Volume 10 No 106 **Rowing Biomechanics Newsletter** *January 2010*

Q&A

We have received quite massive positive feedback on our rigging configurator, which you can find at http://www.biorow.com/RigChart.asp . E.g., Jamie Croly from St Stithians College, South Africa wrote:

“As far as your speed and rigging chart is concerned you seem to have got it spot on! In 2006 I coached a W1x at the Junior World Championships in Amsterdam. She finished 4th. Inputting her height 167cm, weight 62kg, ergo 7:17 into the table produces Inboard 87cm, Oar Length 282cm Span 160cm with a race time of 7:53. Kirsten's rig in the heat was 87cm, 281cm, 159cm and her time was 7:52. Her rate however was around 29/30.”

Here we answer the most common questions, which we have received about the configurator.

Q: “When I input my data for a light-weight woman’s four, I receive an error in the rigging.”

A: There is no such an event as LW4- in the program of the World regattas. Therefore, we don’t have statistics for such categories as well as normative data for the modelling. You can still use the innovative method for rowers of small height and weight, but you have to select their weight category as Open.

Q: “The boats/oars we have do not accommodate the innovative span/spread/inboard/oar length. How could we use the rigging chart in this case?”

A: You can still use traditional rigging variables. We hope that the innovative method could encourage the production of a wider variety of rowing equipment. In fact, the rower’s height can vary more than 20% (from 165 to 200cm), but variation of commercially available oars and sculls is less than 3% (from 367 to 378cm for oars and from 282 to 292cm for sculls). In other similar sports the dimensions of equipment usually varies in proportion to athlete’s dimensions: e.g. the ski length in cross country skiing varies 17% (from 177 to 207cm), the size of bike frames varies more than 30% (from 17 to 23 inches).

Q: “We have rowers of very different heights in our crew. How should we adjust the rigging to make the rowing angles the same?”

A: For a number of reasons synchronous timing at the catch and finish is an imperative in crew rowing. On the other hand, there is no biomechanical reason for the angles to be absolutely same, except that they produce better looking crews. Therefore, the drive time is the main criterion of synchronisation in the crew, but it depends not only on the rowing angle, but also on force application and blade depth. You can use shorter blades for shorter rowers, but make sure to set the gearing ratio (outboard/inboard) in such a way, which provides the same drive time for all rowers. You can check timing of catch and finish with frame-by-frame video analysis and use it as a measure for rigging adjustment.

Q: "When I do the gearing and handle speed calculations for an 8+ and a 4- for different wind speeds, I could only see handle speed as being a constant across the different wind speeds in the same boat type, but not across the two boat types. Where am I going wrong?”

A: Yes, it is correct; the handle speed is different in various boat types because there is a different ratio of boat speed to stroke rate between them (higher speed in bigger boats at the same stroke rate). This is related to a relatively lower drag factor per rower.

For experts, we show the current algorithm of the innovative method of the rigging calculations:

1. Drag factor **DF** was derived as a function of the mass (weight) of the rower **Wr** for each boat type:

$\mathbf{DF = a_1 * Wr + b_1}$

2. Rowing power **P** was derived from ergo score **Te**:

$\mathbf{P = Kde * V^3 = Kde * (2000 / Te)^3}$

3. Prognostic speed **Vp** and time **Tp** was derived from the rowing power **P** and **DF**

$\mathbf{Vp = (P * n * Eb / DF)^{1/3}}$

where **n** – number of rowers in the boat, **Eb** - blade efficiency.

$\mathbf{Tp = 2000 / Vp}$

Alternatively, prognostic time **Tp** can be inputted straight in the Chart or adjusted on the wind speed and direction.

4. Length of the arc **Larc** is derived as a linear function of the rower’s height **Hr**

$\mathbf{Larc = a_2 * Hr + b_2}$

5. Actual **Lin_a** and measured inboard **Lin** were derived

$\mathbf{Lin\_a = (180 * Larc) / (\pi * A)}$

$\mathbf{Lin = Lin\_a - 2cm + Wh / 2}$

where handle width **Wh** = 12cm for sculling and **Wh** =30cm for rowing. Rowing angle **A** is taken as a normative value for each rower’s category (RBN 2007/08) and adjusted for U23 as 98% and for juniors as 96% of the value for adults.

6. Average handle speed **Vh** was derived from **Larc** and drive time **Tdr**

$\mathbf{Vh = Larc / Tdr}$

Drive time **Tdr** was taken as a function of the stroke rate **Rr**

$\mathbf{Tdr = a_3 * Rr + b_3}$

7. Gearing ratio **Gr**, actual **Lout_a** and measured **Lout** outboards were is derived from **Vh** and **Vp**.

$\mathbf{Gr = Vp / Vh * Eb}$

$\mathbf{Lout\_a = Gr * Lin\_a}$

$\mathbf{Lout = Lout\_a + 2cm + Lbl/2}$

Where **Lbl** is a blade length

8. Finally, the oar length **Loar** was derived

$\mathbf{Loar = Lin + Lout}$

We keep working on the Rigging Chart to improve it and make it more accurate. We welcome your feedback and questions.

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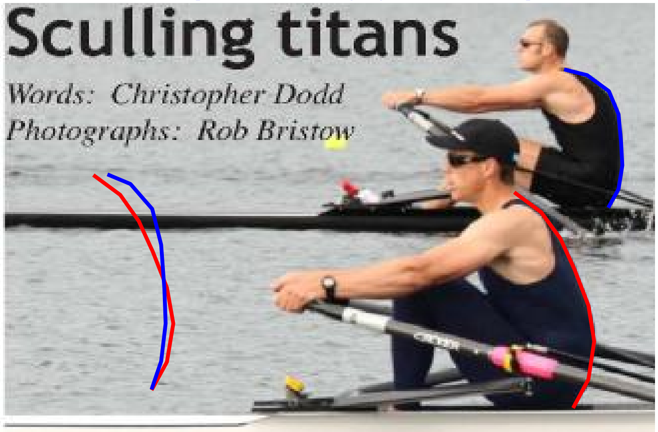
News

Telemetry system BioRowTel v.4 was successfully used during FISA women's' development camp in Seville on 11-13 February. 24 athletes from Sweden, Norway, Estonia, South Africa, Egypt, Pakistan and Puerto-Rico were tested in doubles and pairs and received information about the main characteristics of their rowing technique.

Ideas

The idea came from looking at the photo below found in Rowing Voice N5, thanks to Chris Dodd and Rob Bristow (http://www.total.rowing.org.uk/voice/voice5-i.pdf):



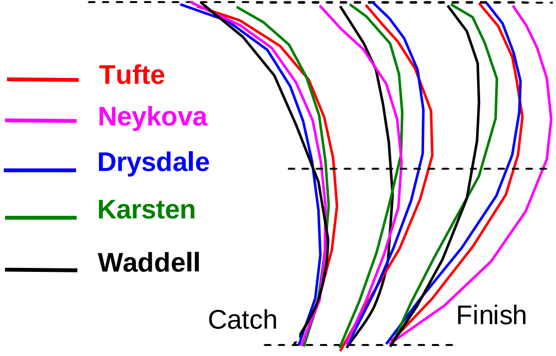
Sculling titans

Words: Christopher Dodd

Photographs: Rob Bristow

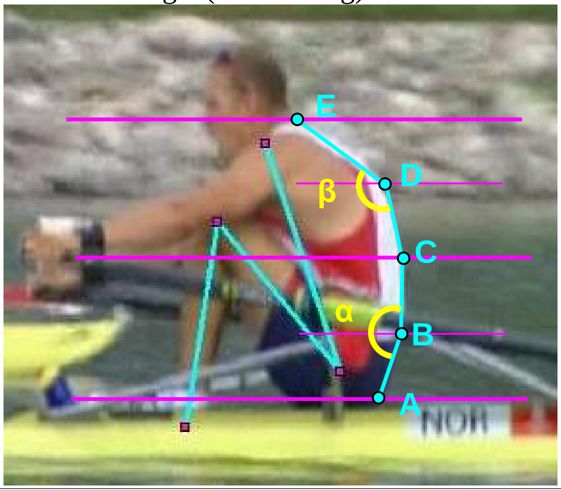
We can see how different the contours of the back in these two great scullers (Rob Waddell in the foreground and Mahe Drysdale in the background). When we draw the contour lines, scale and overlap them, the difference is obvious: Mahe has a straighter lower back and more curvature in the chest, where as Rob has the opposite.

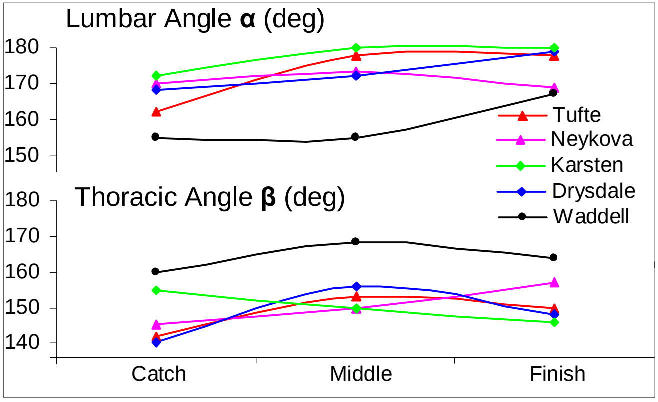
Then we compared the back curvatures of five of the best World single scullers (see images in the Appendix) at the catch, the middle of the drive (near perpendicular position of the blade) and the finish. The diagram below shows the overlapped curves scaled with preserved aspect ratio:



You can see that Wadell's back curves are definitely outstanding: it has more curvature in the lumbar area (especially at catch) and less curvature in the thoracic area in all positions. To get some numbers we conducted a very simple digitising of the back curvature, which was divided into four zones of the same height relative to the vertical Y axis. The coordinates of five points A, B, C, D and E were obtained at the locations, where the back curvature crosses the border of each zone. Lumbar angle **α** was determined between lines AB and BC; thoracic angle **β** was measured between lines CD and DE. Advantage of this method is that it does not require markers on top of the centres of joints as the back curve can be clearly seen from the side.

Analysis of the lumbar and thoracic angles confirmed our qualitative observations: the four best scullers have significantly straighter lumbar angles (160-180 deg) and more curved thoracic angle (140-160deg), while Waddell had a more acute-angled lumbar area (150-160deg) and a straighter thoracic angle (160-170deg).





The hypothesis is the following: a straighter lumbar area can help to transfer the force better from hips to shoulders and prevent injuries, but **more curvature in the thoracic area can be more economical because it uses more elastic properties of the muscles rather then its strength**. The first part of the hypothesis is well known and many coaches emphasise straighter lumbar posture with pelvis rotation around hips in conjunction with trunk (RBN 2005/07). However, the second part has not been widely discussed to our knowledge. Contrarily, a feature of some rowing styles is a straight thoracic back, which can be observed on published posters of rowing technique.

The reasons of more thoracic curvature in top World scullers are not clear yet. It can be related to adaptation to many years of high load as it is more noticeable in experienced scullers. Alternatively, it can be a natural selection of athletes with a specific posture, which allow them to spend less energy in sculling and, therefore, be more successful. More research needed in this area.

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Appendices.

M1x NOR Olaf Tufte, Two times Olympic champion of Athens-2004 and Beijing-2008

W1x BUL Rumyana Neykova, Olympic champion of Beijing-2008

M1x NZL Mahe Drysdale, Four times World Champion 2005-7, 2009

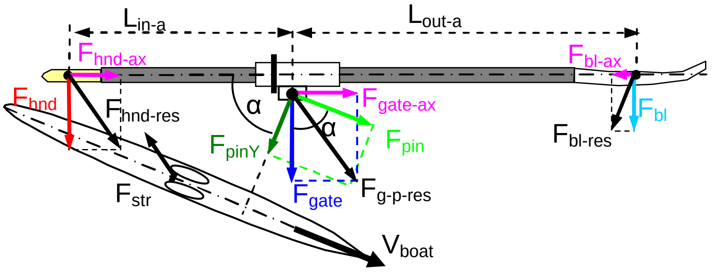
W1x BLR Ekaterina Karsten, Two times Olympic champion of Atlanta-1996 and Sydney-2000

M1x NZL Rob Waddell, Olympic champion of Sydney-2000

Q&A

Q: We have received a number of questions of the following sense: “What is the difference between measurements of the force at the oar handle and at the gate or pin? Which method is the most accurate?”

A: We already discussed some pros and cons of the angle measurements at the oar and at the gate (RBN 2003/05). Similar to the angle, the force can be measured at the oar handle or at the blade, gate or pin.



These methods have the following features:

1. Handle force $\mathbf{F_{hnd}}$ can be measured perpendicular to the oar direction either with strain gauges applied directly on the oar shaft or with detachable sensors. In fact, the sensor measures the oar bend, which is proportional to the torque **M** or moment of the force $\mathbf{F_{hnd}}$ and can be calibrated as a force applied at a known point on the handle. The rower’s power production **P** can be derived as:

$$\mathbf{P = M * \omega = F_{hnd} * L_{in\text{-}a} * \omega} \qquad (1)$$

where $\mathbf{L_{in\text{-}a}}$ is the actual oar inboard lever, $\boldsymbol{\omega}$ is oar angular velocity, which can be derived from a measurements of the horizontal oar angle. In this case the calculated power is not affected by the point of rower’s force application, which is unknown and may vary significantly especially in sweep rowing. Therefore, this is the most accurate method for measurement of rower’s power with an estimated error of 1%. The practical problem of this method is the necessity to calibrate every oar, which can be solved with modern technology (1).

The resultant force $\mathbf{F_{hnd\text{-}res}}$, which the rower applies to the handle, is not always perpendicular to the oar axis. Therefore, it can be resolved into the perpendicular $\mathbf{F_{hnd}}$ and axial $\mathbf{F_{hnd\text{-}ax}}$ components. The last is quite difficult to measure, but it does not produce any mechanical power at the oar. It is statically transferred through the oar shaft and creates axial force at the gate $\mathbf{F_{gate\text{-}ax}}$, which is a sum of vectors $\mathbf{F_{hnd\text{-}ax}}$ and axial force at the blade $\mathbf{F_{bl\text{-}ax}}$. Then, the axial force $\mathbf{F_{gate\text{-}ax}}$ is transferred through the gate, pin, rigger and statically balanced with the stretcher force $\mathbf{F_{str}}$. Therefore, **a rower should apply only a small axial force to keep the button in contact with the gate and pull the handle as perpendicularly as possible**.

The perpendicular component of the blade force $\mathbf{F_{bl}}$ can be measured using the same method as was described above for the handle force and would produce the same accuracy of the rower’s power calculation.

2. The gate rotates together with the oar and the perpendicular $\mathbf{F_{gate}}$ and axial $\mathbf{F_{bl\text{-}ax}}$ components of the gate force can be measured in the reference frame of the oar using various instrumented gates (2, 4). Rower’s power can be derived using the equation 1, but $\mathbf{F_{hnd}}$ must be calculated as:

$$\mathbf{F_{hnd} = F_{gate} * (L_{out\text{-}a} / (L_{in\text{-}a} + L_{out\text{-}a}))} \qquad (2)$$

where $\mathbf{L_{out\text{-}a}}$ is actual outboard length from pin to the centre of the blade force. We do not know exactly $\mathbf{L_{in\text{-}a}}$ and $\mathbf{L_{out\text{-}a}}$ because actual points of force application during rowing are uncertain. We can only guess that they are located at the centres of the handle and blade. The estimated error of rower’s power calculation using this method could be up to 5%. Sum of the normal $\mathbf{F_{gate}}$ and axial $\mathbf{F_{gate\text{-}ax}}$ components is a resultant gate force $\mathbf{F_{g\text{-}p\text{-}res}}$, which is transferred to the pin.

3. The pin is fixed relative to the boat and the pin sensor measures force in the reference frame of the boat (3). Usually, it measures only parallel to the boat axis component $\mathbf{F_{pin}}$ of the resultant gate-pin force $\mathbf{F_{g\text{-}p\text{-}res}}$. Rower’s power can be derived using equations 1 and 2, however gate force $\mathbf{F_{gate}}$ must be derived as;

$$\mathbf{F_{gate} = F_{pin} * \cos \alpha} \qquad (3)$$

In fact, only a part of the rower’s force production can be measured using this method (e.g. only half at the catch oar angle -60° as cos(60°) = 0.5). Also, the readings are affected by axial gate force $\mathbf{F_{gate\text{-}ax}}$, which does not produce power as we have shown above. The estimated error or the rower’s power calculation is 10% in sculling and up to 20% in rowing (see Appendices). Accuracy of this method can be improved with 2D sensors of pin force, which can also measure perpendicular to the boat component $\mathbf{F_{pinY}}$. In this case, the accuracy would match the gate force sensors: the magnitude and direction of the resultant force $\mathbf{F_{g\text{-}p\text{-}res}}$ could be determined and then perpendicular component $\mathbf{F_{gate}}$ derived using known gate angle $\boldsymbol{\alpha}$.

The situation with accuracy is opposite if the purpose is a calculation of balance of forces on the hull, which could be a target in some research studies. Usually, the stretcher force $\mathbf{F_{str}}$ is measured in these studies and propulsive force $\mathbf{F_{prop}}$ can be derived for each rower:

$$\mathbf{F_{prop} = F_{pin} - F_{str}} \qquad (4)$$

If the force is measured at the handle, then $\mathbf{F_{gate}}$ must be derived from $\mathbf{F_{hnd}}$ using $\mathbf{L_{in\text{-}a}}$ and $\mathbf{L_{out\text{-}a}}$ and then $\mathbf{F_{pin}}$ obtained using oar angle $\boldsymbol{\alpha}$. In this case, measurement of the pin force $\mathbf{F_{pin}}$ is the most accurate method and its calculation from measurement of $\mathbf{F_{hnd}}$ can give up to 20% error margins in sweep rowing.

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2. Kleshnev V. 1988. Device for power measurement in rowing. SU Patent 1650171.
3. Peach Innovations Ltd.. PowerLine Rowing Instrumentation system. www.peachinnovations.com
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Appendix 1. Comparison of the measurements of the handle and pin forces in sculling

Handle force was measured using a detachable sensor of BioRowTel v.3 system (1)

Pin force was measured using an instrumented gate of PowerLine system (3) and then handle force was derived using equation 2 above.

Both forces were measured simultaneously over a sample period about 1 min and then averaged to one typical stroke cycle.

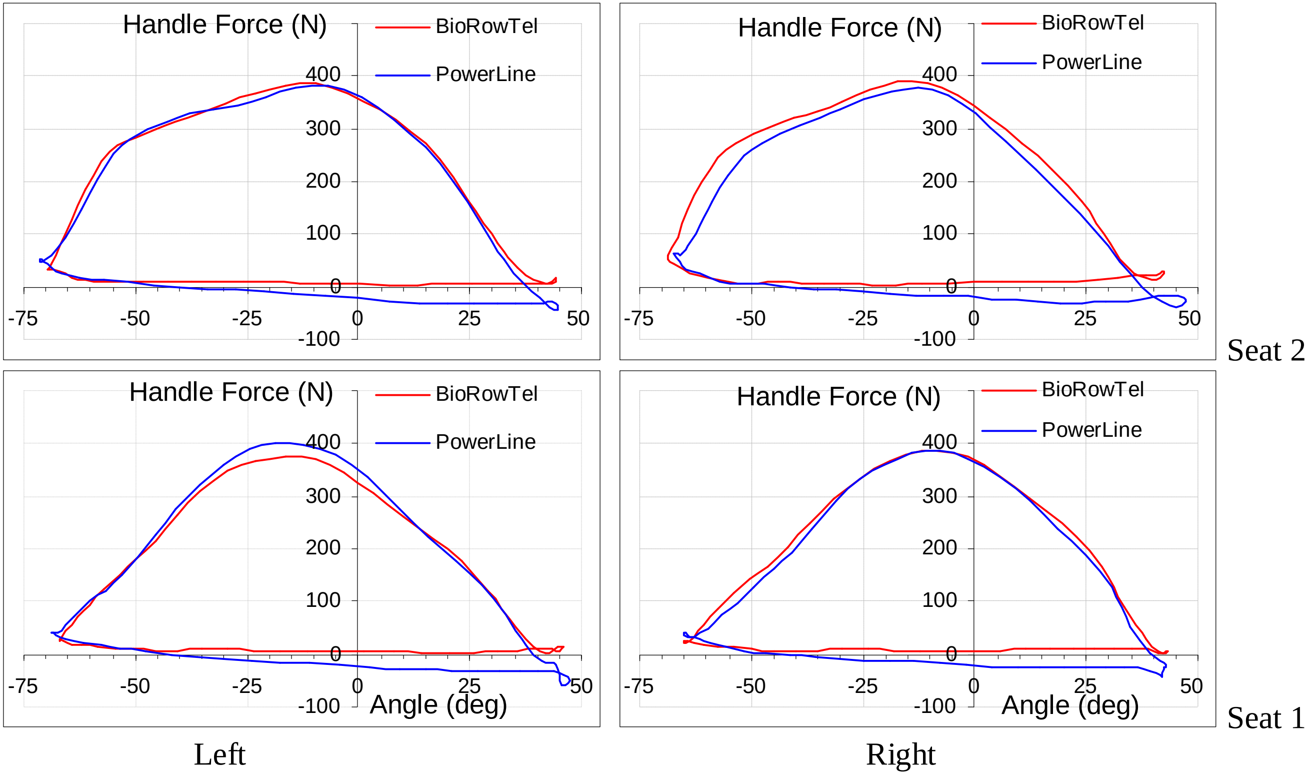


Figure 1. Comparison of the force/angle curves in double scull at stroke rate 30 str/min

Table 1. Comparison of derivative values in a double scull at stroke rate 30 str/min

Data from	Angle BioRowTel (deg)	Angle PowerLine (deg)	Absolute Difference (deg)	Relative Difference (%)	Max.Force BioRowTel (N)	Max.Force PowerLine (N)	Absolute Difference (N)	Relative Difference (%)	Aver.Force BioRowTel (N)	Aver.Force PowerLine (N)	Absolute Difference (N)	Relative Difference (%)
Seat 2 Right	111.1	114.9	-3.81	**3.4%**	391	377	13.3	**3.5%**	220	196	24.0	**11.5%**
Seat 2 Left	114.0	116.0	-2.06	**1.8%**	387	381	5.8	**1.5%**	210	196	13.8	**6.8%**
Seat 1 Right	108.3	107.8	0.48	**0.4%**	386	385	1.0	**0.3%**	173	180	-7.1	**4.0%**
Seat 1 Left	112.8	115.7	-2.91	**2.5%**	376	401	-24.5	**6.3%**	178	184	-5.7	**3.1%**
Average	111.5	113.6	-2.1	**2.0%**	385.1	386.2	-1.1	**2.9%**	195.5	189.2	6.3	**6.4%**

Data from	Rowing Power BioRowTel (W)	Rowing Power PowerLine (W)	Absolute Difference (W)	Relative Difference (%)	Force to 70% BioRowTel (deg)	Force to 70% PowerLine (deg)	Absolute Difference (deg)	Relative Difference (%)	Force from 70% BioRowTel (deg)	Force from 70% PowerLine (deg)	Absolute Difference (deg)	Relative Difference (%)
Seat 2 Right	144	130	**13.3**	**9.7%**	15.1	18.6	**-3.5**	**20.7%**	31.8	38.5	**-6.7**	**19.1%**
Seat 2 Left	146	144	**2.7**	**1.9%**	16.8	18.3	**-1.6**	**8.9%**	29.7	30.1	**-0.4**	**1.3%**
Seat 1 Right	127	123	**3.8**	**3.1%**	30.8	31.8	**-1.0**	**3.2%**	27.2	27.9	**-0.7**	**2.6%**
Seat 1 Left	127	133	**-5.7**	**4.4%**	26.2	28.4	**-2.2**	**8.1%**	36.1	38.6	**-2.5**	**6.7%**
Average	135.9	132.4	3.5	**4.7%**	22.2	24.3	-2.1	**10.2%**	31.2	33.8	-2.6	**7.4%**

Appendix 2. Comparison of the measurements of the handle and pin forces in rowing

Handle force was measured using a detachable sensor of BioRowTel v.3 system (1)
Pin force was measured using an instrumented gate of PowerLine system (3) and then handle force was derived using equation 2 above.
Both forces were measured simultaneously over a sample period about 1 min and then averaged to one typical stroke cycle.

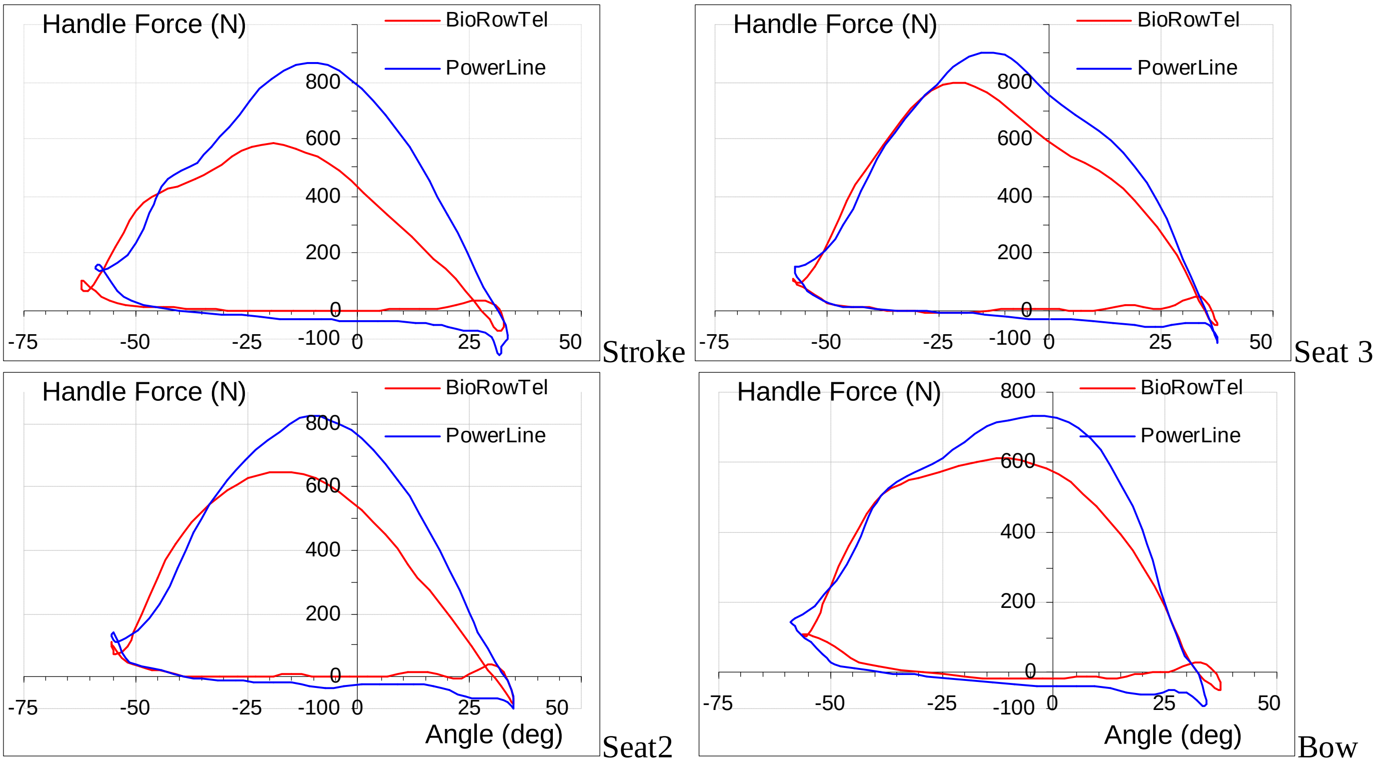


Figure 2. Comparison of the force/angle curves in a four at stroke rate 34 str/min

Table 2. Comparison of derivative values in a four at stroke rate 34 str/min

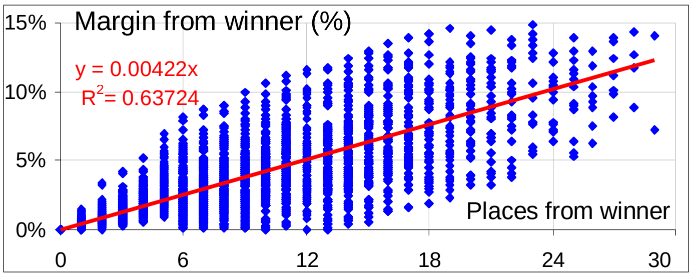
Data from	Angle BioRowTel (deg)	Angle PowerLine (deg)	Absolute Difference (deg)	Relative Difference (%)	Max.Force BioRowTel (N)	Max.Force PowerLine (N)	Absolute Difference (N)	Relative Difference (%)	Aver.Force BioRowTel (N)	Aver.Force PowerLine (N)	Absolute Difference (N)	Relative Difference (%)
Stroke	94.5	92.4	2.03	**2.2%**	583	865	-282.3	**39.0%**	297	457	-159.5	**42.3%**
Seat 3	94.9	94.9	0.01	**0.0%**	800	905	-105.3	**12.3%**	398	459	-61.0	**14.2%**
Seat 2	90.1	90.2	-0.07	**0.1%**	649	822	-173.0	**23.5%**	320	428	-108.4	**29.0%**
Bow	93.5	92.9	0.61	**0.7%**	614	733	-119.0	**17.7%**	339	432	-93.2	**24.2%**
Average	93.2	92.6	0.6	**0.7%**	661.6	831.4	-169.9	**23.1%**	338	444	-105.5	**27.4%**

Data from	Rowing Power BioRowTel (W)	Rowing Power PowerLine (W)	Absolute Difference (W)	Relative Difference (%)	Force to 70% BioRowTel (deg)	Force to 70% PowerLine (deg)	Absolute Difference (deg)	Relative Difference (%)	Force from 70% BioRowTel (deg)	Force from 70% PowerLine (deg)	Absolute Difference (deg)	Relative Difference (%)
Stroke	233	335	**-101.7**	**35.8%**	17.4	28.0	**-10.7**	**47.1%**	30.8	23.8	**7.0**	**25.6%**
Seat 3	321	363	**-42.5**	**12.4%**	19.4	23.2	**-3.8**	**17.9%**	34.4	27.2	**7.3**	**23.6%**
Seat 2	248	308	**-59.2**	**21.3%**	16.2	23.5	**-7.3**	**37.0%**	29.2	24.1	**5.1**	**19.0%**
Bow	271	314	**-43.1**	**14.8%**	13.3	21.1	**-7.8**	**45.3%**	24.6	18.0	**6.5**	**30.7%**
Average	268.2	329.8	-61.6	**21.1%**	16.5	23.9	-7.4	**36.8%**	29.7	23.3	6.5	**24.7%**

Q&A

Q: Wilson Reeberg, president of the Brazilian Rowing Federation asked: "I plan to send to the Worlds Championships only crews with possibilities to classify among the top twelve. Do you have a table with the times to classify a boat among 7th and 12th (Final B) for seniors, juniors and U23, men and women? What percentage should I add to prognostic times of WC winners to have a real chance to stay among the best 12 crews?"

A: To answer these questions we used our database of results of World Championships and Olympic Games from 1993 till 2009 (n=3760). The problem was that often finals A, B, C and others were held in different days, which means the weather conditions were different and it is not possible to compare the boat speed reliably. We plotted margins of all place takers (ratio of their time to the winners time) relative to their ranking, calculated the linear trend and filtered outliers within the limit of ±3SD of the trend line:



The slope of the trend line tells us that, on average, every one place lower in ranking means 0.42% slower boat speed (i.e. 11 places difference between the 1st and 12th places should have 4.64% (=0.42%*11) difference in the boat speed). This value varies among different events, which reflects homogeneity of competitors (M2x with the most uniformity, without strong leaders, W2- with the biggest margins from leaders):

M2x	M4x	M4-	LM2x	M8+	LW2x	LM4-
0.30%	0.36%	0.39%	0.40%	0.42%	0.42%	0.43%
W8+	M1x	M2-	W2x	W4x	W1x	W2-
0.44%	0.44%	0.45%	0.48%	0.49%	0.50%	0.53%

The tables below show average margins in finals:

Table 1. Average margins from winners in World Championships and Olympics during 1993-2009.

Final\Place	1st	2nd	3rd	4th	5th	6th
Final A	0.0%	0.5%	0.8%	1.4%	2.1%	3.0%
Final B	2.8%	3.1%	3.4%	3.8%	4.3%	5.1%
Final C	4.8%	5.2%	5.8%	6.9%	7.7%	8.1%
Final D	7.6%	8.2%	8.9%	9.4%	10.6%	12.6%

Table 2. Average margins in men's events

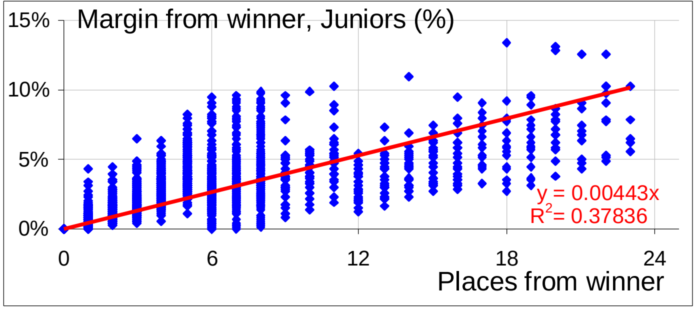
Men	1	2	3	4	5	6
FA	0.0%	0.4%	0.8%	1.3%	2.0%	2.9%
FB	2.5%	2.9%	3.2%	3.5%	4.0%	4.7%
FC	4.5%	4.9%	5.5%	6.5%	7.1%	7.3%
FD	6.8%	7.7%	8.2%	9.2%	9.7%	10.4%

Table 3. Average margins in women's events

Women	1	2	3	4	5	6
FA	0.0%	0.5%	0.9%	1.5%	2.3%	3.2%
FB	3.1%	3.5%	3.8%	4.1%	4.8%	5.5%
FC	5.0%	5.5%	6.2%	7.3%	8.4%	9.0%
FD	8.3%	8.8%	9.7%	9.6%	11.4%	14.9%

The winners of finals B are usually faster than the slowest crews in final A, which reflects tougher competition for the first place in a final. Similar thing can be found when comparing finals C-B, D-C and others. The margins in men's events are a little tighter than in women. No significant time-trend of this data was found over the last 17 years.

In juniors we have data only for the first two finals for most of years, so the trend is less reliable. The slope is similar with adults, just a bit steeper with an average of 0.443% difference between places:



Interestingly, the highest homogeneity of results in juniors was found in M2x and M4x, the same as in the adults:

JM2x	JM4x	JM2-	JW1x	JM4-	JM1x	JM4+
0.29%	0.33%	0.34%	0.38%	0.38%	0.39%	0.42%
JW4x	JW2x	JM8+	JW2-	JW8+	JM2+	JW4-
0.43%	0.51%	0.52%	0.53%	0.67%	0.74%	0.82%

Table 4. Average margins from winners in Junior World championships during 1993-2009.

Finals	1	2	3	4	5	6
FA	0.0%	0.8%	1.3%	2.0%	3.0%	4.1%
FB	3.2%	3.9%	4.4%	4.3%	4.2%	5.1%
FA boys	0.0%	0.6%	1.2%	1.8%	2.7%	3.8%
FB boys	2.7%	3.4%	4.0%	3.4%	3.9%	4.8%
FA girls	0.0%	0.9%	1.6%	2.4%	3.4%	4.5%
FB girls	3.8%	4.6%	4.9%	5.5%	4.8%	5.6%

A brief analysis in the U23 category give us similar results to adults and juniors, but statistics was less reliable because we have data only from 2001.

Concluding, **a crew has chances to get into final B if their speed is no more than 4.5% slower than the winners' speed in men's events and 5.0% in women, in both adults and junior categories.** These numbers vary between events from 3.3% in M2x up to 5.8% in W2 and even up to 9.0% in JW4-.

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Q&A

Q: Csaba Győrösi, a rower from Külker Rowing Club in Budapest, Hungary asked: “I have hand-made slides for a Concept 2 ergometer weighing almost 20 kg. Do you think this extra weight will affect my rowing technique?”

A: This question relates to the topic of inertial losses in rowing, when two significant masses of the rower and boat or machine move in relation to one another (1). Ergo rowing is the simplest case; on-water model is similar, but affected by the acceleration of the whole rower-boat system, so it will be discussed later. From a stationary position at the catch or finish, some energy has to be spent to achieve a velocity **V** between the rower’s centre of mass (CM) and ergo, which is a sum of rower’s $\mathbf{V}_{\mathbf{row}}$ and ergo $\mathbf{V}_{\mathbf{erg}}$ velocities:

$$\mathbf{V} = \mathbf{V}_{\mathbf{row}} + \mathbf{V}_{\mathbf{erg}} \qquad (1)$$

Accelerations of the components and, therefore, velocities $\mathbf{V}_{\mathbf{row}}$ and $\mathbf{V}_{\mathbf{erg}}$ are reversely proportional to their masses:

$$\mathbf{V}_{\mathbf{row}} / \mathbf{V}_{\mathbf{erg}} = \mathbf{M}_{\mathbf{erg}} / \mathbf{M}_{\mathbf{row}} \qquad (2)$$

where $\mathbf{M}_{\mathbf{row}}$ is the rower’s mass and $\mathbf{M}_{\mathbf{erg}}$ is the mass of ergo+slides. This energy is transferred into kinetic energy $\mathbf{E}_{\mathbf{k}}$, which can be expressed as:

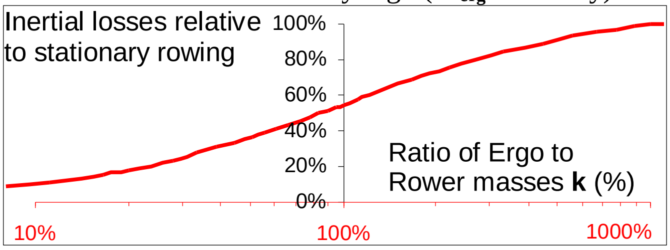
$$\mathbf{E}_{\mathbf{k}} = (\mathbf{M}_{\mathbf{row}}\,\mathbf{V}_{\mathbf{row}}^{2} + \mathbf{M}_{\mathbf{erg}}\,\mathbf{V}_{\mathbf{erg}}^{2}) / 2 \qquad (3)$$

A rower could also spend metabolic energy on the deceleration of the masses at the end of the drive and recovery. However, these losses can be minimised using elastic properties of muscles and ligaments and kinetic energy can be transferred into propulsion (RBN 2006/10). Therefore, we do not take decelerations into account and multiply $\mathbf{E}_{\mathbf{k}}$ by two, bearing in mind that the acceleration happens twice during the stroke cycle (during the drive and recovery).

Combining all three equations above, the total inertial losses $\mathbf{P}_{\mathbf{in}}$ can be expressed as:

$$\mathbf{P}_{\mathbf{in}}=(\mathbf{M}_{\mathbf{row}}(\mathbf{V}/(1+1/\mathbf{k})^{2})+\mathbf{M}_{\mathbf{erg}}(\mathbf{V}/(1+\mathbf{k}))^{2})=\mathbf{V}^{2}(\mathbf{M}_{\mathbf{erg}}\mathbf{M}_{\mathbf{row}}/(\mathbf{M}_{\mathbf{erg}}+\mathbf{M}_{\mathbf{row}})) \qquad (4)$$

Where **k** is a ratio of masses $\mathbf{M}_{\mathbf{erg}}/\mathbf{M}_{\mathbf{row}}$. The higher mass of the ergo or boat, the higher inertial losses, which have the maximal value on stationary ergo ($\mathbf{M}_{\mathbf{erg}}$ = infinity):

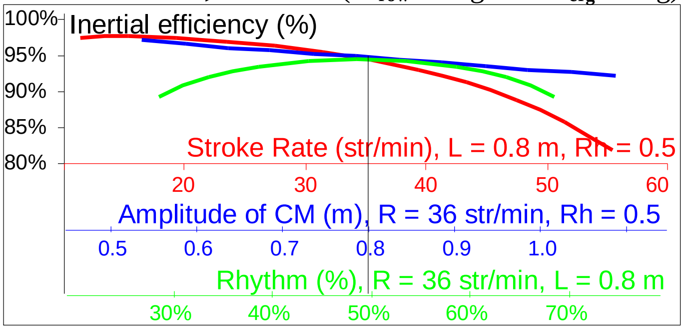


To answer Csaba’s question, the extra 16 kg of his slides (compare to 4 kg standard C2 slides, assuming $\mathbf{M}_{\mathbf{row}}$=90 kg and the stroke rate 36 str/min) would increase inertial losses by 35% (from 32W up to 43W) and by more than 100% compare to a boat or RowPerfect (21W), which requires earlier application of the stretcher force compared to the handle force (RBN 2005/03). Changing the drag factor wouldn’t help in this situation. However, the inertial losses are still only 37% compared to a stationary ergo (116 W).

What can we do to decrease inertial losses? Velocity **V** is the maximal velocity between CM-s and defined by an average velocity $\mathbf{V}_{\mathbf{av}}$ and a pattern of instantaneous velocity curve. The most efficient is a rectangular pattern with constant $\mathbf{V}=\mathbf{V}_{\mathbf{av}}$, but it is not achievable in practice. Triangular pattern with a constant acceleration and deceleration gives $\mathbf{V}=2\mathbf{V}_{\mathbf{av}}$ and increases the inertial losses four times. Sinusoidal pattern, which is the most typical in rowing (RBN 2004/07) and was used in our model here, gives $\mathbf{V}=1.65\mathbf{V}_{\mathbf{av}}$ and 2.7 times less efficient than the rectangular curve.

Average velocity $\mathbf{V}_{\mathbf{av}}$ is defined by the drive and recovery times ($\mathbf{T}_{\mathbf{dr}}$ and $\mathbf{T}_{\mathbf{rec}}$) and amplitude of travel **L** of the rower’s CM relative to machine: **V=L/T**. $\mathbf{T}_{\mathbf{dr}}$ and $\mathbf{T}_{\mathbf{rec}}$ depends on the stroke rate **R** and rhythm **Rh** (= $\mathbf{T}_{\mathbf{dr}}$ / $\mathbf{T}_{\mathbf{cycle}}$).

Absolute inertial losses $\mathbf{P}_{\mathbf{in}}$ significantly increase at higher stroke rates and longer travel of rower’s CM. However, the rower’s power production $\mathbf{P}_{\mathbf{row}}$ also grows (RBN 2004/09), so inertial efficiency $\mathbf{E}_{\mathbf{in}}$ (=$\mathbf{P}_{\mathbf{row}}/(\mathbf{P}_{\mathbf{row}}+\mathbf{P}_{\mathbf{in}})$) do not decrease dramatically. The chart below shows $\mathbf{E}_{\mathbf{in}}$ at various combinations of **R, L** and **Rh** ($\mathbf{M}_{\mathbf{row}}$=90kg and $\mathbf{M}_{\mathbf{erg}}$=18kg):



Between stroke rates **R**=20 and 40 str/min efficiency $\mathbf{E}_{\mathbf{in}}$ decreases only from 96.9% down to 93.8%, but then the curve becomes steeper and steeper, so **42-44 str/min could be an inertial limit of the stroke rate**.

The amplitude affects efficiency linearly: two times longer **L** (0.5-1m) decreases $\mathbf{E}_{\mathbf{in}}$ from 96.5% down to 93.2%. It is difficult to measure the amplitude of CM travel, so we assumed it as a half of the handle travel. Volker Nolte (2) expressed an opinion that a rower should minimise CM travel to decrease inertial losses and maximise the handle travel to increase power production, which is correct mechanically. However, it is likely that it would lead to lower utilisation of big muscles of legs and trunk in favour of smaller muscles of arms and shoulders and could decrease overall rower’s effectiveness.

Efficiency $\mathbf{E}_{\mathbf{in}}$ is the highest at the rhythm **Rh** =50% (drive/recovery=1/1). Deviation of rhythm by 10% changes $\mathbf{E}_{\mathbf{in}}$ only by 0.7%, but another 10% gives a loss of 3.7%.

Concluding, **the inertial losses can be decreased by means of quick acceleration between the rower’s CM and ergo/boat at the beginning of the drive and recovery and maintaining a constant velocity between these masses as long as possible.** This is one more argument in favour of front-loaded drive and fast legs extension at the catch. **An optimal balance of stroke rate, length and rhythm needs to be found to maximise the power and minimise inertial losses.**

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1. Marinus van Holst. 2009. http://home.hccnet.nl/m.holst/KinEn.html
2. Nolte, V. 1991. Introduction to the biomechanics of rowing. FISA Coach 2 (1): 1-5.

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Volume 10 No 111 **Rowing Biomechanics Newsletter** *June 2010*

Ideas

We received very positive feedback on the previous Newsletter and continue discussing inertial losses, now in on-water rowing. We used a similar model: inertial losses equal to amount of kinetic energy, which has to be spent to accelerate the boat and rower's centre of mass (CM) up to a certain maximal velocity during the drive and recovery. We do not take into account the energy required for deceleration, because it can be partially stored in elastic energy at the catch and recycled into propulsive power at the finish (RBN 2006/10). Here we used a reference frame, which moves with a constant velocity equal to the average velocity of the rower-boat system during the stroke cycle. Fig.1 shows velocities of the rower's CM, boat and whole system in this reference frame:

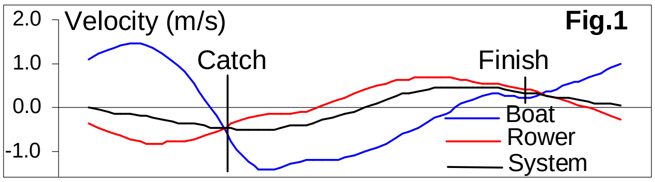

Fig.1

Contrarily to ergo rowing, on water, the whole system accelerates during the drive and decelerates during recovery. A rower can shift emphasis either on acceleration of his CM, pushing the stretcher harder and using legs more or on the acceleration of the boat, pulling the handle stronger and using upper body more. To compare inertial efficiency of these rowing styles, Fig.2 shows two samples of data (two M1x at 41str/min) together with stick-figures from video:

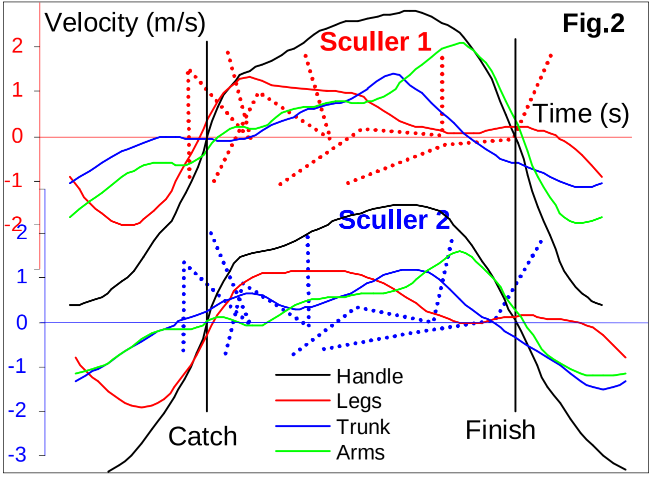

Fig.2

At the catch, velocity of sculler's 1 legs grows faster, earlier than the handle velocity. Sculler 2 use his trunk for the same purpose: for initial acceleration at the blade entry.

At the middle of the drive and finish, sculler 1 is using the trunk more actively and returning it earlier (negative trunk velocity) by means of fast arms pull.

Fig. 3 shows acceleration, velocity and kinetic energy of the boat (measured) and rower's CM (calculated using a method described in 1) for these two scullers.

At the catch, sculler 1 developed both accelerations of the boat and his CM earlier, which lead to a smaller magnitude of negative velocity of his CM. During the drive, maximal positive velocity of his CM also has smaller magnitude because of more active utilization of his upper body at that moment. As a result, peaks of kinetic energy and, therefore, his inertial losses are lower than in sculler 2.

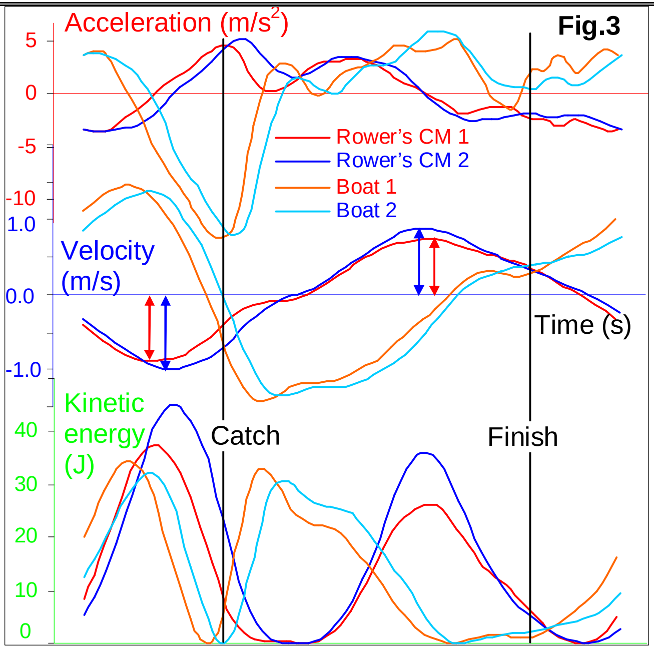

Fig.3

The table below shows amounts of kinetic energy of the boat and rower's CM, inertial losses and efficiency (ratio of the rowing power to its sum with the inertial losses).

	Rower' Inertia			Inertia of the Boat			Total	
Rower	Ekin Recovery (J)	Ekin Drive (J)	Inertial Power (W)	Ekin Recovery (J)	Ekin Drive (J)	Inertial Power (W)	Total Inertial Losses (W)	Inertial Efficiency (%)
1	37.4	26.2	44.2	34.6	33.0	47.0	91.1	**88.0%**
2	45.1	36.1	56.1	32.1	30.5	43.2	99.3	**86.3%**

Sculler 2 has to spend 9% more power to overcome inertia of his CM, being 3kg lighter than sculler 1. The inertial efficiency is 1.7% lower, which alone would decrease speed by 0.43% or by 1.7s over a 2000m race. This is not the only problem, which creates the style of sculler 2: it also makes the catch much less effective (RBN 2006/07, 09), ineffectively utilises muscles-antagonists (RBN 2008/07) and creates a disconnection, a hump on the force curve (Fig.4):

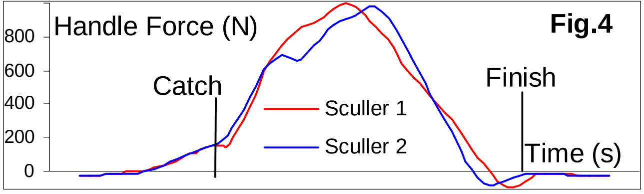

Fig.4

As a result, at the same average force and even higher force per kg of body weight, the speed of sculler 2 was 8.3% slower than sculler 1 (30s per 2k, this could also be affected by weather and 8deg shorter length of the stroke).

Some rowing coaches still believe that the target of efficient rowing technique is maintenance of the most even boat velocity, avoiding of the boat "check" or "disturbing". However, it appeared to be that even velocity of the rower's CM is more efficient and important.

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1. Kleshnev V. 2010. Boat acceleration, temporal structure of the stroke cycle, and effectiveness in rowing. Journal of Sports Engineering and Technology, 224, 1, pp.63-74

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Q&A

We have received positive feedback on the previous Newsletter and an interesting discussion with Marinus Van Holst about the choice of the frame of reference (FoR). He argued that FoR related to the ground of Earth should be used, but not FoR moving with the constant speed of rower-boat system. Being not able to convince each other, I've received another excellent comment from Martijn Weterings, a coach from Wageningen student rowing association Argo, Nederlands, which has resolved our discussion. Here it is with some abridgments:

"To determine internal kinetic energy fluctuations it is very common to use FoR, which is fixed to the CM of the system. Using FoR which moves with constant velocity absorbs the speed fluctuation of the system CM into the equations of the speed fluctuation of the rower and boat (V_{boat}-V_{rower}). However, the speed fluctuation of the CM of the system does not involve energy losses due to internal kinetic energy fluctuations. Therefore, the physical interpretation of the two representations is different. The one using kinetic energy as determined from the reference frame, which does not move with constant velocity, does more purely reflect internal kinetic energy losses. A way to connect the two different paradigms or representations is:

$$E_{kinetic\ total} = E_{rower} + E_{boat} = E_{sys} + E_{in} \quad (1)$$

$$E_{row} + E_{boat} = ½\, M_{row}\, V_{row}^2 + ½\, M_{boat}\, V_{boat}^2 \quad (2)$$

$$E_{sys} + E_{in} = ½\, M_{sys}\, V_{sys}^2 + ½\, M_{in}\, V_{in}^2 \quad (3)$$

The equations 2 and 3 are equal, if:

$$M_{sys} = M_{row} + M_{boat} \quad (4)$$

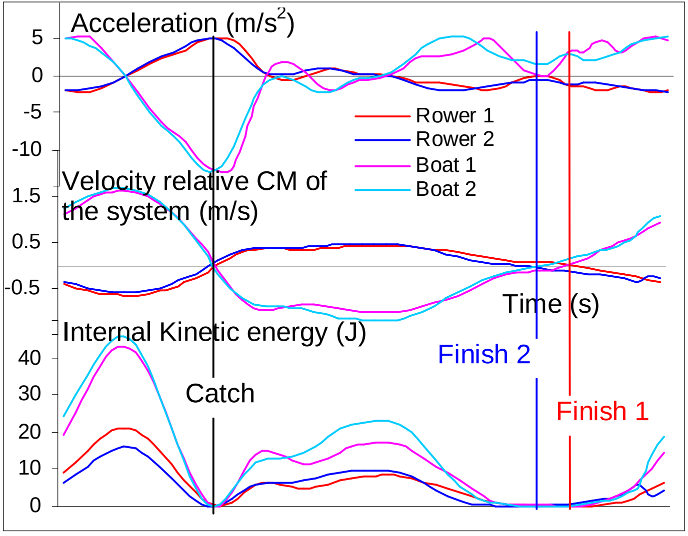
$$V_{sys} = V_{row}\, M_{row}/(M_{row}+M_{boat}) + V_{boat}\, M_{boat}/(M_{row}+M_{boat}) \quad (5)$$

$$M_{in} = M_{row}\, M_{boat} / (M_{row}+M_{boat}) \quad (6)$$

$$V_{in} = V_{row}-V_{boat} \quad (7)$$

Now the difference between the two representations is that E_{in} determines the internal fluctuation inside the rower-boat system and E_{sys} determines fluctuation.." of CM of the whole system in external environment.

We have made additional analysis and calculated velocities and kinetic energy relative to CM of the system, which are presented below aligned at catch for two rowers:



The Table below shows inertial losses associated with internal (variation of $\mathbf{V_{row}}$ and $\mathbf{V_{boat}}$) and external kinetic energy (variation of $\mathbf{V_{sys}}$):

	N	Rower's Inertia (W)	Inertia of the boat (W)	Total Inertia (W)	Energy Losses (%)
Internal Energy	1	20.5	25.4	46.0	**6.4%**
	2	17.9	25.5	43.4	**6.5%**
System Energy	1	23.6	21.5	45.2	**5.6%**
	2	35.6	15.1	50.7	**6.6%**
Total Energy	1	44.2	47.0	91.1	**12.0%**
	2	53.5	40.6	94.1	**13.1%**

The internal inertial losses were still lower in rower 1, but by a very small margin 0.1%. So, most of the difference in speed should be explained by other factors.

Internal and external inertial losses are split nearly equally in these two rowers. In fact, the second one is not "losses" by the nature: this is the amount of kinetic energy, which the system accumulates during the drive and spends during recovery to overcome the drag resistance. In this case, the choice of FoR does matter, because more power required to create propulsive force $\mathbf{F_{prop}}$ and increase kinetic energy at higher velocity $\mathbf{V_{prop}}$ relative to the environment:

$$\mathbf{P = F_{prop}\, V_{prop} = ½\, M_{sys}\, (V_{cm2}^2 – V_{cm1}^2)/dt} \quad (8)$$

It is similar to the acceleration of a car, which requires more power of the engine at a higher speed. Therefore, **FoR based on the substance used to create propulsive force, the water in this case, should be chosen for the whole system. Internal inertial losses should be calculated relative to the CM of the system, which makes them very similar to ones on the ergo** (see RBN 2010/5).

Q: Martijn Weterings also asked: "Did you take into account effects of boat velocity variations on drag? I guess that rower 2 has a lower average of the cubed boat velocity. … I can imagine that the difference would be less pronounced when drag is taken into account."

A: We have found that indeed the difference between maximal and minimal boat velocity during the stroke cycle was lower in sculler 2: 1.34 m/s compare to 1.43 m/s in sculler 1. However, if we take a ratio of these values to the corresponding average boat speed, then sculler 1 had lower relative amplitude of the boat velocity variation: 24.7% compared to 25.2% in sculler 2. When energy losses were estimated, it was found that the boat velocity efficiency (RBN 2003/12) was also higher in sculler 1: 93.1% compared to 92.3% in sculler 2. This means that the first sculler loosing only 2.37% of the boat speed (8.2s over a 2k race) compared to his less efficient opponent, who is loosing 2.64% or 9.9s over 2k race.

We can conclude that **attempts to achieve a more even boat speed by using the upper body at the catch doesn't work**. Sculler 2 had higher variations of the boat velocity and has lost 0.28% more of the boat speed for this reason (1.2s over 2k race), which contributed to the total 8.3% difference in the speed between these two scullers.

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Q&A

Q: "Why are sculling boats faster than rowing boats with the same number of athletes?" This question was discussed on a forum http://groups.google.com/group/rec.sport.rowing.

A: Using our database we compared four categories of boats: 2x vs. 2- and 4x vs. 4- (n=2738). Length of the stroke (Table 1) cannot be compared directly because sculling and rowing use different length of the inboard, which causes different oar angles. Comparison of the length of the arc derived using our method (at 6 cm from the top of the handle in sculling and at 15 cm – in sweep rowing) gives very similar numbers between rowing and sculling:

Table 1	Oar angle (deg)		Arc Length (m)		Arc/Height (%)	
Sex	M	W	M	W	M	W
Rowing	86.9	85.0	1.56	1.54	83.7%	85.2%
Sculling	107.9	105.8	1.58	1.56	83.5%	89.2%

Displacement of each body segment was measured in pairs and doubles (Table 2) and their shares in the total length and power were derived:

Table 2	Legs (%)		Trunk (%)		Arms (%)	
Length	M	W	M	W	M	W
Rowing	35.1%	35.3%	30.7%	32.4%	35.1%	33.8%
Sculling	34.1%	34.0%	27.4%	32.4%	39.0%	34.9%
Power	M	W	M	W	M	W
Rowing	42.7%	42.1%	34.3%	35.2%	22.8%	22.4%
Sculling	43.6%	44.4%	30.2%	33.8%	26.3%	21.7%

Male scullers use relatively longer arms drive and produce more power by arms than sweep rowers. In females this difference was less significant. The possible reasons are: geometry of sculling and specifics of the sculling style.

Table 3	Max.Force (N)		Aver.Force (N)		Av.F/Weight (N/kg)	
	M	W	M	W	M	W
HSw	664.9	503.3	332.8	255.6	3.78	3.48
LSw	576.0		291.5		4.02	
HSc	739.8	529.2	388.0	274.9	4.43	3.70
LSc	699.4	465.2	370.9	250.0	5.06	4.25

Force application was found significantly higher in sculling (Table 3). The possible reasons could be:

- When the force measured as a torque at the oar, inside arm in sweep rowing has much shorter leverage and, therefore, produces much less torque and oar bend.
- Sculling is symmetrical and more comfortable.

Rowing power is highly dependent on the stroke rate, so we need to analyse trends (second order polynomial) of this variable as well as trends of its components (length, force and work per stroke). Figure 1 shows that both relative length and force achieve their maximum at 28-30 str/min in sculling and at 32-34 in rowing. Then they decrease and these drops are more significant in sculling. Consequently, the work per stroke and power are higher in sculling at low stroke rates, they are equal at 38 str/min and higher in sweep rowing when the stroke rate increases further. Probably, this is the reason why racing stroke rate is usually higher in sweep rowing than in sculling (RBN 2005/02): on average it is 38.9 in pairs and fours compare to 37.8 str/min in doubles and quads.

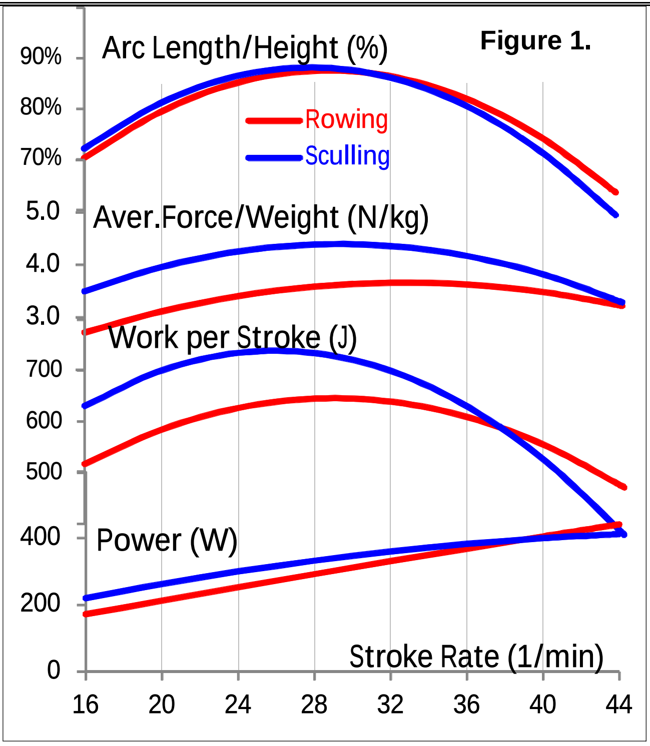
Figure 1.

The chart explains why forces were significantly higher in sculling in Table 3: because the data was averaged over the whole range of the stroke rates. At the racing stroke rates 36-40 str/min the forces are only slightly higher in sculling, but the length became shorter. We can conclude that **power production at the racing stroke rates does not differ significantly between sculling and rowing**.

Table 4.	2- & 2x	4- & 4x	Blade Efficiency
Rowing	79.7%	81.5%	80.5%
Sculling	83.1%	85.3%	84.6%

Table 4 shows that the blade efficiency was on average 4.1% higher in sculling boats, which makes them 1.4% faster than similar rowing boats. The reasons could be:

- bigger total area of sculling blades, which causes lower relative pressure and less slippage in the water
- longer angles at catch in sculling, which cause better utilisation of the hydro-lift effect;
- better manoeuvrability of sculling blades, which cause shorter catch and release slips (RBN 2009/10).

Having the difference in speed between similar rowing and sculling boats 3.3% on average (RBN 2009/04), we could speculate that the rest 1.9% difference could be related to the following factors:

- Sweep oars produce higher air drag during recovery because they are longer. We estimate this loss as 0.3%.
- Rowing boats are usually asymmetrical, which cause a wiggle and additional losses in speed (RBN 2009/11).
- Rowing boats have a rudder creating an extra drag.

We can't estimate yet the effect the last two factors and would leave them for future studies.

Finally, **the difference in speed between sculling and rowing can be explained only by higher efficiency of sculling blades and boats**.

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Volume 10 No 114 **Rowing Biomechanics Newsletter** *September 2010*

Q&A

Here we try to answer five questions regarding pitch.

Q: "Why do we need a certain pitch on the blades?"

A: Pitch of the blade (an angle of leaning of the vertical axis of the blade, Figure 1) is needed, because during the first half of the drive the handle is much lower than the shoulders making it difficult for rowers to pull the handle horizontally. The force vector at the handle can be decomposed into two components: horizontal and vertical. When transferred through the oar as a first class lever, these components change magnitude (according to a gearing ratio) and direction (to opposite). The horizontal component creates a propulsive force at the blade and vertical component makes a downwards force, which sinks the blade. The pitch angle at the blade is needed to overcome this vertical force and allow the blade to move horizontally.

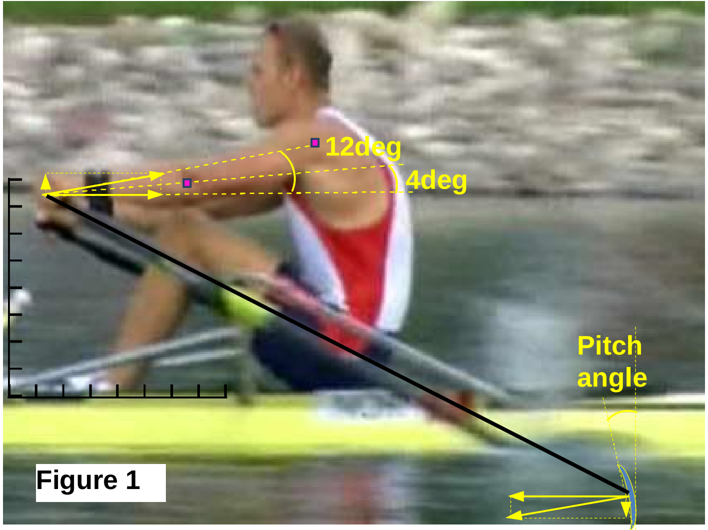


Figure 1

At the catch, when pulling through straight arms, an estimated angle of the force vector should be around 12 deg. If we set this pitch, than 20% of the total force will be directed vertically (sin(α)) and propulsive force will be decreased by 2.2% (1-cos(α)), which is a significant loss.

Rowers have another option: to bend ("grub") the arms and pull more horizontally towards the elbows, which would require less pitch on the blade. Usually, rowers use a combination of these two methods: they "grub" with the arms, but still pull at a small angle to horizon, which requires a small pitch. **In case of the most common pitch 4 deg, only 0.24% of the propulsive force is lost**(9 times less than at 12deg pitch) and the vertical component is 7%.

Q: "Does it make sense to set zero pitch and pull absolutely horizontally, but "grub" the arms more?"

A: It doesn't. It would require more energy from the muscles for a very small gain in propulsive force. Also, it would eliminate the vertical component completely, which plays a positive role because it pushes the boat upwards, reducing its vetted surface and, therefore, drag resistance.

Q: "Can we increase the handle (and the gate) height enough to eliminate "grubbing" arms?"

A: It is not possible for two reasons:

1. The higher a handle (from the stretcher), the lower handle force required to lift a rower from the seat (RBN 2002/05), so a higher handle would limit the force application at the catch.
2. At the finish, when arms are bending, the force vector is directed more horizontally: towards elbows at the level of the middle of the chest (Figure 2):

Figure 2

The most comfortable height of the handle decreases by 10-20 cm during the drive. The slope of the slides reduces this difference by 1-2 cm, but cannot eliminate it at all. It is not possible to increase the slope further because the rower will need to spend ~~a~~ significant energy for the climb, which would reduce propulsive power applied to the handle. Therefore, **the height of the handle (and gate) is defined mainly by a comfort for a rower at finish**.

Q: "Should we change the pitch, when changing gate height?"

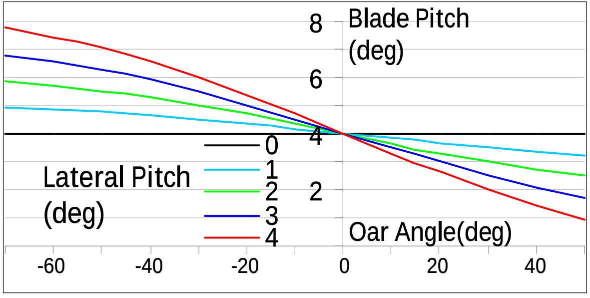
A: Change of the direction of the force vector dP in degrees can be defined as:

$$dP = 180\, dH_g L_{oar} / \pi\, L_{arms}\, L_{out} \qquad (1)$$

where dH_g is the change of the gate height, L_{oar} - actual oar length, L_{arms} - length of the arms from shoulders to the handle, L_{out} - actual outboard length. For common values of above parameters, every 1 cm of decrease of the gate height makes the force vector 0.6 deg more vertical and vice versa. Therefore, **a lower gate height requires more pitch and more significant arms "grubbing and vice versa.** Remember that the handle height depends also on the boat height above water.

Q: "We know that some crews use lateral pitch of the pin. Does this make sense?"

A: Lateral pitch (leaning of the pin outwards) is useful to overcome the difference in comfortable height of the handle and maintain a more constant force vector, because it increases the blade pitch at catch and decreases it at finish:



We recommend a lateral pitch of 2-3 deg, which would increase the blade pitch up to 5-6 deg at catch (4 deg at the middle), and decrease it down to 2.5-3 deg at finish.

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Q&A

Recently, together with Concept2, we performed a pilot study of the new Dynamic Indoor Rower (DIR) and compared its biomechanical features with a stationary erg, erg on slides and on-water rowing in a boat.

On DIR - Hamish Bond, stroke of 2-NZL, World Champions -2009

Below you can find answers to some coaches' questions:

Q: "What are the main characteristics of the Dynamic erg, compared to other ergs and on-water rowing?"

A: Rowing on DIR is quite similar to rowing on an erg on slides: the force increases faster at the catch then on a stationary erg (Fig.1), which is caused by a smaller moving mass and lower inertia forces (RBN 2003/10). The magnitude of the handle force is similar on all types of ergs and significantly higher than on-water, due to the presence of a gearing in a boat (RBN 2005/03).

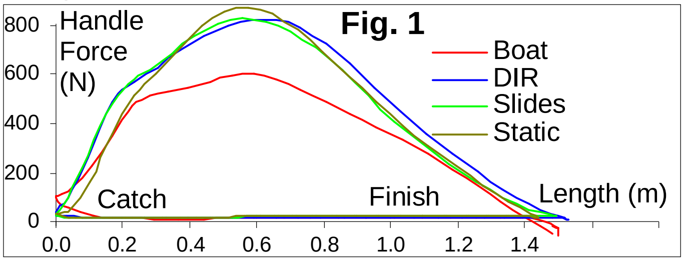

Fig. 1

The DIR had the largest inertial efficiency (RBN 2010/07) 98.1% at 37 str/min,, compared to a boat (95.3%), slides (91.6%) and stationary erg (82.1%). This allows for higher stroke rate on DIR and, possibly, faster times than on stationary erg.

Q: "What sort of interpretation can be given for the seat movement on DIR?"

A: The seat velocity is closely associated with velocity of the rower's centre of mass (CM). On water, it can be presented as the velocity relative to the frame of reference, which moves with a constant velocity, equal to the average speed of the boat over stroke cycle. In this case, patterns of the seat velocity are similar on-water, on DIR and on slides:

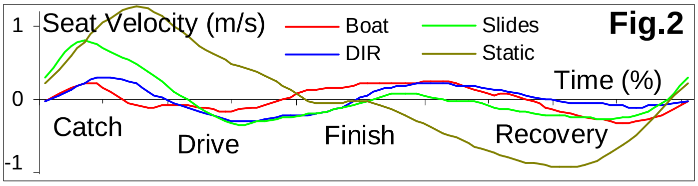

Fig.2

Velocities of the rower's CM and boat (or mobile stretcher on DIR, or erg on slides) are integrals of their accelerations, which depend on the ratio of handle and stretcher forces. Emphasis on the stretcher force accelerates rower's CM, but decelerates boat CM and vice versa. A rower can control these forces by executing various rowing styles. Using legs to initiate the drive increases the stretcher force and acceleration of rower's CM, but decelerates the boat. Using trunk early in the drive increases the handle force and accelerates the boat, but decelerates rower's CM. Fig.3 shows body segments velocities and associated seat and stretcher velocities of two rowers with different styles on the DIR at 37 str/min:

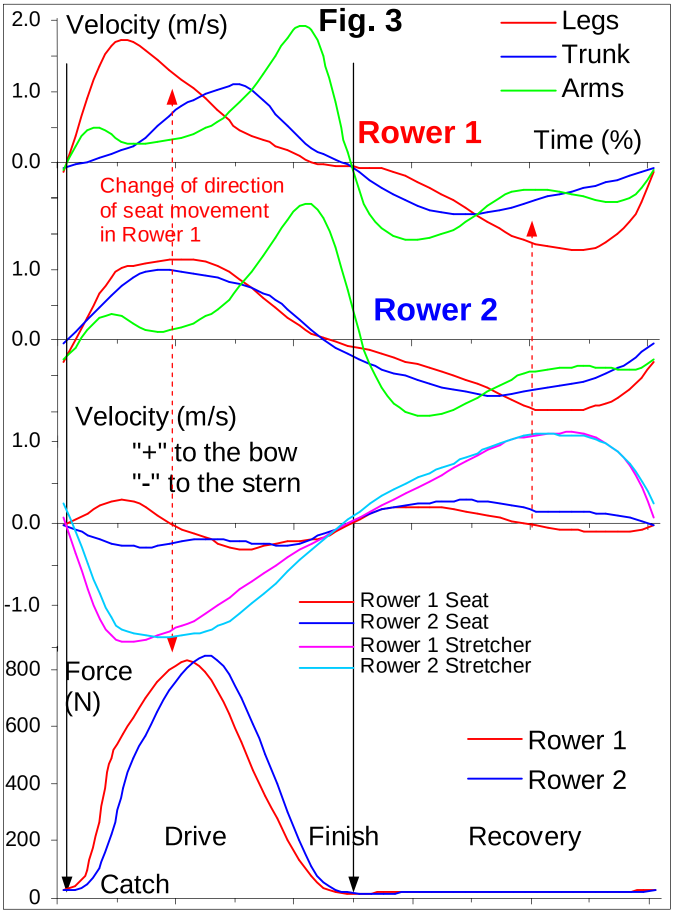

Fig. 3

Rower 1 exhibited a consequential rowing style (in between Rosenberg or Ivanov style, RBN 2006/03), where the drive begins with emphasis on leg drive only. The seat (and rower's CM) moves to the bow first and then starts moving to the stern, when the rower's legs slow down and the upper body becomes more active. The stretcher decelerates sharply to the stern at catch, but then its velocity increases faster, which is similar to the boat acceleration on-water. During recovery, Rower 1 returns trunk first, then follows with legs later but faster, then he pushes the stretcher earlier and seat velocity changes the direction from bow to stern.

Rower 2 has a simultaneous style (in between Adam and DDR) with legs and trunk working together after catch. The seat moves slowly to the stern through out the drive. Also, the stretcher velocity is much more even: no sharp deceleration at catch, but no fast acceleration during the drive either. During recovery, Rower 2 returns legs and trunk closer to each other (mirror principle, RBN 2006/03), which causes continuous movement of the seat to the bow.

It is interesting that Rower 1 had a faster increase of the handle force than Rower 2, which could be considered as an advantage and demonstrates greater effectiveness of the consequential style.

Conclusion: **seat movement on Concept2 Dynamic Erg is a good indicator of rowing style**: Consequential style causes change of the direction of the seat movement during the drive and recovery; in simultaneous style the seat moves continuously towards the stern during the drive and to the bow during recovery. A similar phenomenon can be observed on-water or with erg on slides, but it is more obvious on DIR because the seat moves relative to the stationary frame.

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News

The results of the recent World championships in Karapiro, New Zealand (see Appendix 1 below) show that the leaders, Great Britain have made their position stronger: last year they won six medals in Olympic events, one of them gold, but this year they won nine medals, four of them were gold. The Brits definitely intended to smash their opposition during their home Olympics-2012.

The hosts of the championships, New Zealand won seven medals in Olympic events, three of them were gold. This is one step up compare to the last year, when the «kiwis» got "only" five medals.

The Aussies increased their rank from seventh place last year to third. They doubled the amount of medals compare to 2009 with four medals now, though no gold among them, except gold Thomas Keller medal awarded to the great James Tomkins.

The Germans have fallen from second place down to fourth, with only three medals after five last year. This bitter fact was sweetened by the most prestigious gold medal in M8+.

The Greeks under wise leadership of Gianni Postiglione increased their rank from the ninth place last year to the fifth now. They got three medals, one more compared to 2009, though no gold this year.

The Americans conclude the six best countries of the World with more points than Greeks, but with only two medals, which is one less than last year.

Facts. Did you know that…

…using EMG (electro-myography) is the best method to study muscle activity in any human movement? A pilot study was conducted on a mobile rowing ergometer with the purpose to evaluate the sequence of muscles activation during the stroke cycle. Three most powerful muscle groups were chosen: quads (*Rectus femoris*), hamstrings (*Biceps femoris* and *Semimembranosus*) and gluts (*Gluteus medius*). Delsys Myomonitor® wireless EMG system was used and eight electrodes were placed on right and left muscles of the above groups. Six samples were taken on a sculler of an international level at the stroke rates 20, 24, 28, 32, 36 and 40 str/min. Fig.1 below shows the EMG of three major muscle groups at 36str/min in conjunction with velocities of the body segments.

Activity of the quads began significantly earlier than the catch, because the rower needs to decelerate the relative movements of the masses at the end of recovery and then start their acceleration at the beginning of the drive. It is interesting that activation of the quads decreased down to zero after the legs achieved their maximal velocity (moment 1 on Fig.1) and the rower started using his trunk. Hamstrings and gluts rapidly increase its activation at this moment. This could be a specific feature of this rower as he has a hump in the legs velocity curve at the same time, which may indicate a lack of coordination of activities of the quads and hamstrings (RBN 2008/07). The pattern of the quads activation has three peaks during the drive and the second peak (moment 2) corresponds with the second peak of legs velocity. The third peak of the quads activation occurred at the finish of the drive – beginning of recovery has the highest electrical activity. This can be explained by a hip flexion action (*rectus femoris* is connected to the pelvis) and pulling the stretcher through, which requires straight legs.

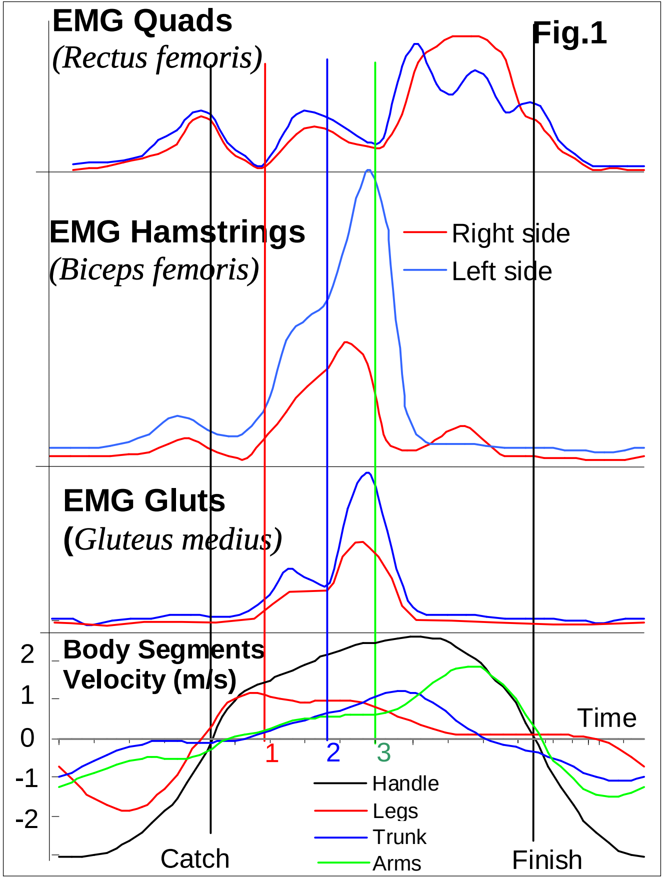

Fig.1

The peak of trunk velocity (moment 3) coincides with the peak of EMG of hamstrings and gluts, which produces the highest power during the drive through rotation in hip joints.

It is noticeable that EMG curves are quite asymmetrical: left hamstring and glut produce higher electrical impulse at the middle of the drive, but right quads do more at the finish of the drive. This could be related to a specific injury of the athlete.

Concluding, **EMG method shows a good correspondence with mechanical variables of rowing and may be used for evaluation of rower's technical effectiveness.** The method requires further development of the analysis routine based on various patterns of rowing technique both on-ergo and on-water.

Acknowledgment for the support of this study is given to the English Institute of Sport and British Rowing.

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Appendix 1

Ranking of the countries based on results in 14 Olympic events on the World Championship 2010 in Karapiro, New Zealand and its comparison with results of 2009 World championship in Poznan, Poland.

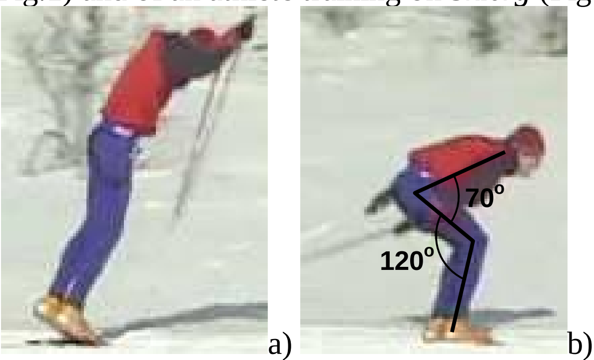
Rank		**Number of places 2010**							**Medals**	**Points**	**Rank**	**Medals**	**Points**
2010	**Country**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**2010**	**2010**	**2009**	**2009**	**2009**
1	GBR	4	4	1	2	2			9	75	1	6	50
2	NZL	3	1	3		1	2	2	7	54	3	5	39
3	AUS		2	2	3	1		1	4	38	7	2	23
4	GER	1	1	1	2	1	3	3	3	39	2	5	55
5	GRE		1	2					3	16	9	2	14
6	USA	1		1		3	1	1	2	25	5	3	27
7	CAN	1	1		1	1		1	2	22	13	1	13
8	ITA		2		1		2		2	20	12	1	16
9	FRA	1		1			1	1	2	16	6	2	27
10	CZE	1			2				1	16	8	2	18
11	CHN			1		2	1	2	1	15	23	0	3
12	SWE	1						1	1	9		0	0
13	CRO	1							1	8	21	0	4
14	BLR		1						1	6	14	1	10
15	UKR		1						1	6	16	1	8
16	ROU			1				1	1	6	11	2	12
17	POL			1					1	5	4	4	32
18	NED				1	2			0	10	10	2	12
19	NOR				2				0	8	24	0	2
20	RUS					1	1		0	5	22	0	4
21	POR						1		0	2		0	0
22	SLO						1		0	2	15	1	9
23	SRB						1		0	2	25	0	3

Red colour means improvement,
blue colour – decrease of results.

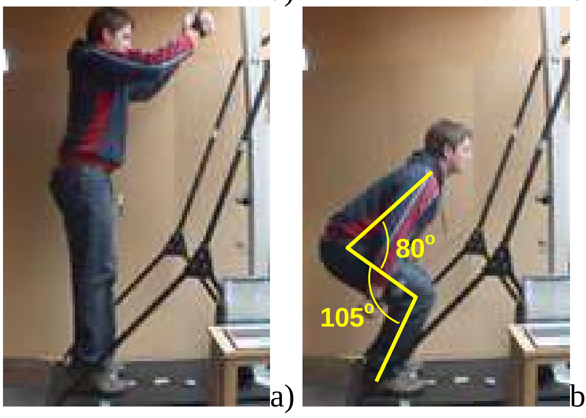
Facts. Did you know that…

…skiing is an excellent aerobic exercise that is often used by rowers as a cross training activity during the winter? Thanks to Concept2 *Skierg* this exercise is available indoor during all weather conditions. A workout on the *Skierg* replicates the movement of double polling, a specific propulsion method used by Nordic skiers to move on snow. At first glance, *Skierg* looks like it emphasizes arm work. However, our analysis reveals that less than half of the power is delivered by arms (on average 44%) and the rest is delivered by trunk and legs (56%).

To make our study comparable with real Nordic skiing we conducted a brief video analysis of a good skier executing the double poll movement on snow (Fig.1) and of an athlete training on *Skierg* (Fig.2).



a) b) **Fig.1.**



a) b) **Fig.2.**

Positions at the drive start were very similar: handles were level the top of the head, legs were nearly straight and feet lifted on the toes. The only difference is forward body lean on-snow. This position results from body acceleration, which is absent on *Skierg*. Positions at the finish were also quite similar: feet on the heels, knee angle between 105-120deg, hip angle between 70-80 deg.

The *Skierg* was equipped with two force transducers installed between the handle and cable and three position transducers, which measured displacements of the handle, top of the trunk (*Th1-C7* level) and pelvis (*Sacrum*). Three athletes performed a set of 4 trials 1 min each at the target stroke rates 25, 35, 45 and 55 str/min. The data was sampled at 50 Hz and averaged over duration of whole trial.

Fig. 3 shows averaged force curves (sum of left and right handles) and their shapes were quite similar to the shapes of force curves measured in rowing. The maximal peak force was a bit less than 500 N, average force was 280 N, which is 20-30% less than in rowing for similar athlete. Contrarily, stroke length was very similar to the length of the arc in rowing: at low stroke rate it was 1.55m and decreased at higher stroke rate down to 1.4m. Power production was quite comparable with rowing (about 400W), which was achieved by higher stroke rate.

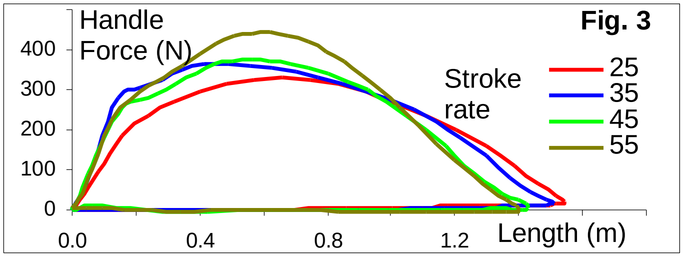


Fig. 3

Sequence of the body segments is also similar to rowing: legs and trunk dominate during the first half of the drive and arms finish the drive (Fig. 4 and 5 represents the highest stroke rate). Legs deliver about 20% of the total handle displacement, trunk – 32% and arms – the rest 48%. However, because the peak force coincides with the highest velocity of the trunk, their shares in power were 20%:36%:44% (legs/trunk/arms). This looks like a mirror to rowing, where segments' shares were 46%:31%:23% (RBN 2002/02).

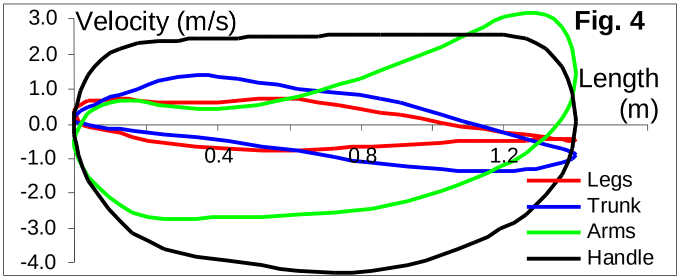


Fig. 4

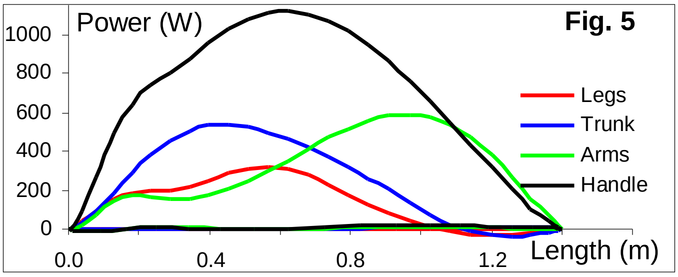


Fig. 5

Surprisingly, *quadriceps femoris* muscles are heavily loaded in the double polling exercise, because they are used in both drive and recovery phases and have practically no chance to relax. During the drive these muscles are used for hip flexion through their upper side connected to the pelvis. During the recovery phase quads are used for knee extension through their bottom side connected to the shin. Gravity force assists legs and trunk performing the drive, but during return phase this force must be overcome by action of muscles antagonists. These movements make a **workout on the *Skierg* a great full body exercise**.

Best wishes for the Christmas and New Year 2011!