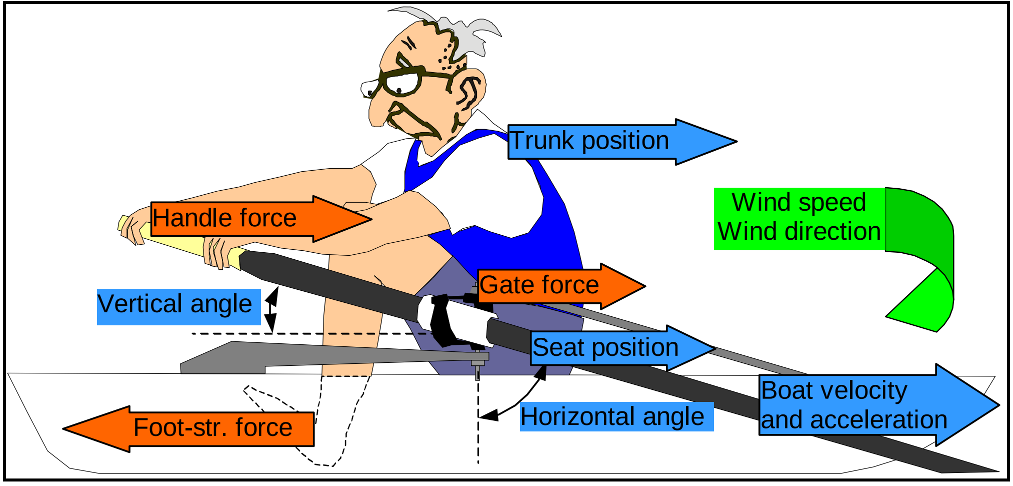


Figure 2. Biomechanical parameters measured in rowing.

Figure 2 represents the main kinematical (blue fill), kinetical (red) and environmental parameters (green) measured in rowing. Next, these parameters will be briefly discussed.

2.1. Rowing kinematics

2.1.1. Oar angle

Since the horizontal oar angle is used to define the phases of the rowing stroke, the oar angle will be studied first. (Figure 3, b). Two different coordinate systems of the oar angle are used in literature: the first one defines zero degree at the perpendicular position of the oar relative to the boat axis (Nolte, 1985, Dal-Monte and Komor, 1989) and the second one identifies zero degree when the oar is parallel to the boat axis (Cameron, 1967, Zatsiorsky and Yakunin, 1991). In this paper, the first coordinate system will be used. In this system, the oar angle at the catch has negative and at the release positive value. We define the start of the stroke cycle at the moment when oar is at zero degrees during recovery (perpendicular position). The catch angle is defined as the minimal one and release angle is the maximal one.

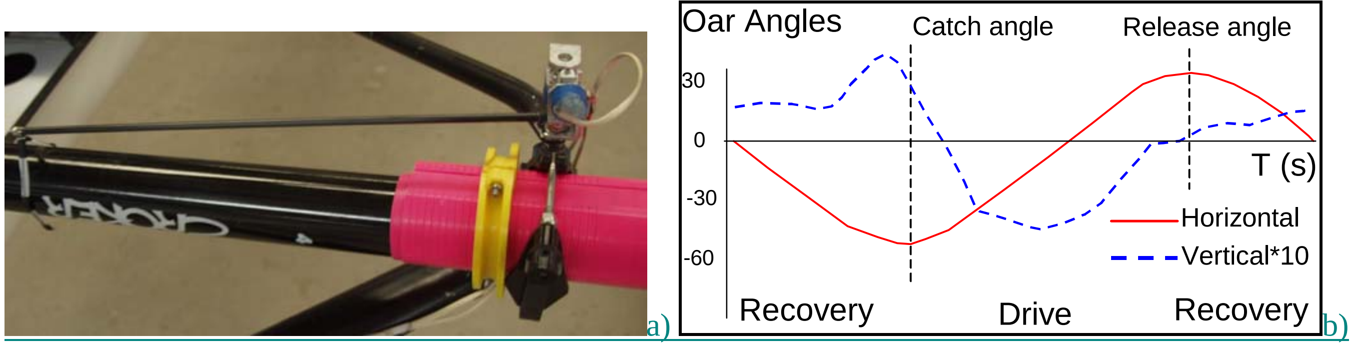


Figure 3. Transducers for the measurement of the horizontal and vertical oar angles (a) and their graphs with phases of stroke cycle (b).

While the horizontal oar angle is one of the parameters that is most traditionally measured in rowing, we recently introduced the measurement of vertical oar angles. The device for the measurement of both angles (Figure 3, a) consists of two servo potentiometers. The first potentiometer measures the horizontal angle and is mounted on top of the pin. The second potentiometer is attached to the first one and measures the vertical angle. It reads zero degree when center of the blade is at the water level. A light stiff rod is mounted on the body of the second potentiometer that attaches to the oar shaft.

2.1.2. Boat velocity and acceleration

Boat speed can be measured with different sorts of impellers and inductive sensors. For this paper, we used an impeller from the Nielsen-Kellerman's SpeedCoach $^{\text{TM}}$ and a custom made electromagnetic pick-up gauge. The boat acceleration along the horizontal axis is measured using a piezoresistive accelerometer.

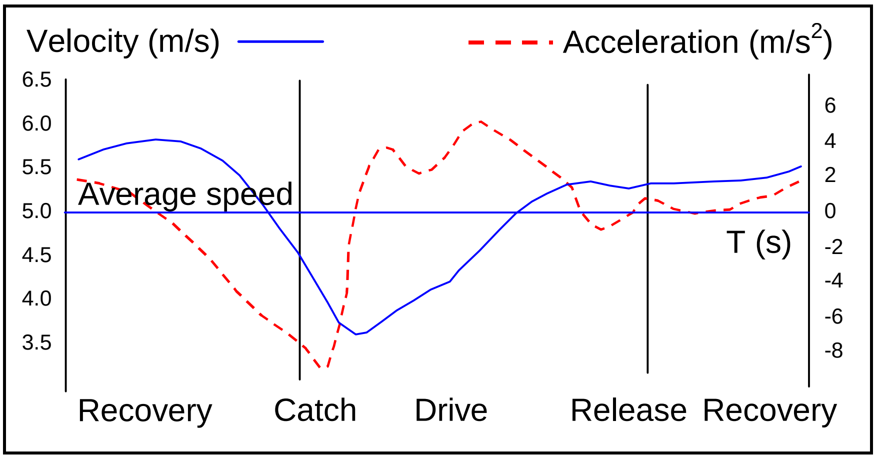


Figure 4. Typical curves of boat velocity (solid line) and acceleration (dashed) during stroke cycle.

The following parameters can be derived from the curves of boat speed and acceleration (Figure 4):

- Average boat speed (a resultant parameter directly connected with performance),
- Minimal and maximal values of the speed and acceleration,
- Standard deviation of the boat speed and its coefficient of variation during the stroke cycle (ratio of the standard deviation to the average value).

2.1.3. Seat and top of the trunk displacements

The linear position of the seat and the top of the trunk relative to the boat are measured using a device, which consists of a multi-turn potentiometer, a radial spring, a pulley and a low stretchable fishing line. The device is mounted on the boat and can be directly connected to the point of interest (e.g. to the seat) or through a pulley, mounted onto a special mast at the same height as the point of interest. (Figure 5, a, b).

Linear velocities of the legs (seat speed) and the trunk movement (difference between top of the trunk and seat speed) are calculated using these position data. The joint of *Sternum* and *Clavicle* was used for the trunk movement. The velocity of the arms is determined by subtracting the velocity of the trunk from the linear speed of the handle, which was calculated using the angular velocity and the inboard radius of the oar.

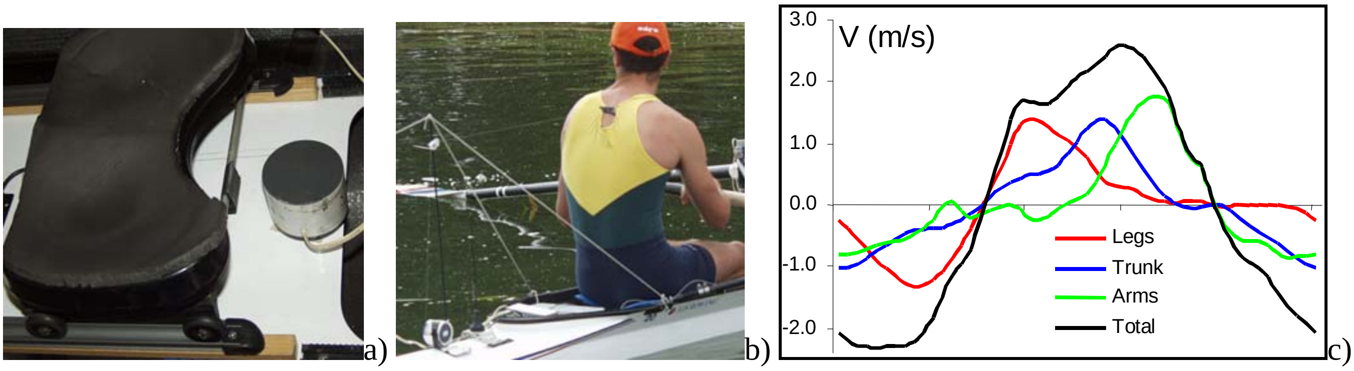


Figure 5. Devices for the measurement of displacements of the seat (a) and top of the trunk (b) and curves of the handle, legs, trunk and arms speeds (c).

The curves of the main three body segments (Figure 5, c) are very useful for defining different rowing styles (Kleshnev, 2000).

2.1.4. Other kinematical parameters

Progress of technology allows us to measure a number of other kinematical parameters such as the 3D acceleration and orientation of the boat using micro-gyroscopes (Wagner et al., 1993, Loschner et al, 2000), a very accurate position of the boat can be obtained using GPS systems, etc. These measurements can be used for research purposes and for improving of rowing technique.

2.2. Rowing kinetics

Kinetics studies the forces, which can be defined as the “internal cause of any motion”. Measurement of the forces has more than a century long history in rowing (Dal-Monte and Komor, 1989). Force production is tightly correlated with rowing power and average boat speed and, therefore, can bring invaluable information about the strengths and weaknesses of each rower in the crew (Secher, 1993). The forces applied by rower can be measured at three points: the handle, the gate and the foot-stretcher. Each method has its own positive and negative issues.

2.2.1. Handle and gate forces

The handle force can be determined measuring the oar shaft bend by means of precise inductive (Gerber et al., 1987) or strain-gauged transducers (Figure 6, a). The disadvantage of this method is its dependence on the characteristics of the oar shaft that require calibration for each particular oar. Furthermore, using the oar bend we in fact measure the moment of the handle force (torque M) and a magnitude of the force can be derived if we know the length of the lever of its application. However, the point of the handle force application is not certain, especially in sweep rowing, where the rower can pull more with the inside or the outside arm. This can create problems if we want to know the handle force (Fh) itself, but it produces more reliable values of rowing power (Ph) applied to the handle, because:

$$Ph = w * M \qquad (1)$$

,where w is the oar angular velocity. You can see here that the handle power does not depend on the inboard and, therefore, not on the point of the force application.

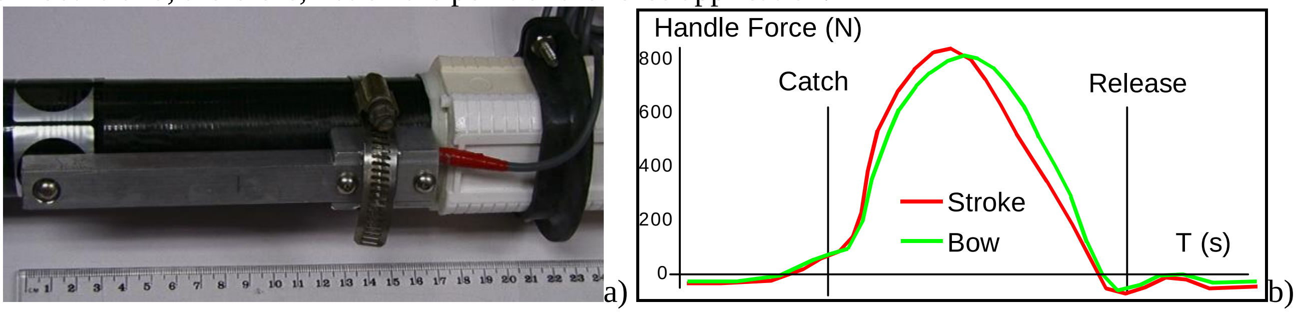


Figure 6. Transducer for handle force measurement (a) and data example for a pair (b).

The gate force can be measured using different sorts of instrumented gates (Nolte, 1985). Up to three force components (forward, lateral and vertical) can be measured relative to the boat (Smith and Loschner, 2000) or to the oar (in our work). This method produces more accurate and informative data on the force applied to the boat, which can be useful for a precise calculation of the net propulsive force for each rower. However, calculation of the handle power (P) from the gate force (Fg), depends on the inboard and outboard ($Rout$) lever and, consequently, on the knowledge of the points of the handle and blade forces applications:

$$P = w * Rin * Fh = w * Fg * (Rin * Rout) / (Rin + Rout) \qquad (2)$$

The outboard lever $Rout$ in this equation changes during the drive, since the point of application of the blade force resultant moves on the blade (Nolte 1985, 163, our unpublished data). Therefore, the gate force measurement does not allow an accurate estimation of the power production of the rower.

2.2.2. Foot-stretcher force

The force applied to the foot-stretcher (Ff) is a valuable parameter for rowing technique and performance evaluation. The most important component of the foot-stretcher force is directed along the boat longitudinal axis.

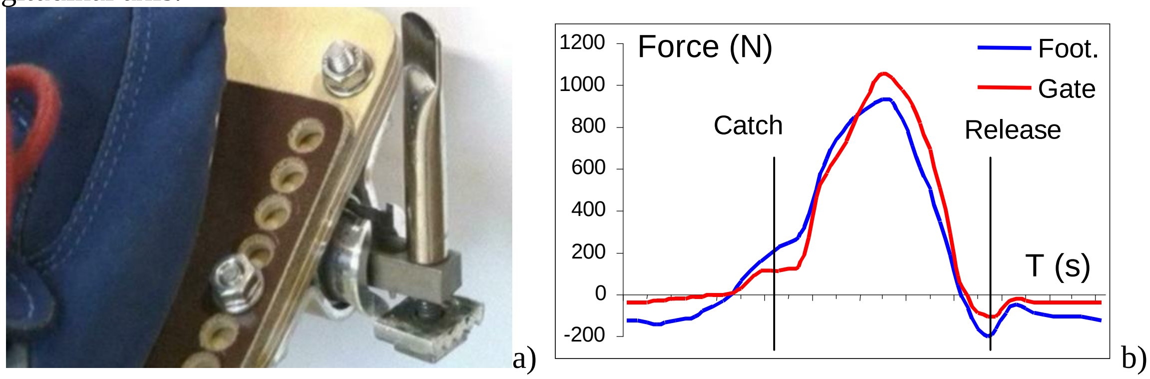


Figure 7. Foot-stretcher force transducer (a) and data example (b). Footstretcher force is positive towards the stern, gate force is positive towards the bow of the boat.

The measurement of the foot-stretcher force is difficult due to the limited space between the foot-stretcher and the boat fittings, together with the importance of its position, height and angle adjustment. In our work we use stain-gauged inserts in the foot-stretcher tube (Figure 7, a) to measure the left and right forces separately. A bottom fitting has a linear bearing for preventing of the force losses through it.

Having the components of the foot-stretcher and gate forces directed along the boat axis (x-axis), we can derive a net propulsive force for each rower (***Fnet = Fg-Ff;*** Figure 8, a) and total propulsive force, which effects acceleration and speed of the boat.

Another value of the foot-stretcher force can be found in a more precise calculation of the rower's power production (Figure 8, b). We have found (Kleshnev, 2000) that due to the non-steady movement of the boat the sum of the powers applied to the handle and foot-stretcher are different (16.8% higher) from the power derived via the traditional method (2.2.1).

The instantaneous handle power (Ph) was derived as:

$$Ph = Fh * Vh * \cos(j) \qquad (3)$$

where Fh is resulting handle force calculated as a vector sum of the normal and axial forces, Vh is resulting handle velocity calculated as a vector sum of the linear handle velocity relative to the boat and boat velocity, j is the angle between Fh and Vh vectors.

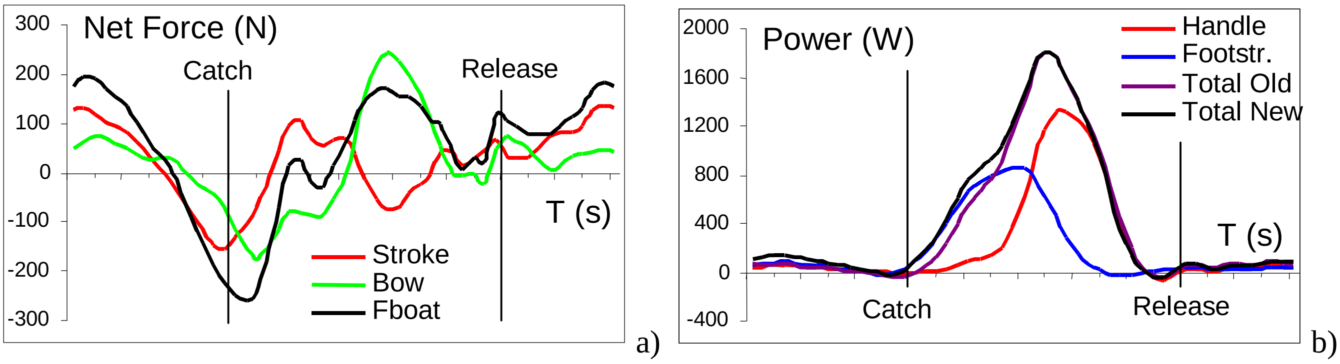
The footstretcher power (Pf) was calculated as a scalar product of the footstretcher force (Ff) and boat velocity Vb.

$$Pf = Ff * Vb \qquad (4)$$

The total power exerted by a rower was derived as a sum of Ph and Pf:

$$P = Ph + Pf \qquad (5)$$

Around 53% of total rowing power was applied at the oar handle (Ph) while the other 47% was applied at the foot-stretcher (Pf).



a) b)

Figure 8. Net propulsive forces in men's' pair (a) and power components of the stroke rower (b).

2.2.3. *Other kinetic parameters*

Some other kinetic parameters can be measured and used for the rowing technique assessment:

- The vertical seat force can reveal a lifting of the athlete's body weight, which is an important feature of the rowing technique;
- Blade force can be measured directly, and provide information about the center of pressure on the blade. This may assist in fine-tuning the gearing and the selection of blade shape;
- 3D forces at the foot-stretcher can help to investigate the fine dynamics of the rowing technique.

2.3. Environmental parameters

Water temperature, wind speed and direction affect the boat speed and rowing technique. In our work we measure the wind speed and direction continuously via a micro-turbine and vane, which are mounted on the shaft of the potentiometer and placed on the boat canvas. The water temperature is measured once during the testing session.

2.4. Non-contact measurements (Imaging technologies)

Usage of the imaging technologies (usually referred to "video analysis") is not an easy task in rowing because the movement is performed over a long distance and cannot be fitted into a laboratory space. Standard camera set-up and calibration routines cannot be used and all digitizing process has to be done manually, making this type of analysis very time consuming. Therefore, quantitative video measurements and analysis in rowing are generally restricted to research purposes (e.g.: Martin and

Bernfield, 1980), and seldom used in day-to-day training. Further development of automatic image recognition and other related technologies could bring more regular usage of quantitative video analysis in rowing.

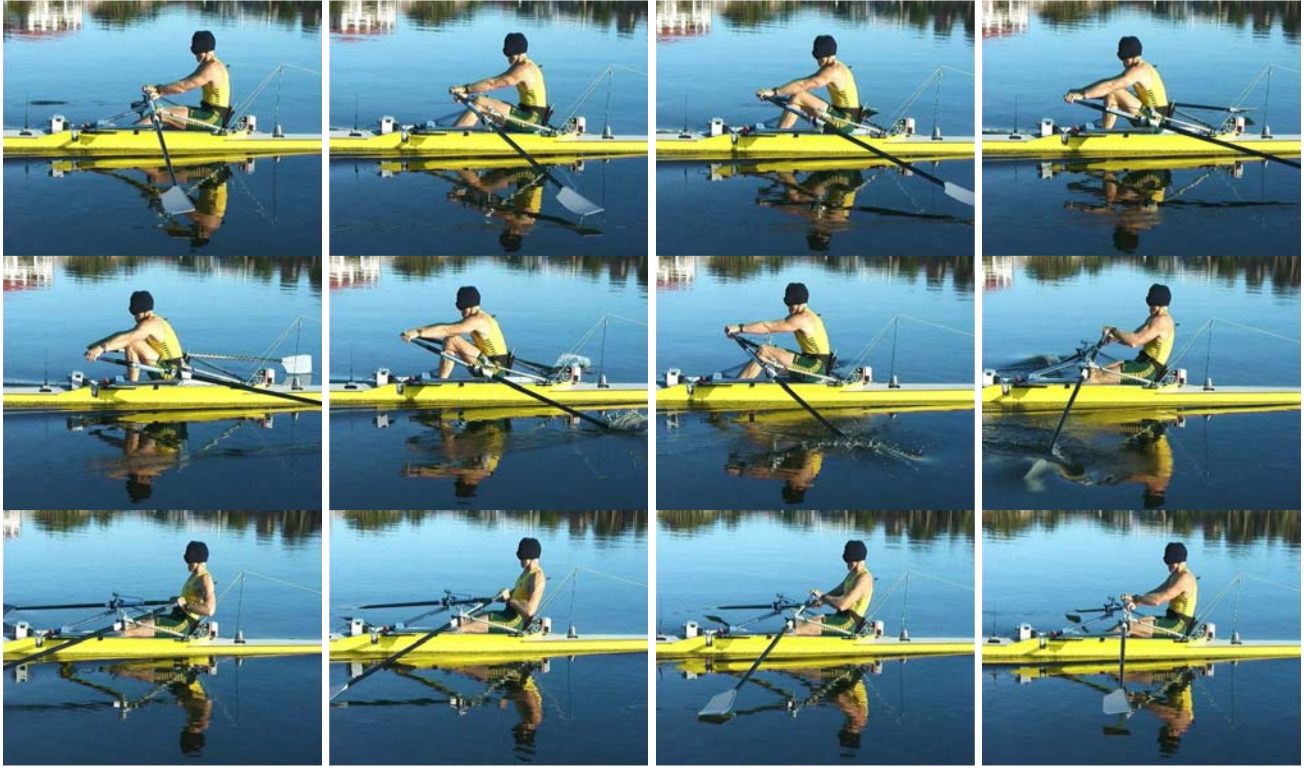


Figure 9. Example of rowing video-gram. Testing session with telemetry and visual immediate feedback.

Qualitative video analysis can be a very useful tool in rowing. Usually, video footage is shot from a speedboat and discussed later together with coaches and rowers. The latest technologies could provide immediate visual feedback for athletes and coaches (see 4.2 below).

Another useful way of visual analysis is capturing video into computer, which is fairly easy with the latest technologies. Captured video files can be replayed and analyzed on the PC display, printed out on a paper as video-grams (Figure 9) and stored in video databases for future reviewing.

3. Biomechanical analysis

The term “analysis” can be defined as the process of converting information into knowledge. In this section we will discuss data processing methods (the basis of any analysis) and three sorts of analysis: statistical analysis, biomechanical modeling, performance (race) analysis.

3.1. Data processing

Rowing is the cyclic sport. This means that athletes perform a number of stroke cycles during the event (around 250 during a 2000m race). While modern computer equipment makes it technically possible to process and output such amount of information, it would be practically meaningless for rowers and coaches. Therefore, the main task of data processing is its conversion into a form, which represents one typical stroke cycle. We call this process normalization (Kleshnev, 1995). Figure 10 represents telemetry software structure and illustrates data normalization process.

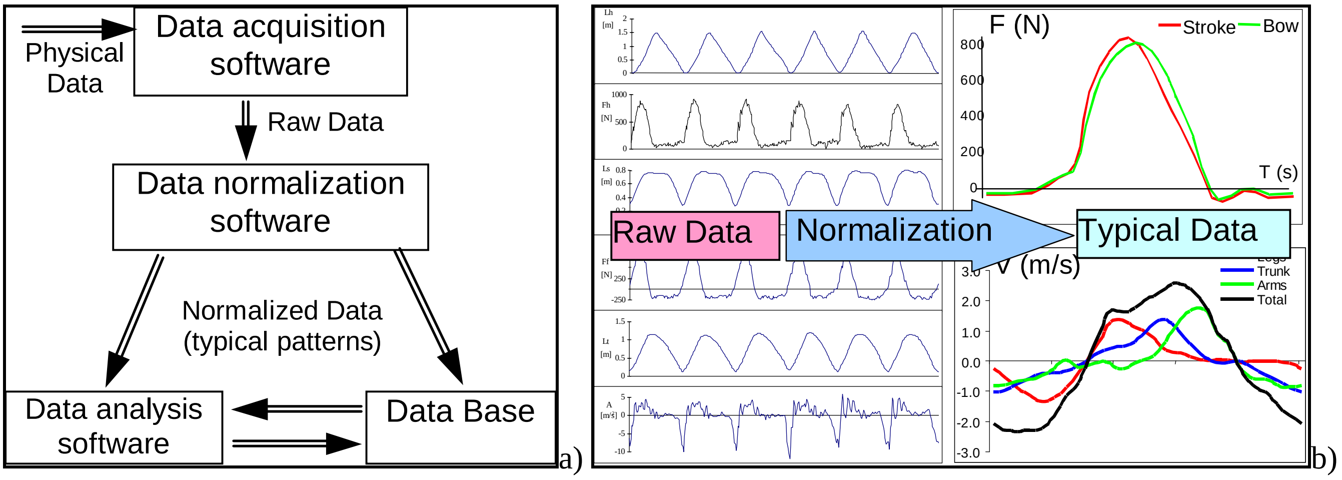


Figure 10. Block-schemes of rowing software (a) and data processing (b).

The main features of our normalization algorithm are:

- All data is normalized relative to the average cycle time over the sampling period (cycles deviating more than a certain percentage from the time of the average cycle are rejected).
- The stroke rower's time of the cycle start (see 2.1.1) is chosen as the trigger for the whole crew.
- Each set of normalized data was then calculated to 50 data points. This amount of points per stoke cycle was chosen as a compromise between data accuracy and volume.
- The average value and its standard deviation are derived for each point of each array.

This means that we derived a normalized set of 50 data points for each measurement (oar angle, gate force etc.) representing the average stroke characteristics. We have checked the validity of the algorithm by means of a comparison of the extreme values (such as catch and release angles, max. force, work and power, etc.), which were calculated using normalized data with ones taken as an average from each stroke cycle. The differences were in a range 0.02-0.85%, this is considered satisfactory for a biomechanical analysis in rowing.

Moreover, the software allows the derivation of selected parameters for each stroke (Figure 11). This is useful for an analysis of the rowers' performance during the race.

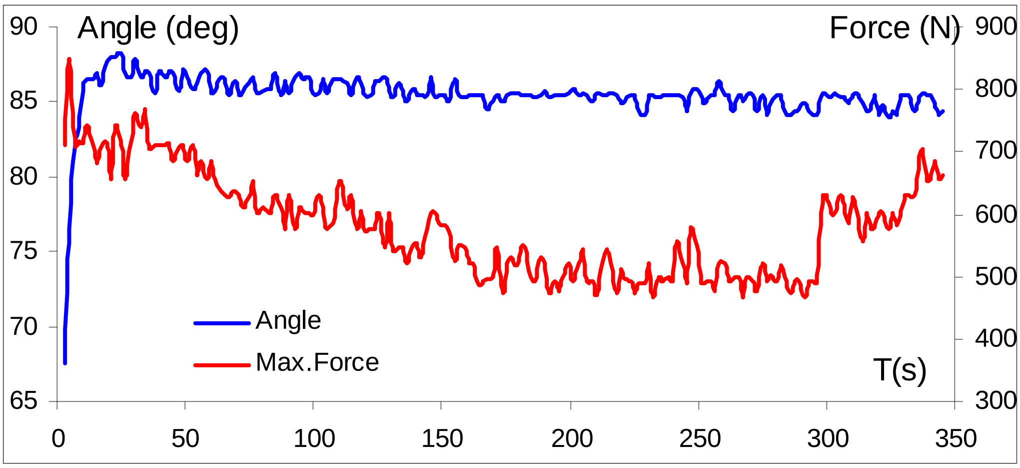


Figure 11. Graphs of the total oar angle and maximum force over a complete rowing race.

3.2. Statistical analysis and evaluation

Having large samples of biomechanical information stored in a database, it is easy to perform a statistical analysis with the purpose of assessing each rower relative to a similar group of rowers. We use MS Access™ database for data storage. After three years of testing the database has more than 400 session records, 1800 boat-samples and 6000 rower-samples.

Figure 12 shows an example of a table for the evaluation of the biomechanical parameters. The values in the table are based on the average (Average = A = middle column for each parameter) and standard deviation SD in each rower's group. The "very low" interval of each parameter is chosen in a range below A–2SD, "Low" is between A-2SD and A-SD, "High" is between A+SD and A+2SD, and "Very high" is above A+2SD.

A more sophisticated statistical analysis can be done with the purposes of correlating biomechanical parameters and assessing their differences in groups of athletes with various skill level, etc. For example, it was found that the blade propulsive efficiency correlates with the shape of the force curve (our unpublished data), or that higher qualified rowers have higher percentage of the trunk power (Kleshnev, 1996).

Rowers' Groups	n	Total Angle (degrees)					Maximal Handle Force (N)				
		Very Low (Less Than)	Low (Less Than)	Average	High (More Than)	Very High (More Than)	Very Low (Less than)	Low (Less than)	Average	High (More than)	Very High (More than)
Men Scull	519	102.8	106.6	110.4	114.2	118.0	593	680	766	853	940
Men Light Scull	161	99.5	103.3	107.1	110.9	114.8	579	636	692	749	805
Men Sweep	1628	84.4	87.8	91.2	94.6	98.0	491	581	671	761	850
Men Light Sweep	808	81.0	84.5	87.9	91.4	94.9	467	528	590	652	714
Women Scull	489	96.7	101.0	105.2	109.4	113.7	394	471	547	624	701
W. Light Scull	739	95.2	99.7	104.2	108.7	113.2	355	416	477	538	599
Women Sweep	1708	80.0	83.5	86.9	90.4	93.8	345	412	479	547	614

Figure 12. Example of one evaluation table of the biomechanical parameters in rowing.

3.3. Biomechanical modeling

Biomechanical modeling is an effective tool in the analysis of rowing technique. A model is obtained via a system of mathematical equations, which describes different components of the biomechanical system and connects them each with others. In rowing we consider the Rower-Boat-Oar (RBO) system. The purposes of the modeling can be the following:

- Prediction of rowing performance (average boat speed) via current biomechanical parameters;
- Determining what combination of biomechanical parameters (stroke rate, angle, force, power) is required for achieving a target boat speed;
- Defining the extremes of the system functioning, i.e. the highest hydrodynamical efficiency, the highest power output;
- Fine tuning the crew and boat set-up.

Biomechanical modeling can be very simple or very sophisticated. Figure 13 shows an example of a very simple modeling of the boat speed and stroke distance (SD) dependencies on the stroke rate. Simple software was developed for this purpose, which inputs results of an on-water step-test (boat speed and SR of three or more pieces with increasing SR), calculates regression equations and outputs their graphs and numerical values. The software could be handy for developing training regimes and assessing of the technique efficiency at different stroke rates.

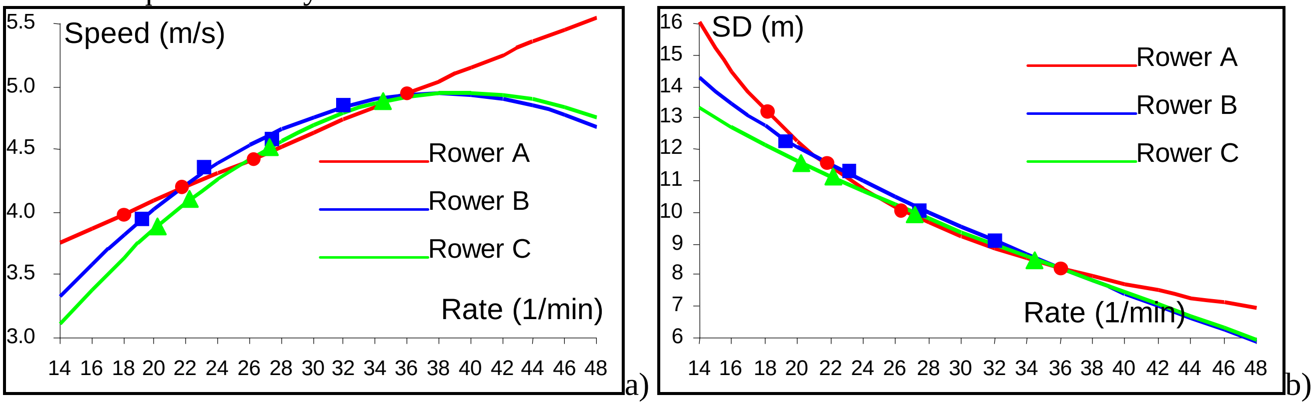


Figure 13. Example of the boat speed (a) and stroke distance (b) relative to the stroke rate modeling.

An example of a more sophisticated modeling is presented in Figure 14. It shows nonlinear regressions of the work per stroke dependence on the rowing angle and the average force in men’s sculling and sweep groups. Note that the shapes of the surfaces are different: Concave in sculling and convex in sweep rowing. This means that longer angles and higher force bring less and less work per stroke in sweep rowing, whereas they are more effective in sculling. This correlates with our previous findings (Kleshnev, 2001, 2) that a larger distance per stroke, which is highly correlated with work per stroke, brings more power and boat speed in sculling, but the stroke rate is more important in sweep rowing.

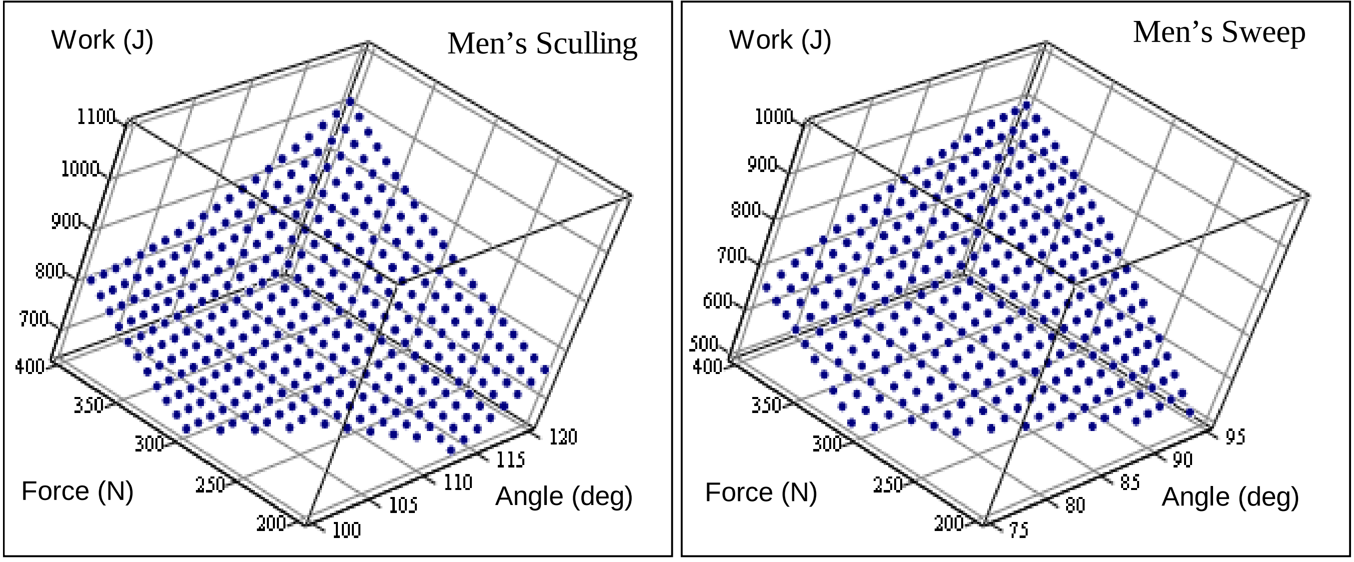


Figure 14. Modeling of work per stroke relative to rowing angle and average force in men’s sculling and sweep rowing.

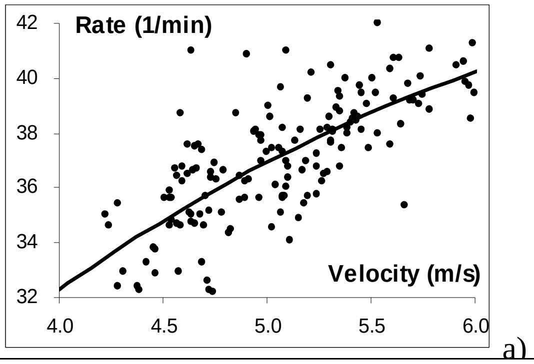
There were a number of attempts undertaken to build a mechanical model of the rower-boat-oar system (Dal-Monte and Komor, 1989, Atkinson, 2000), which can be a useful tool for rowing technique optimization. However, the models lack information about aero-dynamical resistance of the system that does not allow to produce reliable prediction of the boat speed.

3.4. Performance (race) analysis

The measurement and analysis of racing parameters are discussed here separately because of the importance of this information and the special requirements to a data collection process, which must not interfere with the athletes. Therefore, the measured parameters are very basic: split times at each 500 or 250m (sometimes at 100m) and stroke rate (SR) at the same sections of the race.

However, analysis of the race information can be quite sophisticated (Kleshnev, 2001, 1). Different patterns of the race strategy (variation of the boat speed relative to its average value over the race) and tactics (relationship of the boat speed to the other competitors in the same race) can be defined. It was found that the typical race strategy in rowing is described by a fast start and first 500m section (2.5-3.0% faster than average speed), slower second and third 500m sections (1.0-1.5% slower than average speed) and the last 500m with the boat speed equal to the average race speed. Race tactics of the majority of the winners (70%) show their advantage over competitors in the last sections of the race.

The analysis of the racing SR in different boat types shows a very strong correlation with boat speed (Kleshnev, 2001, 2). With the regression equation of the dependence of the SR on boat speed and the “prognostic” times for each boat type, we can derive “prognostic” racing stroke rates (Figure 15).



Boat Type	Rate (1/min)	Boat Type	Rate (1/min)
W1x	35.2	LW2x	36.6
M1x	37.3	LM2x	38.5
W2-	36.2	LM4-	39.8
M2-	38.3	W4x	38.8
W2x	37.0	M4x	40.6
M2x	39.0	W8+	39.5
M4-	40.0	M8+	41.4

Figure 15. Dependence of the stroke rate on the boat speed (a) and "prognostic" stroke rates in each boat type (b).

Boat speed and SR can be used to determine the distance that a boat travels per stroke (DPS). The correlation analysis between the rowers' performance and the SR, DPS (Comment: Shouldn't it be DPS*SR? – otherwise a larger DPS would lead to a smaller value? I mean "SR and DPS", but there is another "and" just before this) showed that races could be won with both higher rate and longer DPS (Kleshnev, 2001, 2). However, a larger percentage of winners, especially in sculling, showed a larger DPS than their competitors.

4. Biomechanical feedback and expertise

The tools and methods for presenting biomechanical information to the rowers and coaches are a very important part of sport science servicing and research. However, excellent measurements and analysis are useless if they are not connected with the coach and rower's understanding of what they should do to improve the performance. Below we will discuss the three main methods or levels of biomechanical feedback, which can be used at the present time and, may be, in a future.

The main trends in the feedback development are: 1) shortening of the delay time between a rower's action and the feedback and, 2) a reduction in the number of components of the feedback loop. Figure 16 illustrates the loops of different levels of feedback.

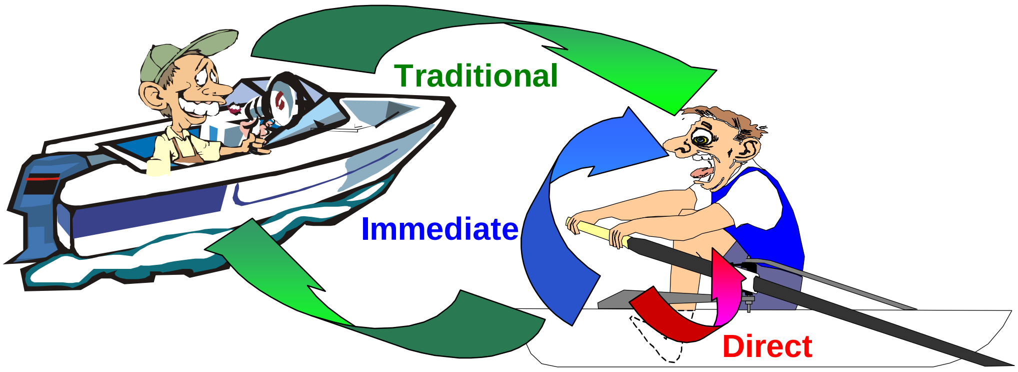


Figure 16. The loops of traditional, immediate and direct feedback in rowing

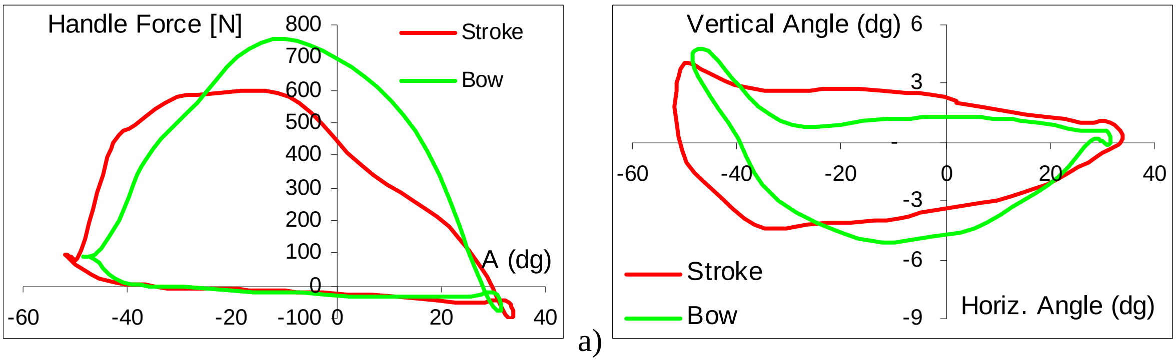
Traditional feedback usually works through the coach and the delay time could be from minutes or hours up to days or weeks. Immediate feedback presents information to an athlete and delay time is in a range of seconds. Direct feedback controls the athlete's muscles directly and the delay time should be in a range of tenths or hundredths of a second.

4.1. Traditional feedback

The main target of traditional feedback is improving the coach's understanding of the biomechanical features of each rower's technique. The information can also be presented to the rowers.

Reports on the testing sessions are usually showed in the form of tables and graphs representing details of the rowing technique. To make a point clearer the X-axis of these graphs can represent horizontal oar angle that helps to connect different parameters with phases of the stroke cycle (Figure 17).

The curves on chart 17 b can be explained as the course of the center of the blade relative to the water level, which is at zero vertical angle.



a) b)

Figure 17. Graphs of the handle force (a) and vertical oar angle (b) plotted relative to the horizontal oar angle.

A useful method of feedback is to overlay biomechanical parameters and video footage. This helps to connect a visual image of the rower with internal biomechanical parameters. Computer animation methods can also be used for an easier understanding of the interaction of different parameters.

4.2. Methods of immediate feedback

The methods of immediate feedback can be classified in three groups according to the sort of information delivered: numbers, graphs or images. Numerical feedback on stroke rate and boat speed can be implemented with such devices as the Nielsen-Kellerman Speed-Coach™. More detailed information on biomechanical parameters (force, angle) in both numerical and graphical form can be presented by a computer display during ergometer rowing (Hawkins, 2000) and portable monitors mounted on the foot-stretcher.

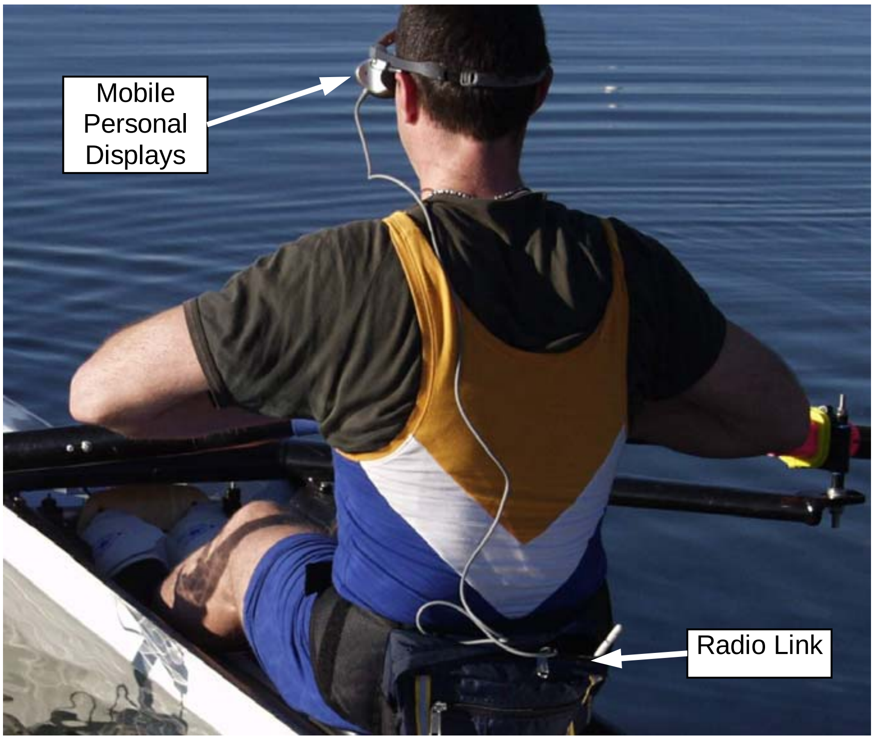


Figure 18. Using of the visual immediate feedback system in rowing.

The next step in immediate feedback development was done using Mobile Personal Displays (MPD, Figure 18). They can provide all three sorts of information in an easily accessible way for the rowers. The simplest method is based on a mirror principle and consists of delivering a visual image of the rower in real time by means of a common video camera and radio link. More sophisticated methods employ computerized telemetry systems, which acquire biomechanical data, process it and deliver it to the rower’s eyes in real time (display of data and/or video pictures on mini-monitor). An important part of this method is a clear understanding by the rower of the information being provided. This must be done in conjunction with a coach and based on traditional methods of feedback. Both traditional and immediate feedback methods can be combined. For example, the coach can make comments on the rower's technique during an immediate feedback session.

4.3. The future: direct movement control

Logically, the next step of biomechanical feedback is bypassing the movement control centers in the athletes' brain and directly controlling of their muscles. This can be done in very simple form. For example, in the Soviet Union during the early 80s the author witnessed experiments involving electro-stimulation of the leg muscles during rowing (publications are not available). *Quadriceps femoris* were stimulated at a specified moment in the legs drive and the trigger signal was taken from the seat position sensor. However, the experiments were not based on sufficient measurement and analysis of rowing biomechanics and failed to achieve their main goal – reliable improvement of the rowers' performance.

Current technologies allow us to control the motor area in the human brain, which, in conjunction with micro-sensors and microprocessors, make a real time optimization of the sporting technique possible (according to environmental parameters, athletes' conditions and fatigue, competitors tactics, etc). Similar technologies were already implemented in Formula-1 car races, but were banned. While using these technologies will probably be considered as "biomechanical doping" in sport competitions, some of them may be used during training. Biomechanics can meet in this area the same ethical and legal problems, which are already faced in biochemistry and other sport sciences.

5. Conclusions

Rowing biomechanics as an applied science works together with other sciences. On the biological side it collaborates with sport physiology (e.g.: in defining of rowing efficiency and methods of muscles training) and psychology (in improvement of the feedback efficiency and methods of motor control). On the technical side it utilizes the latest microelectronics technologies for measurement and analysis, applied physics and mathematics. The third side of rowing biomechanics is their practical implementation, where it deals with rowing coaches, their training methods and "coaching science", rowers with their behavior and culture, and with the entire rowing community including their rules and traditions.

These three neighboring areas of rowing biomechanics can be easily fitted to our Pyramid model, where the technology area is connected with Measurement level, the biological side with the Analysis and practical the rowing with the Feedback. This methodological set-up puts practical aspects on the top of the pyramid and makes them the most important part of the system, which requirements should be considered at the earliest stages of any research and development project.

6. References

1. Atkinson W. (2000) Modeling the dynamics of rowing. www.atkinsopht.com/rowrpage.htm
2. Cameron A. (1967). Some mechanical aspects of rowing. In: Williams J., Scott A., Rowing a scientific approach. Kaye & Ward Ltd. 64-80.
3. Dal-Monte A., Komor A. (1989). Rowing and sculling mechanics. In: Vaughan, C.L., Biomechanics of sport, Boca Raton, Fla., CRC Press, 53 119.
4. Hawkins D. (2000) A new instrumentation system for training rowers. Journal of Biomechanics, 33, 241-245.
5. Gerber H., Jenny H., Sudan J., Stuessi E. (1987) Biomechanical performance analysis in rowing with a new measuring system. In: Jonsson B., ed., Biomechanics X-B, Human Kinetics Pub., 721-724
6. Kleshnev V. (1995) The Application of Computer Technologies to Management of Special Training in Cyclic Sports
7. Kleshnev V. (1996) The effects of stroke rate on biomechanical parameters and efficiency of rowing. XIV Symposium ISBS, Proceedings, Lisboa, Portugal p. 321-325.
8. Kleshnev, V. (1997) The determination of total power during on-water rowing. XVI Congress of ISB, Tokio, Book of Abstracts.
9. Kleshnev, V. (2000) Power in rowing. Proc. Of XVIII Congress of ISBS, Hong Kong, Vol.II, 662-666.

10. Kleshnev V. (2001) Racing strategy in rowing during Sydney Olympic Games. Australian Rowing 24(1), April 2001, 20-23.
11. Kleshnev V. (2001) Stroke rate vs. distance in rowing during the Sydney Olympics 24(2), August 2001, 18-22.
12. Martin T. P., Bernfield Y. S. (1980) Effect of stroke rate on velocity of a rowing shell. Medicine and Science in Sports and Exercise 12(4), 1980, 250 256.
13. Nolte V. (1985) Die Effektivität des Ruderschlages. Bartels & Wernitz.
14. Ozkaya N., Nordin M. (1991) Fundamentals of Biomechanics. Van Nostrand Reinhold, New York. Pp.396.
15. Secher N. (1993) Physiological and biomechanical aspects of rowing. Sports Medicine, 15 (1), 24-42.
16. Smith R., Loschner C. (2000) Net Power Production & Performance at Different Stroke Rates & Abilities During Sculling. http://www.education.ed.ac.uk/rowing/papers/sl.html
17. Wagner J., Bartmus U., de Marees H. (1993) Three Axes Gyro System Quantifying the Specific Balance of Rowing. International Journal of Sports Medicine,14,35-38
18. Zatsiorsky, V.M., Yakunin, N. (1991). Mechanics and biomechanics of rowing: a review. International journal of sport biomechanics, 7, 229-281.