Rowing technique improvement using biomechanical testing

Contents

1. Introduction

Currently, biomechanical methods became important part of rowers' training. Biomechanics can bring invaluable information for coaches, improve their insight and increase efficiency of rowing technique. Providing biomechanical feedback to athletes can accelerate development of efficient rowing technique and dramatically increase performance.
To achieve these goals, biomechanical methods have to follow certain standards, such as:

- Validity of the measurements. We need to know exactly WHAT we measure and WHAT FOR we need this data;
- Accuracy and repeatability. The margins between world's medallists are measured in 0.01%. What is the benefit of taking less accurate measurements?
- The methods must be as unobtrusive as possible, otherwise we will measure not a real rowing, but "obstructed rowing";
- Analysis methods must follow common definitions of the variables and derivative parameters. This will make them comparable and meaningful. We will be able to evaluate rowing technique better and use all available knowledge;
- Feedback information must be clear, meaningful, flexible, it should suit different coaches' needs. Data format should allow effective storage for future comparison.

Rowing technique can be improved using biomechanical testing at various levels, which defer by depth, complexity and time consumption.

2. Level 1. Basic quantitative assessment

At the first level only basic variables of rowing technique are assessed. To achieve a target boat speed, rowers need to produce certain power, which is a combination of three main variables:

- Stroke rate.
- Drive length;
- Force application;

Whale the stroke rate can be easily measured with a stopwatch, the drive length (rowing angles) and force application can be measured accurately only by special biomechanics equipment. Usually, the main quantitative variables are compared with some target values, so called "Biomechanical Gold Standards" (see Table 4 in the appendices) and presented like Table 1 below:

Table 1. Evaluation of the results of Biomechanical testing

Positive points are in blue, Negative points are in red

	LW2x	03/03/11	Name:	Bow Rower
	Criteria	**Target**	**Actual Data**	**%% Difference**
1	Boat speed (Time at 2000m)	06:47.0	06:45.2	0.4%
2	Stroke Rate (1/min)	36.0	34.8	-3.4%
3	Drive Time (s)	0.93	0.93	-0.3%
4	Rhythm (%)	55.0%	53.8%	-2.2%
5	Catch Angle (deg)	-63.0	-64.4	2.3%
6	Release Finish (deg)	43.0	40.7	-5.4%
7	Total Angle (deg)	106.0	105.1	-0.8%
8	Maximal Force (N)	550.0	470.8	-14.4%
9	Average Force (N)	290.0	268.5	-7.4%
10	Rowing Power (W)	350	282	-19.4%

The basic biomechanical variables can be measured quite often (monitored), which could be related to other parts of rower's training: strength, speed and endurance work.
When measured in the race environment, the main biomechanical variables can provide important information about effect of fatigue on rowers' performance and help achieving a better coordinated race strategy in a crew.

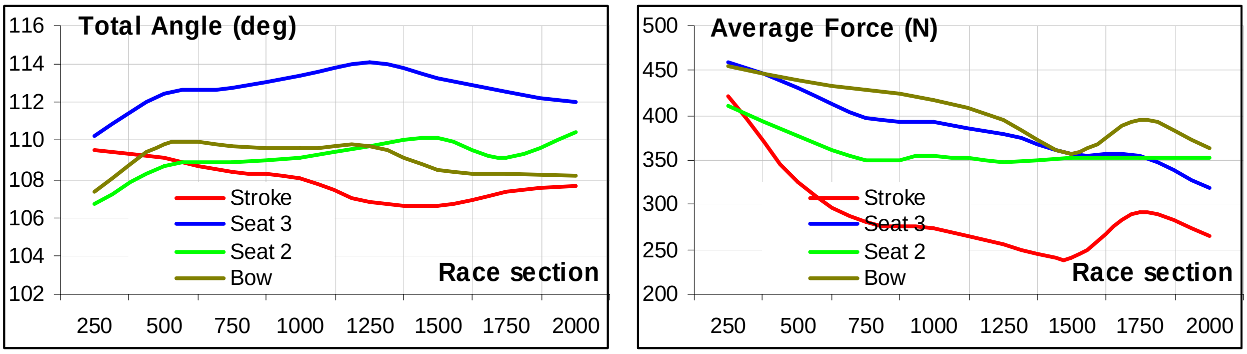

Figure 1. Examples of biomechanical assessment in a race environment.

3. Level 2. Detailed qualitative assessment

At this level patterns also called profiles or curves of biomechanical variables are analysed. BioRowTel software produce typical or normalised profiles during the stroke cycle, which is used for deriving discrete values.

3.1. Boat velocity and acceleration

Boat velocity if a resultant variable, which incorporate both rower's efforts and effect of external environment. Boat velocity is usually analysed in conjunction with boat acceleration, which are closely related: boat velocity is integral of the boat acceleration. Boat acceleration is directly related to the force applied to the boat hull and

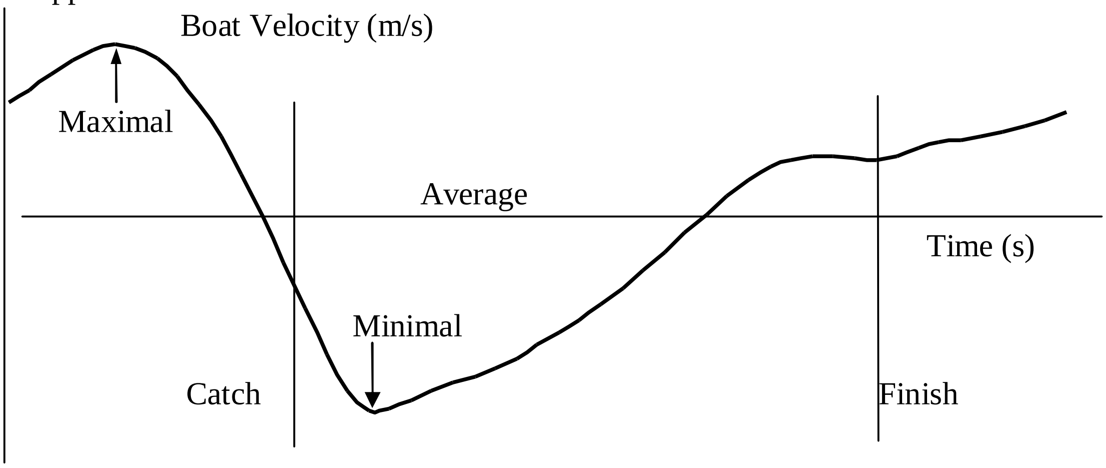

Figure 2. Typical profile of the boat velocity during the stroke cycle.

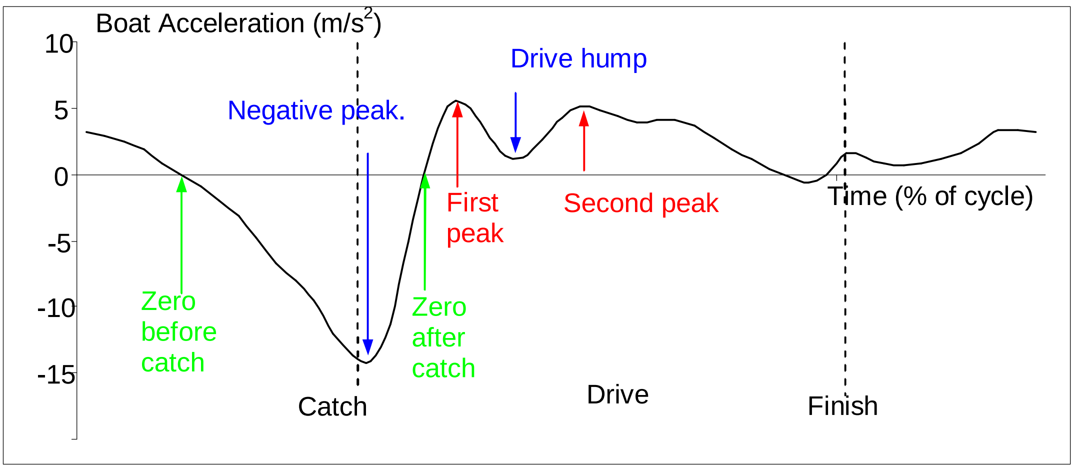

Figure 3. Typical profile of the boat acceleration during the stroke cycle.

The pattern of instantaneous boat acceleration during the stroke cycle is a very informative characteristic of a crew and could be used for evaluation of the rowing technique? Figure 3 shows a typical pattern and its discrete characteristics. Each characteristic can be evaluated by its timing. Peaks and humps can also be evaluated by its magnitude.

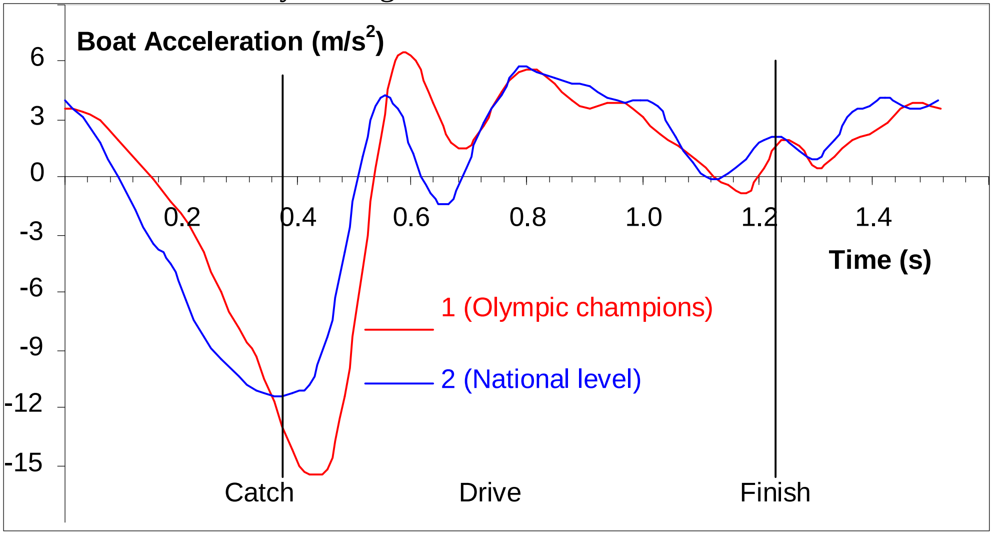

Figure 4. Profiles of the boat acceleration in two crews of different level.

Obviously, we are interested to know how above characteristics related to the performance of a crew, efficiency and effectiveness of rowing technique. Fig.2 shows comparison of the boat acceleration patterns of two pairs at the stroke rate 39 str/min. The better crew 1 (Olympic champions) have the following differences from the crew 2 (National level pair):

- Later time of “Zero before catch” criterion, which is related to later beginning of the push to the stretcher during recovery and longer acceleration of the seat towards the stern before catch.
- Deeper “Negative peak”, which is related to more active legs “kick” to the stretcher, performing catch using “through the stretcher” method (RBN 2006/09).
- Magnitude of the “First peak” is higher, which can be explained by quicker increase of the handle force, more “front-loaded” drive (RBN 2004/12, 2006/06).
- The “Drive hump” is shallower, which can be explained by “better connection” of legs and trunk during the drive, smoother force curve without humps. (RBN 2008/07)

Magnitudes of both negative peak and the first peak of the boat acceleration are highly dependent on the stroke rate (RBN 2002/08). No significant difference was found between sculling and sweep rowing. In various boat sizes the negative peak has slightly lower magnitude in eights. The first peak is quite similar in all boat sizes.

3.2. Pattern of force application (Force Curve)

The force curve is used very often for the assessment of rowing technique.

The most obvious parameter is a maximum force ***Fmax***, which is the highest point on the force curve. An average force ***Faver*** is equal to the height of a rectangle, of which the area is equal to the area under the force curve. The ratio of the average to maximal forces (***Ram=Faver/ Fmax***) reflects “fat” or “slim” force curves:

- For a perfect rectangular shape, ***Ram*** = 100%;
- For a perfect triangular shape, ***Ram*** =50%.

We found this ratio in rowing ranges from 38% to 64% with average 50.9±4.5% (mean±SD).

The term “catch slip” was traditionally used as a definition of how quickly the force increases at the catch and “release slip” was used to indicate its maintenance at the release. In fact, these parameters have very low correlation with a “slippage” of the blade in the water (vertical catch and release slips were mentioned in RBN 2007/04), so we prefer to use the term “gradient of force”. The slippage can be long, but the gradient is steep if the blade moves quickly on a shallow path through the water. At a higher stroke rate, it usually requires a shorter angle to achieve 30% of max. force (r = -0.44), but a longer angle to bury the blade. (The vertical catch slip increases, r = 0.20).

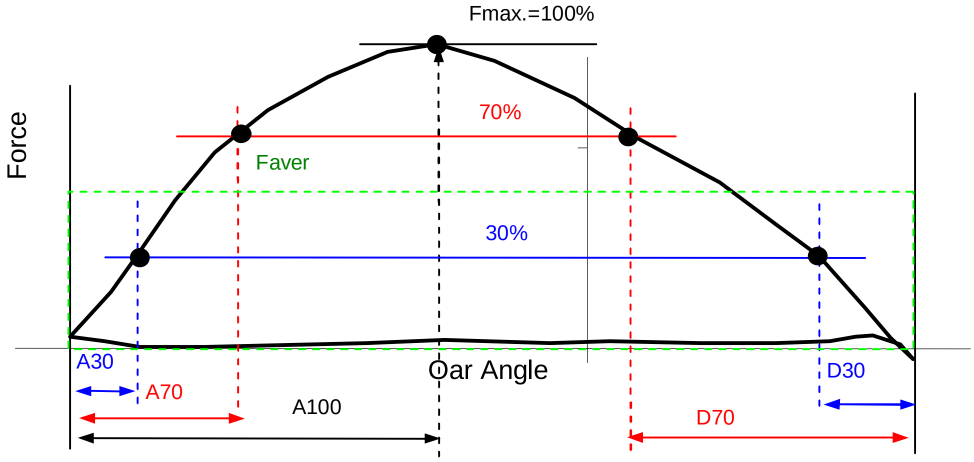

Figure 5. Typical "force curve" and its criteria.

Values of 30% and 70% of the maximum force were usually used as the criteria for the force gradient. We define the catch gradient as an angle, through which the oar travels from the catch point to the point, where the force **A**chieves the criterion (***A30*** and ***A70***). The release gradient is defined as an angle from the point, where the force **D**rops below the criterion to the finish of the drive (***D70*** and ***D30***). Parameter ***A100*** reflects the position of the peak force and can be used as a definition of a "front loaded" drive (RBN 2006/06). Why were values of 30% and 70% used as the criteria? The first of them was adopted from fixed criteria (100N for sculling and 200N for sweep), which were traditionally used in Australia, adjusted to accommodate various categories of athlete in both sculling and rowing. The purpose of this parameter was to determine how quickly the blade grips the water. We found that ***A30* has a correlation with the efficiency** of the blade (r = -0.34). ***Ram*** also slightly correlates with the blade efficiency (r = 0.32) which means that a quicker force increase and a rectangular shape of the force curve reduces slippage of the blade in the water.

Contrarily, the criterion 70% ***A70*** has an insignificant correlation with the blade efficiency (r = -0.13), but ***A70* relates to the effectiveness of rowing technique** (RBN 2004/12). Efficiency means minimising the energy expenditure for an equivalent performance. Effectiveness means the maximising of performance using all available resources. This fundamental difference can be explained by the mechanics of force increase: the 30% level can be achieved by good handling of the oar and using the small muscles of the arms and shoulders, but the 70% level is not achievable without dynamic acceleration of the rower's mass and involvement of the large leg and trunk muscles. As a confirmation, we found that only A70 and D70 correlate with maximal legs velocity (r=-0.28 and r=-0.38), i.e. quicker legs produce steeper gradients of force.

3.3. Oar handling skills

Oar handling skills can be evaluated by means of measurement of vertical oar angle and defining the path of the blade relative to the water level. For practical reasons we assume that, when the centre of the blade is at water level, the vertical angle (VA) of the oar is zero. It is easy to set the zero VA during measurements, when the feathered blade is floating at water level. For the positive direction, we assume VA of the oar is above the water level, and for the negative direction, below the water level.

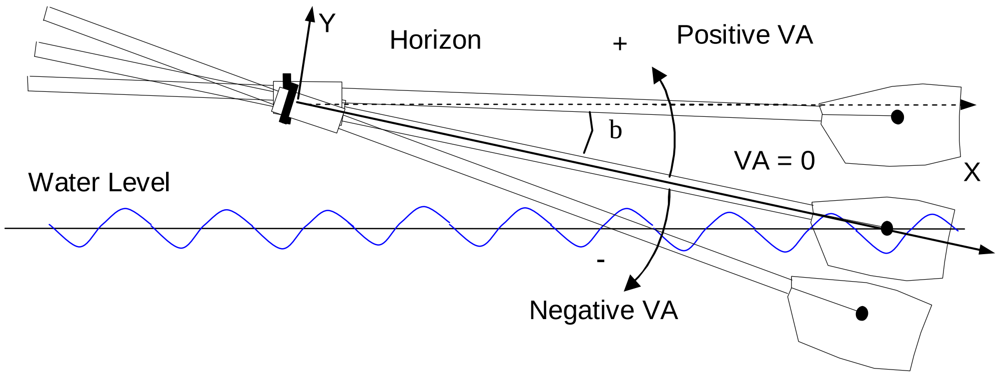

Figure 6. Definition of the vertical angle of the oar.

The trajectory of the blade relative to the water level can be plotted using the above reference system and the criteria of the blade trajectory can be defined, which could be used for evaluation of the rower's blade-work skills.

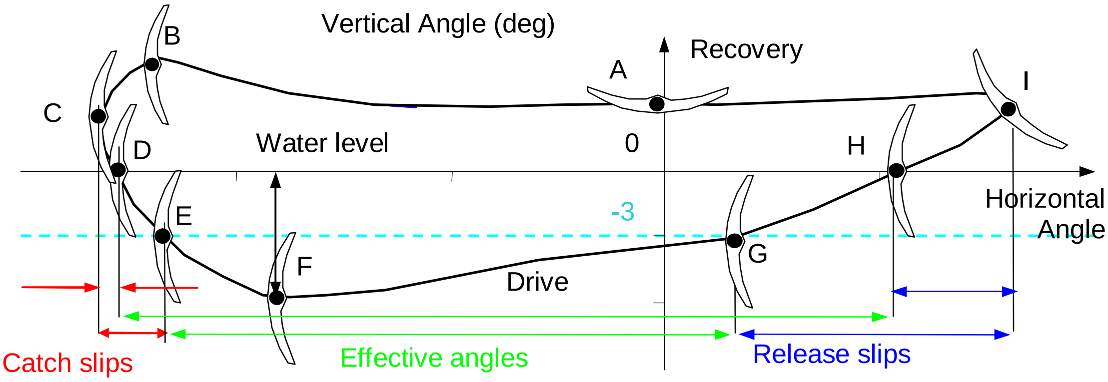

Figure 7. Typical profile of the vertical angle of the oar and its criteria.

Catch slip could be defined in two ways:

- From catch point C to point D, where the centre of the blade crosses the water level. We found that this is enough to apply propulsive force, which overcomes the drag and starts moving the system boat-rower forward.
- From catch point C to point E, where the whole blade is immersed below the water level and full propulsive force is applied. The VA at this point may vary depending on the blade width and outboard length. For simplicity, we set the criterion at -3 deg, which would guarantee blade coverage at all oar dimensions.

It was found that blade propulsive efficiency has moderate correlations with both effective angles (r=0.45 for 0VA criterion and r=0.38 for -3VA). Measurements of the vertical oar angle can help to improve the blade propulsive efficiency and increase boat speed. Telemetry system BioRowTel allows to measure and analyse both vertical angle and propulsive efficiency of the oar, as well as the roll and 3D acceleration of the boat.

3.4. Rowing style

Rowing style is defined by coordination of movements of three main body segments: legs, trunk and arms. Two main factors were defined, which distinguish rowing styles: simultaneous or consequent timing activity of two biggest body segments and emphasis during the drive (on legs or trunk).

The rowing style can be evaluated by means of measured velocities of the body segments.

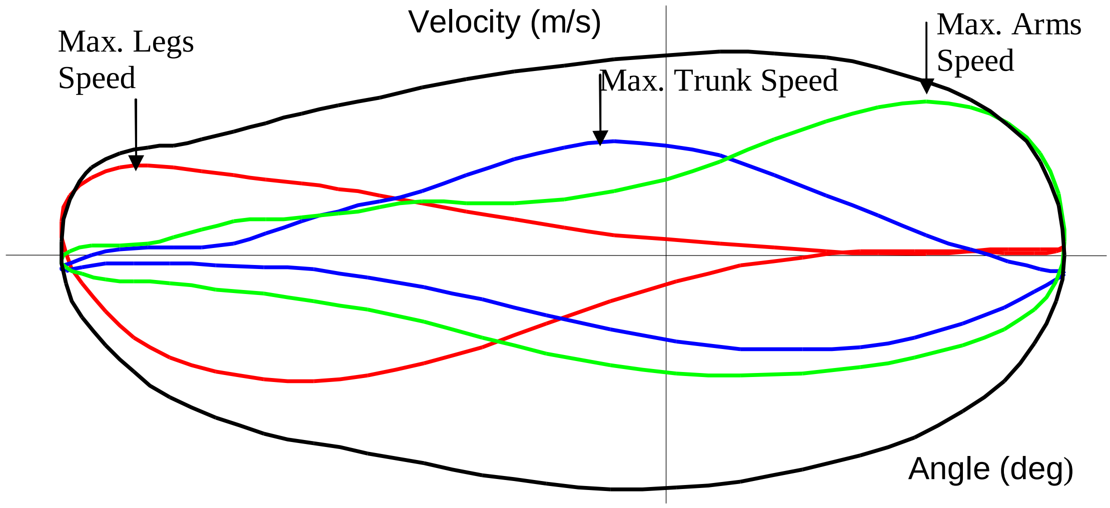

Figure 8. Typical profiles of the body segments velocities.

Simultaneous work of the legs and trunk produces a more rectangular shape of the power curve, but the peak power is lower. More even pressure on the blade improves its propulsive efficiency. However, slower and more static movement of the legs and trunk does not allow the delivery of the optimal power.

Sequential work of the legs and trunk produce a triangular shape of the power curves and higher peak power values. This leads to higher slippage of the blade through the water that causes energy losses. However, lower blade propulsive efficiency can be more than compensated by higher values of force and power produced per kg of body weight. Active usage of the trunk produces even more power, so the Rosenberg style can be considered as the most powerful rowing style.

Emphasis on the legs or trunk affects the position of the force and power peaks. Styles with leg emphasis allow a quicker increase of the force and earlier peak of the force curve. This improves the initial boat acceleration micro-phase D3 (RBN 1-2/2004) and makes the drive timing more effective.

Styles with trunk emphasis produce more power owing to better utilisation of big muscles (*gluteus* and *longissimus* muscles). However, these muscles are slow by nature as they are intended to maintain body posture in humans. This fact does not allow a quick increase of the force and power when using trunk muscles. A shift of the peak of the power curve closer to the middle of the drive makes the temporal structure of the drive less effective.

3.5. Synchronisation of the crew

For a number of reasons, time synchronisation of rowers' movements and force application at the catch and finish is the most imperative condition of effective rowing. There are no direct biomechanical reasons, why rowing angles and drive length must be the same in all crew members. However, the spatial variables are closely related to timing and, therefore, important for synchronisation.

The rowers in a crew are mechanically connected to each other through the stretcher and boat hull. It can be illustrated using the concept of "the trampoline ef-fect" (RBN 2006/07), which explains the summation of accelerations the boat and rower's mass. Imagine two jumpers hit the same trampoline board at different times: when it recoils to accelerate the first jumper, the second one arrives. Acceleration of the board would be stopped by impact of the second jumper and the first one couldn't jump high. The second jumper would re-ceive a jolt from the board, which moves fast towards his feet and could be injured. Therefore, rowers have to move and apply forces synchronously, otherwise effectiveness of the crew would be diminished.

The simplest method to measure synchronisation is to check the time of catch and finish, when the oar changes direction of movement. This could be done with frame-by-frame video analysis (high speed video is recommended for accuracy) or with biomechanical equipment (telemetry system). With the last method, the handle velocity could be derived from measured oar angle and known actual inboard.

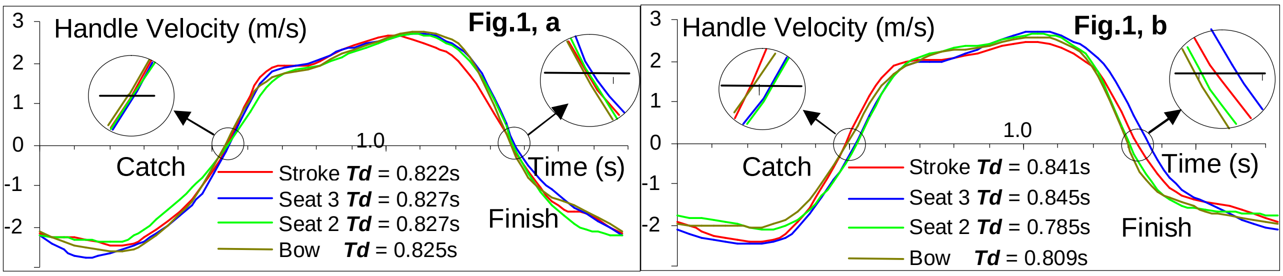

Figure 9. Examples of a good (left) and bad (right) synchronisation in two crews.

Figure 9 shows pat-terns of the handle velocity in two men's fours:

- The first crew (a) of World medallists level has very good synchronisation at the catch (max. time difference ΔT=12 ms) and finish (ΔT=13 ms).
- The second crew (b) of a club level has poor syn-chronisation in both the catch (ΔT= 34ms) and fin-ish (ΔT= 61ms).

4. Level 3. Advanced assessment and treatment with immediate feedback

Feedback information for the coaches and athletes can be given in three forms: static, interactive and immediate (real time).

4.1. Static feedback

The main form of the static feedback is a report as a hard copy or in electronic form.
Each report should contain a cover page with the following information: date and place of biomechanical measurements, boat type and rowers' category, coach and crew names, environmental and rigging constants.
In regards of the data analysis, the report can contain three sorts of pages:

- Whole boat data, number of samples (comparison of velocity, acceleration, etc.)
- One rower data, number of samples (at different stroke rate, longitudinal comparison, etc.)
- One sample, whole crew data (comparison of the rowers in the crew)

Recommended report structure: from summarised information in the beginning to more details in the end of the report.
In regards of types of biomechanical parameters, the following sorts of pages can be presented:

- Boat parameters (velocity, acceleration, etc.);
- Oar work parameters (angles, force, power, etc.);
- Body segments parameters;
- Data comparison and modelling.

The report can be accompanied with a set of still pictures, which represent one stroke cycle and can be linked to the biomechanical data by means of corresponding frame number.
See Appendix 3 for examples of the reports.

4.2. Interactive feedback

Interactive feedback can be provided by means of replacing biomechanical data on display that can be done standalone or in conjunction with video. Two types of data can be replayed: primary and typical (normalised) data.
Primary data can be linked with corresponding full length video clip automatically (by means of frame number) or manually (using unique event such as start command, flash light, etc.).
For replaying the typical data, the video clip must be trimmed to a number of stroke cycles (three strokes is recommended) from the start to the end of the cycle (perpendicular position of the oar relative to the boat).

4.3. Immediate (real time) feedback

Immediate or real time feedback can be provided by means of displaying biomechanical, video or both (overplayed) types of information. Two sorts of devices can be used for immediate feedback during on-water rowing:

- Portable displays mounted in the boat. These devices are preferable for displaying numerical and graphical data acquired from biomechanical system.
- Head-mounted personal monitors. Because of better eye-contact these devices can be used for immediate feedback using video.

The main principles of immediate feedback:

- The information must be meaningful for rowers. They must understand what does it mean and what their target is.
- Sufficient minimum of information should be provided. Athletes should not be overloaded with in information.
- The main target is to connect feedback with rower's perceptions and improve them, but not to replace perceptions with feedback.

5. Level 4. Special purpose biomechanical research

Many other biomechanical variables can be measured:

- Foot-stretcher forces in 2D and 3D;
- Vertical force at the seat;
- Vertical forces at the handle and the gate;
- Rudder rotation angle;
- Electromyography (EMG) of the main muscle groups.

These measurements are usually used in special research studies for in-depth investigation of Rowing Biomechanics.

6. Methods

6.1. Types of biomechanical service

There are three versions of the biomechanical testing, which differ in a level of obtrusiveness and complexity. This relates to both on-water and ergo-meter testing.

6.1.1. In training environment

On-going testing in the training environment can be performed in any boat type (usually, in rower's own training or racing boat). It requires measurement of a minimal set of parameters. This testing can include any additional parameter, providing it does not affect rowing technique.

6.1.2. In race environment

Data collection in race environment must be absolutely unobtrusive. Non-contact methods are preferred (visual, video-analysis). Minimal equipment can be placed on boat.

6.1.3. Specialised research testing

This sort of testing can be performed with some obtrusiveness additional devices, which interfere with rowers (e.g. cables on rower's body, using special dedicated boats, etc.). This sort of testing is important for in-depth research, which will extend our knowledge about high performance rowing.

6.2. Test Procedures

There are three main versions of biomechanical procedures: two standard protocols: Step-rate and Race and Free protocol.

1. Step-rate protocol (SP) consists of five 250m pieces with increasing of the stroke rate: 20, 24, 28, 32, 36 str/min. Rest time is until recovery (usually 3-5 min).
2. Race protocol (RP) consists of one full-effort race piece 2000m. The samples are to be taken at each 250m section of the race.
3. Free protocol measurements can include any sorts of workload. They are useful for experimenting with rowing technique and feedback methods.

Standard tests are important for longitudinal tracking of rower's technique and for comparison of different athletes and groups. It is recommended performing them for all rowers 3-6 times a year.

6.3. Athlete / Environment conditions

Athletes must be in good health and adequately recovered after previous training session. Biomechanical testing in rowing can be conducted only in adequate environmental conditions:

- Wind speed is not higher than 5 m/s,
- Temperature is in a range 0-40 C^o,
- There is no heavy rain, thunderstorm or hailstorm.

6.4. Telemetry system

The current BioRowTel v4.5 data acquisition system has the following specifications:

- Sampling frequency 25-100Hz;
- Analogue-to-digital converter 14 bits,
- Number of channels is scalable from 24 for 1x and 2- up to 64 for 4x and 8+.
- Data logging with memory size 2Gb is enough to store more than 100 hours of data in training and race modes;
- Battery life is up to 8 hours.
- Radio-transmission can be used for a real-time feedback to coaches.

6.5. Transducers

6.5.1. Force transducers

- Handle force transducer is light (70g) and easy to install. Accuracy is provided by direct calibration using a special load cell.
- Gate force transducer measure force relative to the oar.
- Foot-stretcher force transducer 2D and 3D versions;
- Handle force transducer for an erg can be wired and wireless designs.

6.5.2. Oar kinematics transducers:

- Horizontal gate angle transducer.
- Vertical oar angle transducer.

Both oar angle transducers can be combined in one unit.

6.5.3. Boat kinematics transducers:

- Boat position and velocity sensor based on GPS.
- Boat velocity transducer relative water (impeller).
- Boat 3D acceleration transducer.
- Boat orientation (Yaw, pitch and roll),

Boat kinematics transducers are combined in one unit.

6.5.4. Rower's kinematics transducers:

- Seat and trunk position transducers (string-loaded potentiometers),

6.5.5. Environmental transducers

- Wind velocity and direction transducer.
- Water temperature.

6.6. Calibration

Calibration of the transducers is the process of acquiring of mathematical equations, which relate numerical data *N* received from electronic device with physical values ***P*** of measured variables. The main purpose of the calibration is to provide accurate and reliable data. There are two main methods of the calibration:

- Static calibration is performed by means of setting known physical value on the transducer and recording corresponding reading from data acquisition unit. At least four data points must be recorded, which should cover at least 80% of the transducer range.
- Dynamic calibration is performed by means of applying additional pre-calibrated transducer with parallel data acquisition. Number of points is not limited and at least 80% of the transducer range must be covered.

Four types of calibration equations can be used. Reliability of each transducer is evaluated using Pearson correlation ***r*** coefficient between input numbers and physical values obtained during the calibration process. The correlation coefficient must be higher than 0.99.

6.7. Error Analysis

There are three sorts of errors in biomechanical measurements in rowing: calibration errors, data acquisition errors (aliasing) and normalisation errors

6.7.1. Calibration errors

There are two main reasons of the calibration errors: non-linearity of transducers and hysteresis. Non-linearity of transducers must not be higher then 0.25% in the range of measurement.
A measure of hysteresis is a coefficient of determination R^2 between calibration equation and real data. It must be not less than 0.99.

6.7.2. Data acquisition errors (aliasing)

Two factors affecting data acquisition errors (aliasing) are sampling rate and resolution of ADC. To provide sufficient 0.5% accuracy, the sampling rate of data acquisition system in rowing must not be less than 25 Hz. The resolution of ADC must not be less than 12 bits.

6.7.3. Normalisation errors.

Normalisation errors are defined by dimension of the data array and method of producing of discrete values. To provide sufficient 0.5% accuracy, the normalised variable must be at least 50 members array. Second order polynomial interpolation must be used for producing of discrete values.

6.8. Data processing

6.8.1. Normalised data

Rowing is a cyclic process. The acquired primary data represents a number of stroke cycles, which usually vary in their biomechanical variables. Though this data can be useful, people experience difficulties observing and evaluating it. Also, using the primary data creates difficulties longitudinal and inter-personal comparison.
Therefore, primary data for certain sampling period should be processed. We call this process normalisation. Each normalised variable are derived from the corresponding raw variable by means of averaging of the values, corresponding to particular part of the stroke cycle. Resultant data should represent one typical stroke cycle for this sample. Normalised data for each variable is presented as a fixed-length array. Array length 50 is used as a compromise of the accuracy and data volume.

Point of the start and end of the stroke cycle is defined as a time, when oar angle equal to zero during recovery phase.
Names, dimensions, and definitions of the normalised variables are the same as for the corresponding raw variables. It is important to use unified structure of the data, which allow information exchange and storage data in data bases.

6.8.2. Derivative variables

Derivative primary or normalised variables can be calculated using primary or normalised data and the constants, e.g. normalised power variable can be calculated using force and angle variables and oar inboard/length constants. See

7. Appendices

Table 2. Definition of the main variables in rowing biomechanics.

No	Variable type and	*Unit*	***ID***	Conventions/Comments
1.	Normal Gate Force	***N***	***Fgn***	Component of the gate force perpendicular to the face of the gate (also perpendicular to the long axis of the oar when it is fully engaged with the gate). Positive towards the pin.
2.	Normal Handle Force	***N***	***Fhn***	Component of the handle force perpendicular to the oar axis (also perpendicular to the blade). Positive towards the bow.
3.	Shear Gate Force	***N***	***Fgs***	Component of the gate force parallel to the face of the gate in the horizontal plane. Positive is outwards from the long axis of the boat (towards the blade).
4.	Vertical Gate Force	***N***	***Fgv***	Component of the gate force parallel to the face of the gate and perpendicular to the horizontal plane. Positive upwards.
5.	Stretcher Horizontal Force	***N***	***Ffh***	Horizontal component of the stretcher force parallel to the long axis of the boat. Positive is a force directed towards the bow.
6.	Stretcher Vertical Force	***N***	***Ffv***	Vertical component of the stretcher force. Positive is a force on the boat upwards.
7.	Horizontal Oar Angle	***deg***	***Ah***	Angle between the long axis of the oar and a line perpendicular to the long axis of the boat. Zero is perpendicular to the long axis of the boat. Positive direction is where the handle is closer to the bow.
8.	Vertical Oar Angle	***deg***	***Av***	Angle between the long axis of the oar and the horizontal plane of the boat. Zero is the centre of blade at water level. Positive direction - blade upwards.
9.	Boat Velocity	ms^{-1}	***Vb***	Velocity of the boat in the direction of the long axis of the boat relative to the water.
10.	Boat Horizontal Acceleration	ms^{-2}	***Abp***	Component of boat acceleration parallel to the long axis of the boat. Acceleration of the boat towards the bow is positive.
11.	Boat Vertical Acceleration	ms^{-2}	***Abv***	Component of boat acceleration in vertical direction. Upward is positive.
12.	Boat Yaw velocity	$deg\ s^{-1}$	***Byv***	Angular velocity of the boat around its vertical axis. Positive is bow moving to the stroke side.
13.	Boat Pitch velocity	$deg\ s^{-1}$	***Bpv***	Angular velocity of the boat around its transverse axis. Positive is down at the bow.
14.	Boat Roll velocity	$deg\ s^{-1}$	***Brv***	Angular velocity of the boat around its longitudinal axis. Positive is right gate (to the rower) up.
15.	Seat Position	***m***	***S***	Distance of the seat from the front chocks. Positive is towards the bow.
16.	Trunk position	***m***	***T***	Position of the trunk C7 relative to the boat. Positive is towards the bow.
17.	Wind velocity	ms^{-1}	***Wv***	Velocity of the wind relative to the boat. Always positive
18.	Wind direction	***deg***	***Wd***	Direction of the wind relative to the boat. Measured clockwise from above the centre of the boat with coming from the bow as zero.

Table 3. Definition of derived variables types.

No.	Variable	*Dim.*	*ID*	*Formula*	*Definition*, Conventions/Comments
1.	Gate Propulsive Force	***N***	***Fgpr***	*Fgn cos(Ah) – Fgs sin(Ah)*	Component of the gate force parallel with the long axis of the boat. Positive is towards the bow
2.	Gate Transverse Force	***N***	***Fgtr***	*Fgs cos(Ah) + Fgn sin(Ah)*	Component of the gate force in the horizontal plane perpendicular to the long axis of the boat. Positive is directed outwards.
3.	Handle normal force	***N***	***Fhn***	*Fgn (Louta /Loara)*	Force of rower on the handle normal to the long axis of the oar. It can be calculated on the basis of the gate force measurements.
4.	Handle propulsive force.	***N***	***Fhpr***	*Fhn cos(Ah) – Fga sin(Ah)*	Force of rower on the handle along the long axis of the boat. Positive is towards the bow.
5.	Propulsive Boat Force	***N***	***Fprop***	$\sum_{0}^{n}(Fgpr + Ff)$	Net effect of n pin and stretcher forces on the boat.
6.	Boat Yaw	***deg***	***By***	$\int dt \cdot Byv$	Rotation of the boat around its vertical axis. Positive yaw is bow displaced towards the stroke side.
7.	Boat Pitch	***deg***	***Bp***	$\int dt \cdot Bpv$	Rotation of the boat around its transverse axis. Positive pitch is bow displaced downwards at the bow.
8.	Boat Roll	***deg***	***Br***	$\int dt \cdot Brv$	Rotation of the boat around its longitudinal axis. Positive roll is top of the boat displaced to the bow side.
9.	Oar angular velocity.	$deg\ s^{-1}$	***Avh***	$\frac{dAh}{dt}$	Angular velocity of the oar in the horizontal plane.
10.	Handle velocity.	ms^{-1}	***Vh***	*Avh Lina*	Linear velocity of the handle.
11.	Handle propulsive velocity.	ms^{-1}	***Vhpr***	*Vh cos(Ah)*	Velocity of the handle parallel with the long axis of the boat.
12.	Seat velocity	ms^{-1}	***Vs***	*S / dt*	Velocity of the seat. Positive towards the bow.
13.	Trunk velocity	ms^{-1}	***Vt***	*(T-S)/dt*	Velocity of the trunk C7 relative to the seat.
14.	Arms velocity	ms^{-1}	***Va***	*Vh – (Vt + Vs)*	Velocity of the handle relative to the trunk C7.
15.	Rowing Power	***W***	***P***	*Vh Fhn*	Power applied to the oar handle
16.	Blade Waste power	***W***	***Pw***	*Waste(Ah,Fh,Vb)*	Part of the Rowing Power, which goes to a slippage of the blade through water.
17.	Propulsive Power	***W***	***Ppr***	*P-Pw*	Part of the Rowing Power, which goes to propulsion of the rowers-boat system.
18.	Leg power	***W***	***Pl***	*Vs Ff*	Product of stretcher force and seat velocity
19.	Trunk power	***W***	***Pt***	*Vt (Fh+Ff)/2*	Product of trunk velocity and average of stretcher force and handle forces.
20.	Arms power	***W***	***Pa***	*Va Fhn*	Product of handle force and arms velocity.

Table 4. Biomechanical standards used at the 1st Level of assessment.

	M1x	M2x	M4x	LM2x	M2-	M4-	M8+	LM4-	W1x	W2x	W4x	LW2x	W2-	W8+
Target speed (Time of 2000m)	**06:32.5**	**06:02.1**	**05:33.2**	**06:07.2**	**06:16.5**	**05:41.0**	**05:18.6**	**05:46.2**	**07:11.5**	**06:39.5**	**06:08.5**	**06:47.0**	**06:52.9**	**05:53.1**
Racing Stroke Rate (1/min)	37	39	40	36	38	40	41	40	35	37	38	36	36	39
Drive Time (s)	0.90	0.85	0.80	0.93	0.85	0.80	0.78	0.80	0.93	0.88	0.83	0.93	0.88	0.81
Rhythm (%)	54%	54%	54%	55%	53%	53%	53%	53%	54%	54%	54%	55%	53%	53%
Catch Angle (deg)	-70	-70	-70	-66	-60	-60	-60	58	-66	-66	-66	-63	-58	-58
Release Finish (deg)	44	44	44	44	34	34	34	34	44	44	44	43	34	34
Total Angle (deg)	114	114	114	110	92	92	92	90	110	110	110	106	90	90
Maximal Force (N)	850	850	850	750	760	760	760	660	650	650	650	550	550	550
Average Force (N)	460	460	460	390	380	380	380	340	340	340	340	290	300	300
Rowing Power (W)	550	550	550	500	500	500	500	460	460	460	460	350	400	400

	M1x	M2x	M4x	LM2x	M2-	M4-	M8+	LM4-	W1x	W2x	W4x	LW2x	W2-	W8+
Vertical Catch Slip (deg)	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Vertical Release Slip (deg)	15.0	15.0	15.0	15.0	12.0	12.0	12.0	12.0	15.0	15.0	15.0	15.0	12.0	12.0
Effective Angle (%)	84%	184%	284%	84%	80%	80%	80%	80%	84%	84%	84%	83%	80%	80%
Ratio Aver / Max. Forces (%)	54%	54%	54%	55%	50%	50%	50%	50%	52%	52%	52%	53%	51%	51%
Position of Max.Force (% of Total Angle)	40%	36%	33%	36%	39%	35%	30%	35%	40%	36%	33%	40%	40%	32%
Force up to 70%Max (deg)	17.0	17.0	17.0	16.0	14.0	14.0	14.0	13.0	16.0	16.0	16.0	16.0	13.0	13.0
Force down from 70%Max (deg)	25.0	25.0	25.0	24.0	20.0	20.0	20.0	20.0	24.0	24.0	24.0	24.0	20.0	20.0
Legs Travel (m)	0.58	0.58	0.58	0.54	0.60	0.60	0.60	0.54	0.55	0.55	0.55	0.52	0.56	0.56
Legs Max. Speed (m/s)	1.40	1.45	1.50	1.40	1.40	1.45	1.50	1.45	1.30	1.35	1.40	1.30	1.3	1.4