Volume 9 No 94 **Rowing Biomechanics Newsletter** *January 2009*

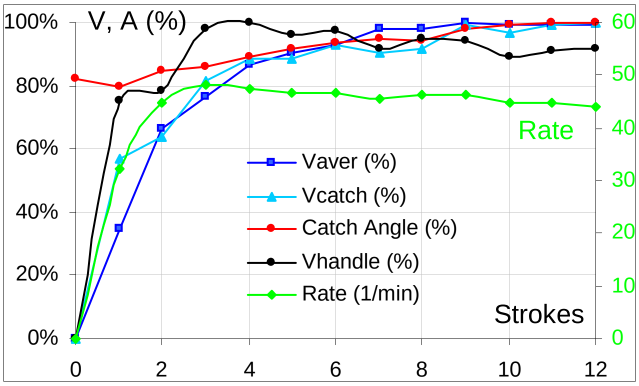
Q&A

Q: *Aj Harper, a coach of the high performance regional program in New Zealand asked: "Have you any information on the best possible racing start for a boat/types? Most people I speak to tend to use the basic, full, half, three quater, full scenario. However I was speaking to someone the other day who suggested just full strokes only is the way to go."*

A: Definitely, doing full strokes is not the best way to do starts for the following reasons:

- The gear ratio is higher (heavier) with a long catch angle (RBN 2007/03), which makes rowers work in a slow, static and inefficient mode.
- The hydro-lift effect doesn't work at low boat speeds (RBN 2007/12), so pushing the blade outwards at the catch increases its slippage through the water and amount of energy wasted.

To evaluate correlation of the catch angle with the boat velocity we have analysed a start of an international level crew:



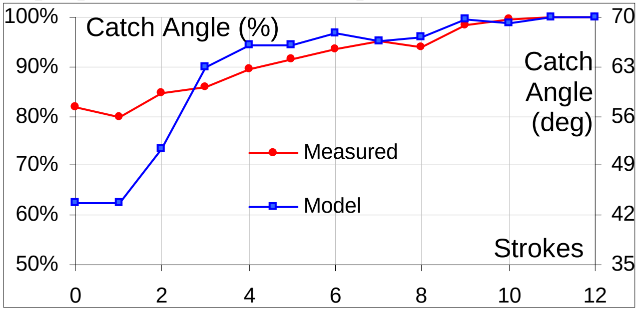
The average boat velocity over the stroke cycle ***Vaver*** achieved 90% of its maximal value at the 5th stroke, 98% at the 7th and 100% at the 9th stroke. The boat velocity at the catch ***Vcatch*** is not the same as ***Vaver*** because the speed varies during the stroke cycle. The most significant difference was after the first stroke, because there was the highest variation of the boat velocity from the stationary position. We used ***Vcatch*** for further calculations because it defines the interaction of the blade with the water at the catch.

The catch angles were approximately 80% of the maximal value during the first three strokes. Then the length increased gradually and reached its maximum in the same stroke (the 9th) as the boat speed.

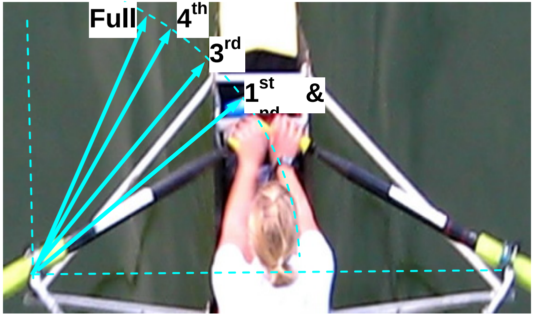
When we divided ***Vcatch*** by the actual gearing ratio derived using the catch angle (RBN 2007/03), we obtained the corresponding handle speed, ***Vhandle***, which was significantly lower during the first two strokes. This means the rower had to work in a slow, heavy mode, which decreased the boat acceleration and muscle efficiency.

We made the hypothesis that maintaining a more even actual gearing may increase the efficiency of the start. In simpler words, it means that the catch angle should increase proportionally with the boat speed during the start. What sort of angle should a given crew use in this case?

The chart below shows the measured angles from the previous chart and modeled angles, which are proportional to the boat speed (***Vcatch***):



At the catch of the first stroke the boat speed is zero, so we assumed its angle would be equal to the angle at the second catch. The optimal sequence is the following: the 1st and 2nd strokes – 62% of the full catch angle, the 3rd – 73%, the 4th – 90% and then gradually increasing to 100% at the 9th stroke. To give you some numbers in degrees we put them on the right Y axis, assuming the full catch angle is 70 deg. What should these angles look like in a boat? The picture below illustrates them:



The first two catches should be made with the handle position above the toes of the stretcher, so-called "half slide"; the 3rd catch – "three quarters slide", the 4th – about 10cm shorter than the full length, which should be achieved by the 9th stroke.

The hypothesis needs to be proved in practise by means of analysis of various start techniques. Also, blade slippage and hydro-lift effect should be considered. We hope to do it in the future.

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Q&A

Q: *Roger Moore a senior boys coach at Pembroke School, Adelaide, South Australia asked: "Do you have any figures regarding coxswains weight and the effect on boat speed, in particular an the eight? I have an important race in a few weeks and my coxswain is 11kg overweight. Our recent races have been decided by only 1-2s."*

Another coach asked a similar question: "Would it be possible to use the formula for determining the effect of dead weight on boat speed … to calculate the expected time for a coxed four based on their 2000m time in the coxless fours. In other words: Is a coxed four nothing more than a coxless four with 55 kg of excess baggage in terms of drag factor?"

A: There are three components of the influence of extra dead weight on the speed, which affect it in different directions:

1. Higher drag resistance force caused by higher mass of the system and consequently greater water displacement;
2. Higher inertial losses, which decrease propulsive power because the rowers have to move a heavier mass back and forth;
3. Lower energy losses caused by reduced fluctuations of the hull velocity in the water.

The first component can be estimated using empirical equations for the dependence of the drag factor on the rower's mass (RBN 2007/07). The drag factor depends on the amount of water displaced by the hull, which equal to the total mass of the system. Therefore, we can add the dead weight to the rower's mass. We need to calculate two values (DF_1 and DF_2) for the drag factor for each mass (without and with deadweight) using equations in Table 1 of RBN 2007/07. Then using the equation $P = DF * V^3$ and assuming that power production P is constant we can derive the equation for the ratio of the speeds:

$$V_1 / V_2 = (DF_1 / DF_2)^{1/3}$$

Drag caused by 1kg of extra dead weight per rower decreases the boat speed by 0.061% or 0.21s over a 2k race in a time of 5min 40s.

The second component (inertial losses) can be derived using mathematical modelling with sinusoidal movement of two known masses relative to each other. We found that at a rate 36 str/min and relative displacement 0.6m, each 1kg of extra dead weight per rower decreased the boat speed by 0.33% or 1.13s over a 2k race. This value depends on rowing technique and can be decreased by means of transferring kinetic energy to blade propulsion at the finish of the drive (RBN 2006/10). Using the measured data analysis we took it as 0.24% or 0.81s over a 2k race.

We modelled the third component in a similar way and found that each 1kg of extra dead weight per rower would make the boat speed smoother and increase its average value by 0.11% or 0.37s over a 2k race. We think this is a maximal value; if, with poor technique, the rowers rush the recovery increasing fluctuations in hull velocity, then this value will be reduced (RBN 2007/10).

The table below summarises these values, assuming that rowing technique is good:

1kg per rower extra DW	Speed losses (%)	2k race in 5:20	2k race in 7:10
Drag factor	-0.061%	+0.20s	+0.26s
Inertial losses	-0.240%	+0.77s	+1.03s
Speed fluctuations	+0.110%	-0.35s	-0.47s
Sum	**-0.191%**	**+0.61s**	**+0.82s**

Every 1kg of extra dead weight per rower can decrease the boat speed by 0.19% or about 0.7s slower over a 2k race in 6:00.

If we refer to the second question about coxed and coxless fours, we find that 55kg of extra dead weight (EDW) in a four (13.75 kg per rower) would make the boat 9.5s slower over a 2k race in 6:00. Similar analysis for a pair (27.5kg of EDW per rower) gives us 21.3s slower over 2k in 6:40.

We compared these values with the results of Olympics-92, where the coxed four and pair events were last contested. The difference in results between M4- and M4+ for the winners was 4.3s and the average for the finalists was 6.4s, which is lower than the above value. In M2+ and M2- these differences were 22.1s and 20.5s respectively, which is very close to the predicted value.

Biomechanical conditions are also quite different; in heavier coxed boats, it is more difficult to transfer power through the stretcher (RBN 2008/12). The leg drive is slower and more load is applied to the upper body, and so rowing in coxed boats more closely resembles ergo rowing. In coxless boats, a fast leg drive and work though the stretcher are more important.

Our summed factor -0.19% corresponds quite well with findings of other authors (1, 2). However, they analysed only the drag factor component, which represents only 30% of the total value in our analysis. Probably, a further discussion is required.

References

1. Atkinson B. 2001. The Effect of Deadweight. http://www.atkinsopht.com/row/deadwght.htm
2. Dudhia A. 2008. Effect of Weight in Rowing. http://www-atm.atm.ox.ac.uk/rowing/physics/weight.html#section7

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Coach and Biomechanics: Jurgen Grobler

Jurgen Grobler is one of the most successful coaches not only in the rowing World, but also in all Olympic sports. His crews won gold medals in all eight Olympics from 1976 to 2008, a total of 9 Olympic gold and 2 bronze medals, and his athletes also contributed to 7 other Olympic titles.

Jurgen was born soon after the World War II in a small town Burg near Magdeburg, East Germany into the family of a successful architect. In childhood, he enjoyed a variety of school sports: handball and other ball games, swimming and water-polo, fishing, etc. He discovered rowing at the age of 16 and tried nearly all boat types from singles to eights, winning titles in the National student championships. Jurgen also liked photography, which he did as “a pioneer” after-school activity. This hobby and his dreams to travel around the world inspired him to become a TV cameraman. However, only 3-4 interns for this profession were required in the DDR, which was not a very big country. Therefore, Jurgen decided to become a coach and in 1965 entered the sport education faculty of Leipzig University. At Uni, he studied all sport sciences: Physiology, Biomechanics, Psychology, Biochemistry, training theory and also communist philosophy; the last was not really interesting for a rowing coach. The topic of his master’s thesis was Biomechanics of Canoeing. Force transducers were attached to a canoeing paddle and kilometers of oscillographic paper were consumed recording the signals. During his last year in Uni, Jurgen had to practice as a coach at the Dresden rowing center. His mentor was Dr. Hans Eckstein, who coached the Olympic champions in M4- at Mexico-68 and Munich-72. Another mentor was the head of the National team Prof. Korner. They both gave Jurgen a lot of insight and knowledge in rowing.

After graduation from Uni in 1970, Jurgen became a sculling coach at the Magdeburg high performance centre. He was very innovative, trying various “crazy” things. In spring 1972, at the Moscow regatta his double lost only to the USSR crew, who became Olympic champions a few months later. Then a sculler (Gueldenpfenning) from his double won the National championship and qualified for the Munich Olympics, where he won the bronze medal. That was a real success for a 26 year-old coach. He repeated this result the next year at the European Championships. After this, Jurgen became a recognised coach for the National Team and achieved fantastic success at the Olympics-76 in Montreal. Two of his crews won gold medals, in the M2+ (Jaehrling/Ulrich) and M4x (Gueldenpfennig/ Reiche/ Bussert/ Wolfgramm) events.

At that time, Sport Science was rapidly developing in the DDR and evolved into a centralized system, which could be accessed by all the regional centers such as Leipzig, Dresden, Magdeburg and Rostock. Such well known scientists as Profs. Korner, Burmann, and Schwanits worked with rowing at Humboldt Uni in Berlin. National frameworks were developed centrally in various areas of science and had to be followed by all coaches in the country. Biomechanical testing was provided regularly 2-4 times a year by FES in Berlin, which had a big team of scientists and technicians. They developed various sorts of transducers and used special dedicated boats. They used a solid frame connecting the stretcher with the swivel (similar to the sliding rigger, of later years), and they were able to measure the propulsive force of each rower. First, the information was recorded on a magnetic tape, and then radio data communication was used. In Moscow-1980, Jurgen’s coxed pair repeated their Olympic success. The next Games in Los Angeles were missed owing to the political boycott. At the Seoul-88 Olympics, Jurgen switched to females with his usual success, the double Peter/Schroeter winning the gold.

After the fall of the Berlin Wall in 1989 and the unification of Germany, the East German sport system collapsed and was acquired by its “big brother”. In 1990 Jurgen took on a new challenge and accepted an invitation from the Leander Club and went to the UK. Rapidly, he became the National coach and worked with the Redgrave/Pinsent pair, who won the gold medal at the Barcelona-92 and Atlanta-96 Olympics. In 2000, the two famous rowers moved into a four and at the Sydney Olympics Jurgen helped Steve Redgrave to win his fifth gold medal. His coxless fours also won at the last two Olympics. At Athens, Matt Pinsent won his fourth gold medal, and in Beijing a new crew James/Williams/Reed/Hodge won with a fantastic finishing spurt.

Grobler believes that a combination of scientific and practical approaches is the key to his phenomenal success. He says, “A coach has to have a feeling of what he is doing. First of all, the coach needs to motivate athletes to do unusual things.” He always tries to bring Biomechanics and Physiology together as well as training and racing rowing technique. Jurgen reckons that leg work is the key component of an effective drive. The next one is the trunk, and acceleration of the rower’s mass is the main target of the drive. Some of Jurgen’s coaching expressions are: “Treat the stretcher as fragile eggs during recovery, then smash them very late at catch”; “Let hands go before catch, then pickup a flying wheel with the handle”. He says that the catch should not be soft. The faster the boat, the more front-loaded the force curve should be. The rower’s mass should always move relative to the boat. The finish of the drive must be dynamic; the rower should use the oar bend, hold the knees down and return using the handle to save energy and avoid overloading the boat.

Jurgen pays attention to long oar angles, but says that they must be optimal for an individual rower’s physique. We saw a very wide grip by his Olympic coxless four in Beijing. Jurgen’s comment was: “The optimal grip in sweep rowing is with two hands’ width between, but my rowers found a wider grip more comfortable and I didn’t argue. The inside arm controls the handle and the outside arm pulls it. In fact, their outside arm is strong enough to hang on handle and inside arm was bent at catch to keep the body straighter. It is more important to keep legs straight without wobbling and connect both feet to the stretcher. I wouldn’t say we had an ideal grip, but it worked quite well for us”.

This example is good illustration of Grobler’s approach: “**There are some rules to follow, but a coach must be creative to find new ways. It is very important not only teach athletes, but also learn from them.**” His successes looks supernatural, but everybody who worked with Jurgen saw that it was just a combination of scientific and practical methods, a lot of hard work and a bit of luck.

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Q&A

***Q:** Jamie Croly, Gauteng Schools Provincial Coach, South Africa kindly sent us a collection of the data on performance of junior and U23 crews over the last 19 years. Jamie has asked if this data can be used for developing prognostic times for juniors and under 23 categories of rowers.*

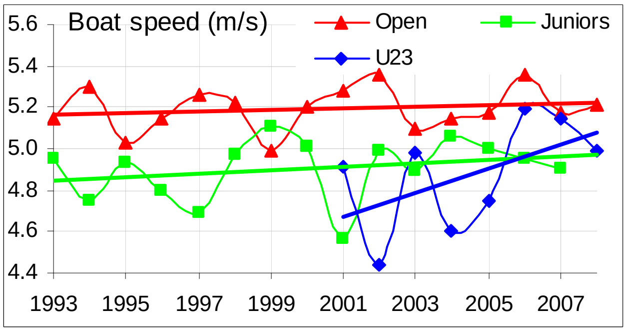
A: Analysis of the world best times in the open, under 23 (U23) and junior categories has shown that on average U23 crews are 3.5% slower and juniors 5.1% slower than their adult colleagues:

Boat	Open	U23	Jun	U23	Jun
W1x	7:07.71	7:27.81	7:39.61	95.5%	93.1%
M1x	6:35.40	6:46.93	6:57.95	97.2%	94.6%
W2-	6:53.80	7:14.91	7:11.53	95.1%	95.9%
M2-	6:14.27	6:27.84	6:36.15	96.5%	94.5%
W2x	6:38.78	6:53.40	7:00.15	96.5%	94.9%
M2x	6:03.25	6:14.05	6:19.40	97.1%	95.7%
M4-	5:41.35	5:53.19	6:00.86	96.6%	94.6%
W4x	6:10.80	6:24.55	6:32.62	96.4%	94.4%
M4x	5:36.20	5:46.44	5:50.39	97.0%	96.0%
W8+	5:55.50	6:06.68	6:13.81	97.0%	95.1%
M8+	5:19.85	5:30.43	5:35.43	96.8%	95.4%
			Average	**96.5%**	**94.9%**
LW2x	6:49.77	7:03.16	-	96.8%	-
LM2x	6:10.02	6:19.77	-	97.4%	-
LM4-	5:45.60	5:58.88	-	96.3%	-

Small boats and female crews display greater differences from the corresponding open categories than large boats and male crews.

The World Best Times do not show how performance changes over the years. Therefore, we analysed trends on the boat speed of the winners of World Championships. It was found that in juniors the speed grew by 0.203% every year over the period 1993-2008. In U23, performance grew much faster, from 2001 (when the first U23 Worlds took place) to 2008 the average annual improvement was 1.09%. The reasons of this huge improvement could be statistical (too small sample and high variation of boat speed owing to weather conditions), but also could be a real increase in performance related to tougher competition in this relatively new event. If we relate the data to the 0.082% per year improvement by the winners in the open category (RBN 2008/09), we can conclude that in juniors the performance improved more than twice as fast as in adults. The speeds of silver and bronze medallists also grew faster than that of winners (by 1.11% and 1.15% in U23 and by 0.205% and 0.207% in juniors categories), which means the competition became tougher everywhere.

The chart below shows the average boat speed and its trends in 11 comparable boat categories:



How can we derive prognostic times? This question is not simple to answer. There are a number of possible approaches here:

- Using world best times. However, in this case the standards can be affected by some exceptional speeds dependent on both performance and weather.
- Using average speed of the winners over the years and its trends (RBN 2005/11). However, in this case the prognostic speed will not be high, because it will be related to average weather conditions. Various methods of filtering are quite ambiguous and not statistically significant.

Here we try to solve the problem by using a combination of both methods. The average boat speed for all boat types was taken from the World best times. Then, it was multiplied by the ratio of speeds in various boat types taken from the average of the winners over 1993-2008. Finally, trends were applied from average over the category (U23 trend was taken as average of open and juniors, because its unreliable value, which produced a very high predicted value).

In this way, we obtained the following prognostic times for the winners in 2012:

Boat type	Open	U23	Juniors
W1x	7:11.5	7:25.7	7:32.0
M1x	6:32.5	6:45.5	6:51.4
W2-	6:52.9	7:06.7	7:12.6
M2-	6:16.5	6:29.0	6:34.6
W2x	6:39.5	6:52.7	6:58.7
M2x	6:02.1	6:14.1	6:19.6
M4-	5:41.0	5:52.4	5:57.6
LW2x	6:47.0	7:00.4	-
LM2x	6:07.2	6:19.4	-
LM4-	5:46.2	5:57.7	-
W4x	6:08.5	6:20.7	6:26.3
M4x	5:33.2	5:44.3	5:49.4
W8+	5:53.1	6:04.9	6:10.2
M8+	5:18.6	5:29.2	5:34.1

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Q&A

Q: *Torsten Heycke, a member of the Ashland Rowing Club, Oregon asked us if we "can estimate/measure or model an uneven application of power in a sculler's two oars and express this in some meaningful equation (or even an English sentence)… e.g., a stern wiggle by a single sculler of 3 centimeters and back translates into **x** number of lost watts and **y** number of lost seconds over a 2000-meter course"*

A: Unfortunately, not all questions can be answered with the currently available data and knowledge. If we try to answer this question empirically, how should we run an experiment to measure it? Asking the same sculler to scull symmetrically and asymmetrically? However, it is very likely that he will be at his most efficient in his usual mode. If we compare different crews (symmetrical with asymmetrical) then many other factors would affect efficiency (force profile, stroke length, etc.). The main problem such experiments is the effect of weather conditions, which affect boat speed and efficiency much more than changes in rowing technique.

We asked Marinus van Holst if it is possible to model this issue. Marinus kindly supplied results which show a very small effect of asymmetrical force application; for a stern wiggle of 3cm the losses were found to be 0.1% of the power and 0.033% of the speed, which equates to 0.12s over a 2k race. These numbers are approximate because there are unknown factors in the modelling equations, such as drag factors for the hull at various angles of attack relative to the stream. Again, to obtain them we need to run on-water experiments.

Concluding, common sense tells us that it is obviously better to scull symmetrically, but currently we can't reliably evaluate the effect of the boat wiggle caused by asymetrical force application. Do we really need to do it?

Q: *We have received positive feedback on the previous Newsletter with prognostic speed for U23 and junior crews. A number of coaches asked about normative data for the handle force and rowing angles for younger crews.*

A: The target boat speed was taken from the previous Newsletter. The modelling method published in RBN 2007/08 was used to derive force. Lower values for body weight were used for younger rowers, which affected very slightly the drag factor (RBN 2009/02). On average, the required power production was found to be 10.2% lower in the U23 category and 14.8% lower for juniors. It is logical to assume that younger rowers would use a lower racing rate and shorter angles, so in the model we decreased them proportionally by 1.5% for the U23 category and by 2.4% for juniors. The normative data is shown in the tables below:

Open Category

Boat	Time	W (kg)	Rate (1/min)	P (W)	Angle (deg)	F_{max} (kgF)	F_{aver} (kgF)
W1x	7:11.5	85	34.1	399	107	72.8	37.9
W2x	6:39.5	80	35.9	387	107	67.2	34.9
W4x	6:08.5	80	37.4	399	110	66.6	34.6
W2-	6:52.9	85	37.4	396	87	66.0	34.3
W8+	5:53.1	80	39.1	405	89	64.6	33.6
M1x	6:32.5	95	36.3	556	112	90.4	47.0
M2x	6:02.1	90	38.2	546	113	84.5	43.9
M4x	5:33.2	90	39.3	567	113	85.3	44.3
M2-	6:16.5	95	38.8	548	92	83.3	43.3
M4-	5:41.0	95	40.5	554	93	80.8	42.0
M8+	5:18.6	95	40.0	593	94	87.6	45.6
LW2x	6:47.0	60	36.1	330	99	62.0	32.2
LM2x	6:07.2	70	38.8	474	104	78.3	40.7
LM4-	5:46.2	70	40.6	469	86	74.0	38.5

U23 category

Boat	Time	W (kg)	Rate (1/min)	P (W)	Angle (deg)	F_{max} (kgF)	F_{aver} (kgF)
W1x	7:25.7	83	33.8	359	106	67.3	35.0
W2x	6:52.7	78	35.5	348	106	62.0	32.2
W4x	6:20.7	78	37.0	359	108	61.4	31.9
W2-	7:06.5	83	37.0	356	86	60.9	31.7
W8+	6:04.9	78	38.6	364	88	59.6	31.0
M1x	6:45.5	93	35.9	499	110	83.4	43.4
M2x	6:14.1	88	37.8	491	111	77.9	40.5
M4x	5:44.3	88	38.9	509	111	78.6	40.9
M2-	6:29.0	93	38.4	492	91	76.9	40.0
M4-	5:52.4	93	40.1	498	92	74.5	38.7
M8+	5:29.2	93	39.5	532	93	80.8	42.0
LW2x	7:00.4	60	35.7	300	99	56.9	29.6
LM2x	6:19.4	70	38.4	430	104	71.7	37.3
LM4-	5:57.7	70	40.1	425	86	67.8	35.3

Juniors

Boat	Time	W (kg)	Rate (1/min)	P (W)	Angle (deg)	F_{max} (kgF)	F_{aver} (kgF)
W1x	7:32.0	81	33.6	340	104	64.8	33.7
W2x	6:58.7	76	35.4	330	104	59.7	31.1
W4x	6:26.3	76	36.8	340	107	59.2	30.8
W2-	7:12.6	81	36.8	338	85	58.7	30.5
W8+	6:10.2	76	38.5	345	87	57.4	29.8
M1x	6:51.4	91	35.8	474	109	80.3	41.8
M2x	6:19.6	86	37.6	465	110	75.0	39.0
M4x	5:49.4	86	38.7	483	110	75.6	39.3
M2-	6:34.6	91	38.2	467	90	74.1	38.5
M4-	5:57.6	91	39.9	472	91	71.7	37.3
M8+	5:34.1	91	39.4	504	92	77.7	40.4

On average, to achieve their targets, **U23 rowers should apply 7.4% lower force than adult and juniors should pull 10.2% less**. These values can be used in strength training and testing, but they are valid for stated combination of stroke rate and angles. Obviously, it is possible to use various combinations, e.g. higher stroke rate at lower force or angles and vice-versa.

Would you like to measure force and angles for your crew? Contact us or choose the optimal solution on our web site.

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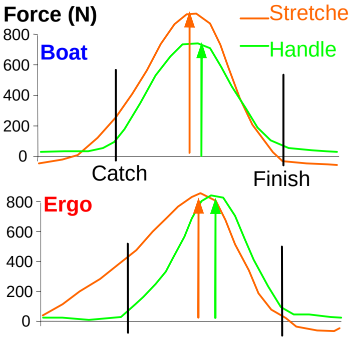
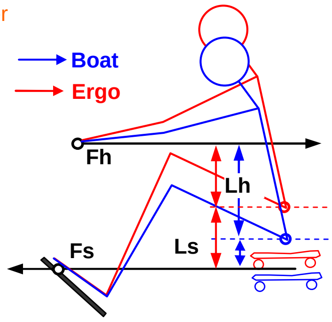
Ideas. What if…

In RBN 2003/10 and 2005/03 we explained that during rowing in a boat the stretcher force is about 40% higher than the handle force but that on an ergo the forces are nearly equal. How do rowers adjust their efforts to produce such different forces? We used the model of Einar Gjessing (RBN 2008/07) to explain this phenomenon. We modified the model and derived levers from the horizontal components of the force vectors relative to the hip joint, because this is the way that forces move the rower-boat system, and we measured them in this direction only:





If we neglect forces due to inertia, which are low in the middle of the drive, then:

$$Fh\ Lh = Fs\ Ls \quad \text{or} \quad Fh / Fs = Ls / Lh$$

The magnitudes of the handle force (***Fh***) and stretcher (***Fs***) forces are inversely proportional to their corresponding levers, relative to the hip joint, ***Lh*** and ***Ls***. This means that on an ergo the levers must be equal, whilst in a boat the lever of the handle force ***Lh*** must be longer than the lever of the stretcher force ***Ls***.

The practical implication of this finding is that the height of the hips in a boat must be closer to the stretcher than to the handle, whilst on an ergo the hips must be equidistant between the points of application of the handle and stretcher forces. If we assume that the stretcher-handle height is the same in both cases, then the seat height must be lower in a boat and higher on an ergo. If the seat heights were the same, then the rower would have to apply force differently, pushing more with the toes in a boat or more with the heels on an ergo, and pulling the handle higher in a boat or lower on an ergo.

How high should the seat be if we want rowing on an ergo most closely to simulate rowing in a boat? Calculations were made for a height of hip joint above seat of 10 cm and a height of gate above seat of 15 cm (with the same handle height in the boat and on the ergo of 22 cm). It was found that, in the boat, the seat must be 1.5cm **lower** than the point of application of the stretcher force, but 1.5cm **higher** on an ergo, which means **the seat height relative to the stretcher on an ergo must be about 3cm higher than in the boat**.

Obviously, the real picture is not so simple. During the drive, the ratio of handle to stretcher forces changes significantly owing to inertia forces. At the catch, on a stationary ergo the stretcher force is much higher, so rowers have to push the stretcher more with the toes. In contrast, at the finish, more stretcher force should go through heels.

How can our findings be related to previous studies? Caplan and Gardner (3) found that a higher position of the stretcher on an ergo allows greater power production. They suggested: "this improvement in effectiveness is due to a reduction in the active downward vertical forces applied to the foot stretchers which does not contribute to forward propulsion, and thus a reduction in energy waste during each stroke". However, vertical forces do not produce any energy in this case because there is no significant vertical movement in the stretcher, in the handle, or in the rower's CM. Contrarily, our model explains this fact perfectly; a higher position of the stretcher reduces the levers ***Ls*** and ***Lh*** which must be equal on an ergo and allows the application of higher stretcher and handle forces for the same muscular torque.

Soper and Hume (4) found that "Ergometer rowing performance improves over 2000 m when using a steeper foot stretcher angle". They also explain this fact by vertical forces and stated that "It is unclear why the male rowers benefited more from a steeper foot-stretcher angle than the female rowers." Our model explains this improvement in performance; a steeper stretcher angle creates a higher point of application of the stretcher force which shortens the lever ***Ls*** and allows the application of greater force for the same muscular torque. The difference between male and female rowers can be explained by invoking the concept of the force that lifts the rower's weight from the seat (RBN 2002/05). This force is lower at steeper stretcher angles. The lower lift force increases the limit of force application and allows physically stronger male rowers to produce more power. For physically less strong females, the limit is less achievable anyway, so the steeper stretcher affects their performance less.

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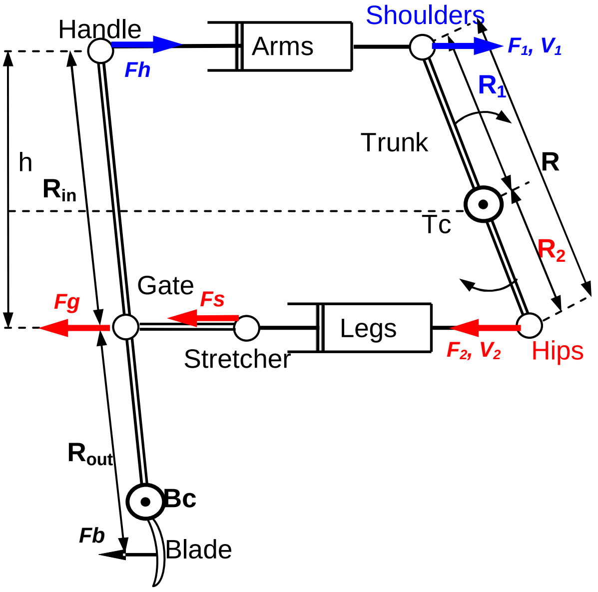
Ideas. What if…

We received a number of replies about the previous Newsletter, which questioned our hypothesis about the torque of the forces relative to the hips. We agreed that it is incorrect to derive the torque from the horizontal components of the forces only. Here we try to analyse this issue from a different point of view.

The question remains: how does a rower manage to vary the ratio of forces applied to the handle and stretcher? This question has implications for deriving trunk power (1, RBN 2004/06) and, further, for rowing styles (RBN 2006/05). The following simplified model can be considered as a development of the Dal-Monte and Komor model (2).



A cricitism of the previous analysis was the assumption that the hips are the fulcrum of the trunk rotation. In fact, the hips are not fixed and move together with the boat and seat. Therefore, power generated by the trunk can be transferred through both ends (shoulders and hips) and, further, through the handle or stretcher (RBN 2008/12). In RBN 2004/06 we expressed an idea that the fulcrum of the trunk rotation is the rower's centre of mass (CM). However, there are no mechanical reasons for it and the fulcrum can be just a virtual point **Tc**. Similarly, the fulcrum of the oar rotation is a virtual point **Bc** on the shaft, the position of which depends on the ratio of the boat velocity and the velocity of the blade slippage in the water.

The position of the fulcrum of the trunk **Tc** is defined by the ratio of the levers R_1 and R_2, which is difficult to determine using the velocities of the shoulders and hips (similarly, with the fulcrum of the blade) because they depend on the choice of the coordinate system. Therefore, it was decided to use a ratio of the forces, assuming they are proportional to the velocities. Ignoring inertia of arms, legs and boat, let us assume that $F_1 = Fh$ and $F_2 = Fs = Fg$. Therefore:

$$R_1 / R_2 = F_2 / F_1 = Fs / Fh = Fg / Fh = k \qquad (1)$$

For a boat, the coefficient **k** is determined by the ratio of the actual oar length **Loar** = **Rin + Rout** to the actual outboard **Rout**:

$$k = (Rin+Rout) / Rout \sim 1.44 \qquad (2)$$

If the ratio **R1/R2** is expressed in percentages, then in the boat it approximates to 59/41. For an ergo, if again we disregard inertial forces, **R1/R2** = 50/50. The stretcher/handle height **h** is divided in the same proportion, so the difference 9% at h = 22 cm gives the position of the fulcrum of the trunk 2 cm higher for an ergo than for a boat.

Do we really need to adjust the stretcher height to accommodate this difference? It is quite unlikely because of the virtual character of the trunk fulcrum. Muscles always create torques around joints, but geometrical rotation could occur around a virtual point because joints themselves move.

How can we derive the trunk power **Pt** from the measured handle and stretcher forces (***Fh, Fs***) and the linear velocity ***Vt*** between hips and shoulders? This question is difficult to answer strictly and we would be happy if a better method can be found. Currently, we use the following logic. Calculated force and power produced by the trunk depend on what reference point is chosen. If the hips are used as a fulcrum, then $Pt_1 = Vt.Fh$, if the shoulders, then $Pt_2 = Vt.Fs$, which gives about 1.44 times greater power. As the fulcrum is located in between these two points, the force produced by the trunk was estimated as an average of the handle (***Fh)*** and stretcher (***Fs)*** forces, weighted in the proportions stated above, so:

$$Pt \sim Vt\,(0.59\,Fh + 0.41\,Fs) \qquad (3)$$

What could be the practical implications of this analysis of one of the most difficult areas of Rowing Biomechanics? The following very simple idea can be useful for coaches: **in a boat, the trunk should work not only "through the handle", but also "through the stretcher"**. Power transferred through the stretcher can be generated not only by the legs, but also by the trunk. On a stationary ergo, a rower has no choice and must apply power only through the upper end of the trunk, i.e. through the shoulders and handle.

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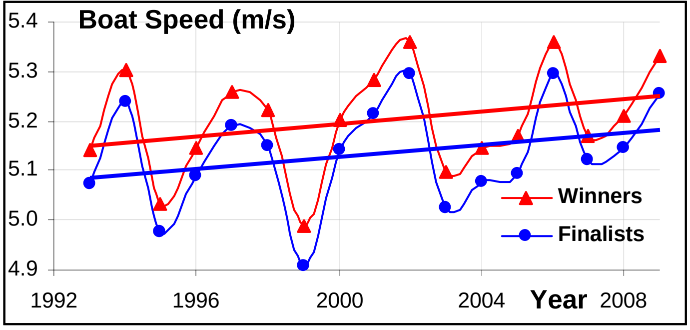
News

Strong tail winds and warm water made the boat speeds fast during the finals of the World Championships, which just finished in Poznan, Poland. The chart below shows the average boat speed for all 14 Olympic boat types and its trends over the last 17 years:



Average speed of the winners was 5.33 m/s, which is the third fastest average after Seville-2002 and Eton-2006 Worlds (both 5.36 m/s). The trend in the speed has grown by 0.12 % per year. However, human factors cause only 8.5 % of variation of the boat speed; the remaining 91.5 % is the effect of the weather.

One world record was set in Poznan in the M1x by Mahe Drysdale, New Zealand, whose time of 6:33.35 beat the previous record by 2.05s. The silver medalist Alan Campbell, Great Britain also beat the previous record by 1.10s.

It is interesting to compare the results of the winners with our prognostic times (RBN 2009/04). The growth of the boat speed in based on data for 17 years.

	Boat	Prog-nostic	Worlds-2009	% Progn. Speed	Growth % per year
1	M2-	6:16.5	6:15.93	100.15%	-0.02%
2	W1x	7:11.5	7:11.78	99.94%	0.10%
3	M1x	6:32.5	6:33.35	99.78%	0.03%
4	LM2x	6:07.2	6:10.62	99.08%	0.28%
5	LW2x	6:47.0	6:51.46	98.92%	0.26%
6	LM4-	5:46.2	5:50.77	98.70%	0.24%
7	M2x	6:02.1	6:07.02	98.66%	-0.06%
8	M4x	5:33.2	5:38.33	98.48%	0.19%
9	M8+	5:18.6	5:24.13	98.29%	0.25%
10	M4-	5:41.0	5:47.28	98.19%	0.02%
11	W2x	6:39.5	6:47.18	98.11%	-0.04%
12	W4x	6:08.5	6:18.41	97.38%	0.11%
13	W2-	6:52.9	7:06.28	96.86%	-0.02%
14	W8+	5:53.1	6:05.34	96.65%	0.30%
	Average			98.51%	0.12%

It is noticeable that small boats were the fastest according to the percentage values. The boats racing on the second day of finals showed very similar speeds at Beijing-2008 and Poznan-2009; curiously, the USA crew (winners in W8+) clocked absolutely the same time 6:05.34! However, small boats were faster this year owing to the weather.

Q & A

Q: We have received a number of questions from coaches like these: "What is the best time of the year to use biomechanical measurements to improve rowing technique?" "Our rowers are young and not technically advanced yet; when do you think we can start using Biomechanics with them?"

A: It is quite a common coaches' mistake to treat Biomechanics as the icing on the cake. When the coach is offered biomechanical testing early in a season, the reply is often: "Oh, we are not ready yet. Firstly, we need to gain some strength, and do some speed work on the water, and only after that we can show you some good rowing technique."

In fact, if the technique is good, the rower does not need biomechanical support. The main purpose of Biomechanics is to detect mistakes in technique and identify areas where it can be improved. If it is not done early, the rower may repeat an incorrect pattern of movement in every stroke, thousands of times. As a result, this habitual pattern of movement becomes so ingrained that it is not possible to change it, unless the rower performs a similar number (thousands!) of strokes in the correct way. Very often mistakes identified and apparently corrected at the last minute re-emerge under competitive stress, when an athlete is fatigued or at a higher stroke rate.

The same is true for teaching younger rowers, but even more so. If taught wrongly, young rowers develop strongly ingrained habits of inefficient technique that create nightmares for coaches working with them in older age-groups.

Obviously, a qualified and experienced coach can see mistakes in technique and correct them effectively. However, "Errare humanum est" as the Romans said, which means "To err is human". Rowing technique is quite complex and sometimes a controversial matter. Trying to improve one thing, a coach could exaggerate or affect negatively other components of technique; e.g. in trying to improve the leg drive, "bum shoving" could be developed; in trying to produce more power with the trunk, one could make the finish of the drive inefficient, etc. Examples are endless. Biomechanics can provide you with objective information and find a correct balance of all components of rowing technique.

The conclusion is simple: **The earlier you start using Biomechanics to diagnose and improve rowing technique, the more correct strokes you will perform and the more stable and efficient technique you can develop.**

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Facts. Do you know …

? …which have been the most successful rowing nations over the last two decades? How have the performances of countries varied over the years? To answer these questions we analysed the number of points acquired by each country using the standard system 8, 6, 5, 4, 3, 2, 1 for the places from 1st to 7th respectively. Presumably, the main goal for all countries is medals, not the points. One gold medal is much more significant than two fourth places, although they both give the same eight points. However, the points system reflects quite well the overall performance of a country, allowing comparison between countries with very different levels of results (with and without medals) and can give smoother trend lines. Table 1 and Figure 1 show the distribution of points for 14 Olympic boat types over the last 17 years, and also the linear trend, which reflects variation in performance over the years.

In total, Germany scored about 40% more points than each of its nearest rivals, Australia and Great Britain. However, the trends are quite different: GBR exhibited continuous growth of performance (+5.6% per year). AUS maintained a very constant level (0.2%), but GER's performance decreased slightly (-2.5%), related mainly to the unsuccessful years of 2007-8.

Statistics reveal a slight decrease in the number of points for the next five successful countries: USA, Italy, Canada, France and Romania. However, in most cases, it does not really reflect any weakening in performance, but does reflect increasingly close competition, in which points are shared between more competitors. NZL is in ninth place, but displaying a real improvement in performance since 2003, reflected by a 10% growth in the trend. The next two (Denmark and Nederland) have displayed negative trends.

There are four rising powers at the start of the second ten which all displayed positive trends: Poland (12th place, 6%), Belarus (13th, 4.2%), China (14th, 5.5%) and Czech Republic (15th, 10%). However, the highest growth (24% per year) was by Greece (27th place) with a rapidly improved performance since the Athens Olympics. Quite good positive trends were displayed by Estonia (26th place, 12.7%), Finland (34th, 18.5%) and Cuba (36th, 10.4%).

? … which country is the most successful in juniors? Table 2 displays the points for juniors calculated using the same method as above. The superpower here is the same: Germany, which gained nearly 2.5 times as many points as the second Italy and third Romania. The changes in performance are quite small, which is evidence for a stable system for junior rowing in these three countries. The next in the ranking (Australia) displayed a moderate negative trend (-4.5%), then Great Britain, a very constant trend (-0.2%) and France (6th, -3.3%). Russia is still in seventh place, but it has displayed a strong negative trend (-7.4%) caused by a sharp fall in performance over the last five years. Russia could be overtaken soon by USA (8th place, +3%), Poland (9th, -0.2%), Belarus (10th, 1.1%) and Czech Republic (11th, 1.1%). The highest growth in juniors can be found in China (14th place, +14%), New Zealand (15th, 11.4%), Greece (21st, 9%), Bulgaria (22nd, 12%) and Lithuania (27th, 13.2%).

? … how do performances by juniors and adults correlate with each other? We found a high positive correlation (0.85) between points scored in the open and junior categories in the 36 best countries. This is quite a trivial observation, because the countries with better development of rowing would probably perform better in both categories. The correlation between percentages of growth was smaller (0.36) but also positive and statistically significant ($p<0.05$). This means that the changes in performance in junior and adult categories are related. We have not analysed the U23 category here because the status of their World Championship was established only in 2001.

? … what factors affect performance in the open and junior categories? Can we see an influence of one on the other? It is quite difficult to answer these questions statistically. Figure 2 shows comparisons of performance in both categories in various countries. In some countries (GER, DEN, RUS) we can see that changes of performance in juniors happened 3-4 years before they occurred in the open category, which could be related to the progression of a generation of athletes from juniors to adults. For other countries (ITA, ROU, NZL) peaks and troughs in performance occurred simultaneously in both categories. This could be explained by overall trends in rowing development in those countries: funding level, training methodology, coach education, etc. A third group of countries (GBR, USA, CAN) displayed quite independent trends of performance in juniors and adults. This probably reflects the separation in organisational structure for junior and elite rowing. Their elite rowing has been organised mainly on a professional basis, but the junior structure is based on clubs and school rowing.

Concluding, **there is a relationship between performances in the junior and adult categories, but its nature varies significantly in different countries**. The information provided here could be useful for further studies of organisational and sociological factors in rowing development in various countries.

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Table 1 Points in World Championships and Olympic Games in 14 Olympic boat types

	Country	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Total**	**Growth**
1	**GER**	62	70	59	39	65	59	55	47	65	69	62	45	41	50	36	28	55	**907**	-2.5%
2	**AUS**	23	30	28	48	19	30	48	46	30	35	45	34	26	43	31	32	23	**571**	0.2%
3	**GBR**	22	19	20	17	34	34	22	26	35	31	35	27	28	38	53	49	50	**540**	5.6%
4	**USA**	47	24	29	33	33	40	27	34	26	15	18	20	31	27	20	31	27	**482**	-2.6%
5	**ITA**	19	34	33	22	31	28	26	33	39	41	31	16	29	16	19	11	16	**444**	-3.0%
6	**CAN**	26	26	38	46	25	14	22	16	15	22	33	16	10	25	18	28	13	**393**	-3.6%
7	**FRA**	32	33	18	22	24	24	27	24	25	7	16	17	21	25	25	17	27	**384**	-1.8%
8	**ROU**	22	16	11	20	35	30	22	29	32	12	16	27	11	3	15	13	12	**326**	-3.8%
9	**NZL**	14	14	5	6	1	9	15	12	12	9	10	20	34	26	35	27	39	**288**	10.5%
10	**DEN**	10	22	27	24	30	20	12	7	9	21	9	13	10	10	15	14	6	**259**	-5.2%
11	**NED**	17	19	28	25	8	9	19	21	17	9	8	20	12	8	6	20	12	**258**	-3.8%
12	**POL**	21	4	8	1	11	23	0	10	18	16	11	16	22	17	12	19	32	**241**	6.0%
13	**BLR**	5	6	3	13	15	3	9	12	19	21	19	13	12	10	19	11	10	**200**	4.2%
14	**CHN**	21	14	4	10	0	6	9	0	1	4	7	8		28	25	29	3	**169**	5.5%
15	**CZE**	8	3	5	3	3	6	4	0	10	9	19	16	15	15	17	14	17	**164**	10.1%
16	**RUS**	5	4	7	8	14	21	18	10	10	12	10	12	14	5	1	2	4	**157**	-3.0%
17	**SLO**	5	9	8	8	8	4	8	12	14	10	11	6	14	10	11	6	9	**153**	2.0%
18	**UKR**	7	13	5	7	10	2	13	6	6	10	4	12	7	11	6	5	8	**132**	-0.6%
19	**NOR**	8	8	7	9	8	9	8	6	8	5	8	9	7	4	5	8	2	**119**	-3.2%
20	**SUI**	12	12	10	19	10	11	13	16	8	0	0	0	0	0	0	0	1	**112**	-16.4%
21	**BUL**	5	0	0	0	4	4	8	9	2	8	8	14	10	3	6	8	5	**94**	7.1%
22	**HUN**	10	4	1	0	0	1	3	3	11	8	3	3	8	0	1	0	0	**56**	-4.8%
23	**SWE**	5	1	17	8	5	6	0	0	0		0	0	3	6	2	3	0	**56**	-10.4%
24	**CRO**	2	3	3	3	0	0	5	5	6	9	6	6	2	0	1	0	4	**55**	0.0%
25	**RSA**	0	0	2	0	0	0	1	8	5	9	5	5	7	1	3	3	2	**51**	8.2%
26	**EST**	0	0	6	0	0	0	1	2	2	1	2	10	5	5	5	6	5	**50**	12.7%
27	**GRE**	0	0	0	0	0	0	0	0	0	3	0	5	4	5	9	8	14	**48**	24.4%
28	**AUT**	2	2	6	6	5	8	6	0	8	2	2	0		0	0			**47**	-9.7%
29	**BEL**	7	7	7	1	2	0	0	0	0	0	0	2	6	5	1	4	4	**46**	-3.5%
30	**IRL**	0		0	4	0	0	0	0	16	1	7	2	9	7	0	0	0	**46**	5.1%
31	**ESP**	8	7	4	4	2	2	0	0	1	1	1	2	0	0	0	0	1	**33**	-19.4%
32	**SRB**			0		0	5	0	3	8	3	0	4	0	0	2	1	3	**29**	-0.3%
33	**LTU**	11	0	1	0	1	1	4	5	3	1	0		0	0	0	0	1	**28**	-14.3%
34	**FIN**	0	0	1	0	0	0	0			0	0		5	2	6	6	0	**20**	18.5%
35	**ARG**	2	2	5	0	0	0	0	0	3	1	0	4	0	0	0	0	0	**17**	-11.5%
36	**CUB**		0	0	0	0		0	1	4	0	0	0	3	0	0	2	1	**11**	10.4%
37	**EGY**			0	0	8	2	0	0	1	0	0	0	0	0	0	0	0	**11**	-23.9%
38	**JPN**	0	0	0	0	0	0	1	2	3	0	0	2	0	1	2	0	0	**11**	7.2%
39	**LAT**	6	0	0	0	1	0	0	0	0		0		0	0	0			**7**	
40	**CHI**						0		0	3	0	0	0		0		0	0	**3**	
41	**KOR**			0	0	3	0	0	0	0		0	0	0	0	0	0	0	**3**	
42	**URU**	3	0	0				0				0	0				0		**3**	
43	**POR**	1	0	0	0	0	0	0		0	0	0		0	0	0	0	0	**1**	

Figure 1. Charts of the number of points and the ranking of the 12 best countries during 1993-2009 in 14 Olympic boat types

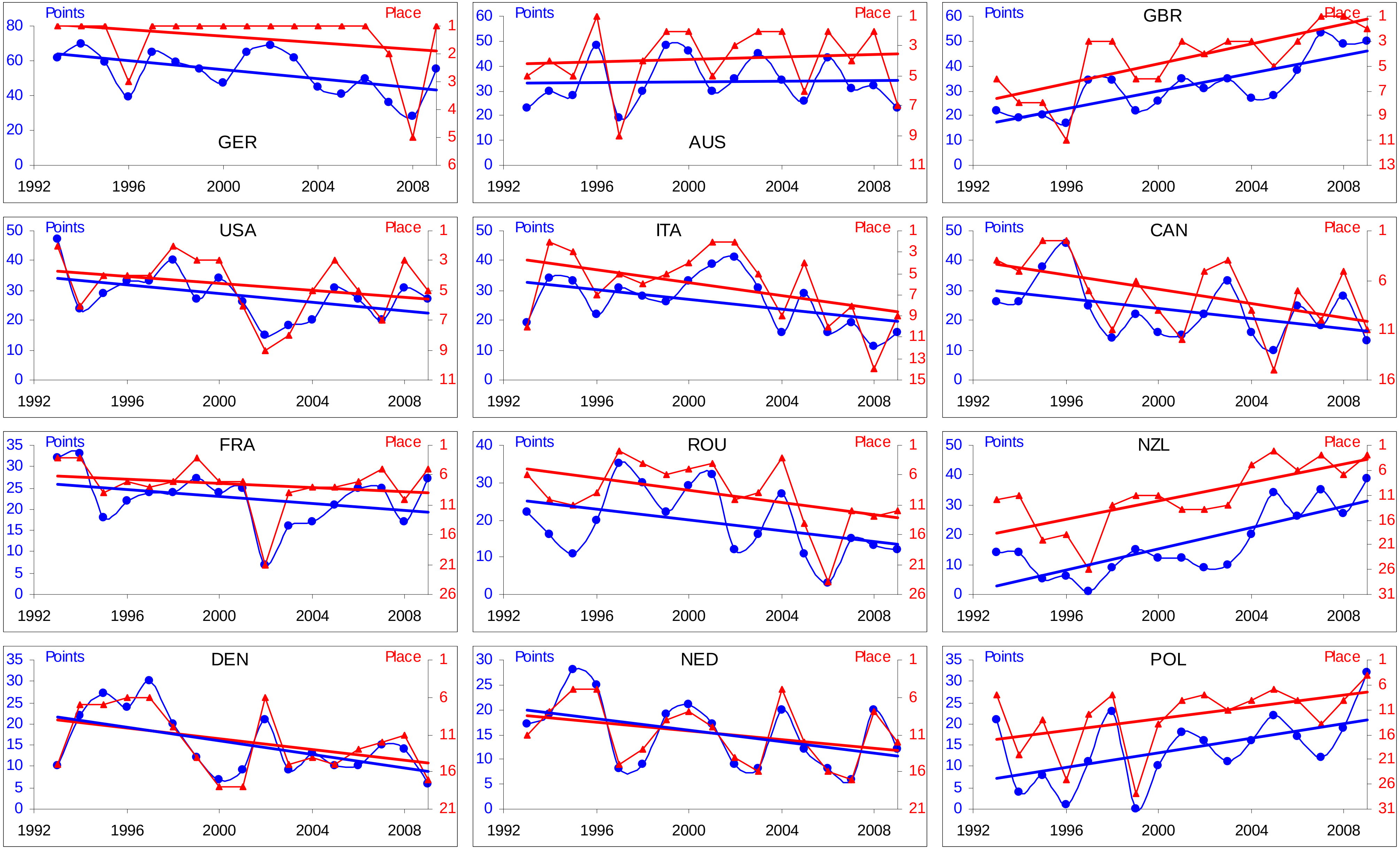
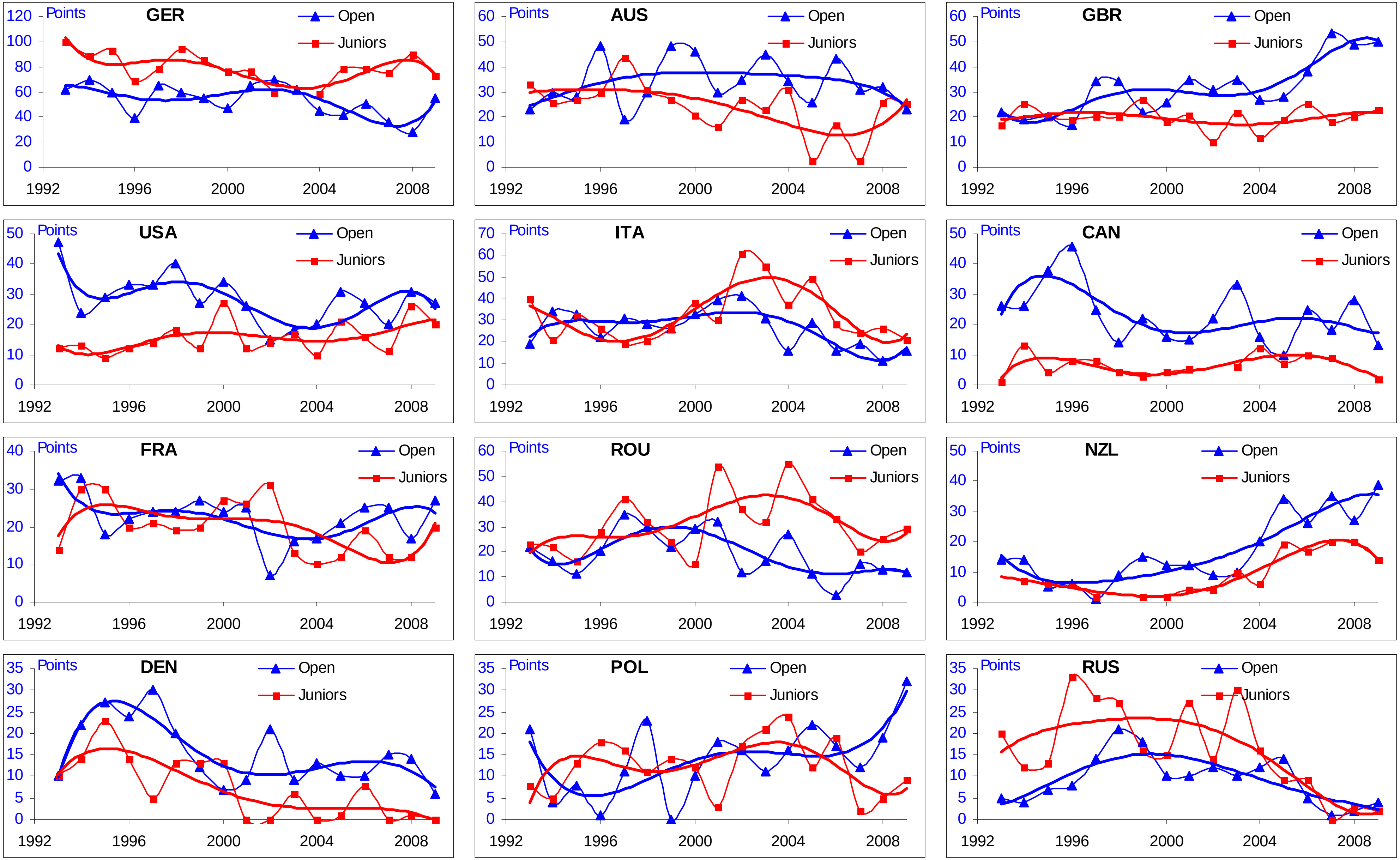


Table 2 Points in Junior World Championships

	Country	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Total	Growth
1	**GER**	100	89	93	68	79	94	85	76	76	59		58	78	78	75	90	73	**1271**	-1.3%
2	**ITA**	40	21	32	26	19	20	26	38	30	61	55	37	49	28	24	26	21	**553**	0.7%
3	**ROU**	23	22	16	28	41	32	24	15	54	37	32	55	41	33	20	25	29	**527**	1.8%
4	**AUS**	33	26	27	30	44	31	27	21	16	27	23	31	3	17	3	26	25	**410**	-4.5%
5	**GBR**	17	25	20	19	20	20	27	18	21	10	22	12	19	25	18	20	23	**336**	-0.2%
6	**FRA**	14	30	30	20	21	19	20	27	26	31	13	10	12	19	12	12	20	**336**	-3.3%
7	**RUS**	20	12	13	33	28	27	16	15	27	14	30	16	9	9	0	3	2	**274**	-7.4%
8	**USA**	12	13	9	12	14	18	12	27	12	14	17	10	21	16	11	26	20	**264**	3.0%
9	**POL**	8	5	13	18	16	11	14	12	3	17	21	24	12	19	2	5	9	**209**	-0.2%
10	**BLR**	4		12	6	9	3	16	23	30	24	10	13	13	5	11	13	7	**199**	1.2%
11	**CZE**	12	11	6	6	10	3	6	21	15	27	14	19	12		6	3	12	**183**	1.1%
12	**UKR**	8	15	16	9	12	6	17	14	11	5	1	22	12	9	8	5	9	**179**	-2.4%
13	**SLO**	6	5	11	25	9	16	14	6	5	8	16	8	9	14	9	6	7	**174**	-1.7%
14	**CHN**		11		8	5	19	6	5		7			0		67		35	**163**	14.7%
15	**NZL**		7	6	6	2		2	2	4	4	10	6	19	17	20	20	14	**139**	11.4%
16	**CRO**	4	10	19	6	12	5	3	15	10	2	7	6	11	17	5	4	2	**138**	-2.8%
17	**SRB**			1	6	10	10	12	7	1	9	8	11	17	9	2	8	13	**124**	3.5%
18	**DEN**	10	14	23	14	5	13	13	13	0	0	6	0	1	8	0	1	0	**121**	-14.5%
19	**NED**	5		10	12	11	2	15	8	10	9	11	6	0	1	9	5	3	**117**	-5.1%
20	**ESP**	8	23	16	5	9	4	0	1	3	2	6	4		5		10	12	**108**	-4.2%
21	**GRE**	2	1		9	2	1	5	6	0	2	19	15	1	14	9	13	6	**105**	9.0%
22	**BUL**	2	2	0	3	5	0	2	9	17	4	1		4	12	14	23	5	**103**	12.0%
23	**LAT**	5		2	4		4		3	10	16	21	5	10	2	5	12	0	**99**	2.5%
24	**CAN**	1	13	4	8	8	4	3	4	5		6	12	7	10	9		2	**96**	1.3%
25	**SUI**	12	18	8	10	6	9	3	0	5		0	4	3	12		4	1	**95**	-9.1%
26	**AUT**	6	8	6	6	4	9	3		1		3	0		11	11	9	2	**79**	0.4%
27	**LTU**	0		0	0	0	0		6	3	10	12	4	2	8	8	6	9	**68**	13.2%
28	**NOR**	20	7		4	1		8	6	0	0	0			3	7	6	0	**62**	-10.3%
29	**EST**		0	0	0		8	8		0	6	6	4	6	8	6	0	0	**52**	3.6%
30	**SWE**	11	0	11	6	1	3	1		0		0			3	1	2	0	**39**	-12.6%
31	**BEL**	7	3	4	2	0	2	5		1	1	3			4	1	4	1	**38**	-4.1%
32	**RSA**	1	0			0	3	0	6	0	0	5	4	2	4	0	6	3	**34**	8.9%
33	**ARG**	0	4	2			8	2	2	2	0		4	0			6	2	**32**	1.3%
34	**HUN**	5	3	1	0	0	0	0		4		10	4	1	2		0	1	**31**	0.0%
35	**POR**			0		0	1	8	0		3	0			4	3	0	0	**19**	-0.1%
36	**IRL**	3	4	3		3				0		0		0				4	**17**	-5.4%
37	**SVK**	0	2		1		0				0	8	0				0	0	**11**	-0.2%
38	**TUR**											1					8	1	**10**	13.5%
39	**AZE**																8	0	**8**	
40	**CUB**													2				4	**6**	

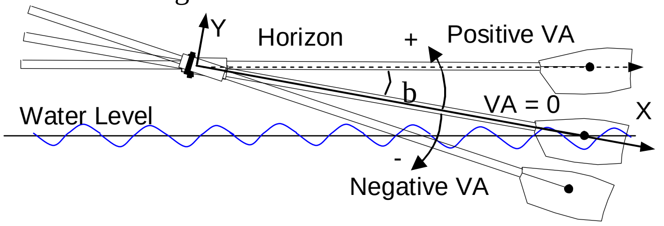
Figure 2. Correlation of the points in the open (adult) and juniors categories



Q&A

Q: John Ewans of Upper Thames Rowing Club is asking: “What is the approximate angle that the blade goes below horizontal on both sculling and rowing”

A: We have already touched upon vertical oar angles in previous Newsletters (2001/04, 2007/04, 2007/06, 2008/03). The picture below shows the reference system, which we use for the measurements of the vertical angle.



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.

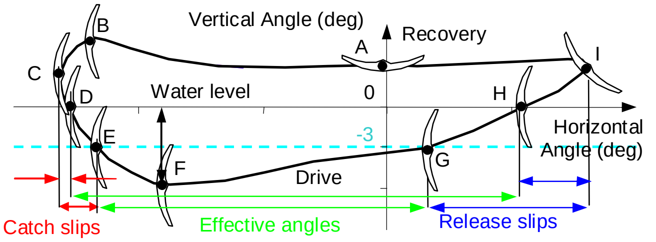
The table below can give you an impression of how angle b (between zero oar angle and the horizon) depends on the outboard and height of the swivel above water level (WL). As the latter usually ranges between 22 and 26cm (1) the most common angle b is 9-10deg in sculling and 6-7deg in rowing.

Angle b **(deg)**	Outboard Sculling (cm)			Outboard Rowing (cm)		
Swivel Height above WL (cm)	190	195	200	260	265	270
20	8.2	8.0	7.8	5.9	5.8	5.7
25	10.0	9.7	9.4	7.2	7.0	6.9
30	11.7	11.4	11.0	8.4	8.2	8.1
35	13.5	13.1	12.7	9.7	9.5	9.3

Suspension of the rower’s weight during the drive and changes in the roll and pitch of the hull affect the height of the swivel above the water and subsequently the VA. The amplitude of this variation could be up to 5cm within one complete stroke cycle, which would change the vertical oar angle by up to 1.7 deg in sculling and 1.2 deg in rowing. This limitation could be corrected using measurement of the roll and 3D acceleration of the hull.

The trajectory of the blade relative to the water level can be plotted using the above reference system. Let us describe the criteria of the blade trajectory, which could be used for evaluation of the rower’s bladework skills. The analysis is based on our database (n=6600).

The stroke cycle starts at point A during recovery (at which the the oar axis is perpendicular to the boat). The VA here is 2.4±0.8 deg (mean±SD) and does not differ between sculling and rowing. Before catch the blade rises to provide space for squaring. The VA reaches its maximum elevation at point B which is 4.9±1.2 deg in sculling and 4.1±1.2 deg in rowing. The blade starts descending after this point, moving horizontally a further 2-4 deg towards the bow and changes direction at point C, which represents the catch angle. The VA at point C is very close to +3 deg, which means the bottom edge of the blade is close to the water level.



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.

At point F the blade achieves its minimal (deepest) VA, which is -7.2±1.3 deg in sculling and -5.7±1.2 deg in rowing. Similarly, release slips could be defined in two ways: starting (1) from point G at -3 deg VA or (2) from point H at 0 deg VA, both ending at the release angle at point I. The table below shows catch and release slips and the corresponding effective angles, which are components of the total angle, within which the blade is immersed according to the defined slip criteria:

	Catch Slip to 0 VA (deg)	Catch Slip to -3 VA (deg)	Release Slip to 0 VA (deg)	Release Slip to -3 VA (deg)	Effective Angle at 0 VA (%)	Effective Angle at -3 VA (%)
Sweep	4.8	13.1	3.4	14.3	90.1%	68.4%
±SD	2.9	5.1	3.2	7.2	4.6%	8.1%
Scull	4.1	10.0	6.5	18.5	89.7%	73.1%
±SD	2.0	3.1	3.9	6.5	3.8%	6.7%

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 v.4 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.

References

1. Filter K.B. 2009. The System Crew – Boat. Lecture during FISA juniors’ coaches’ conference, Naples, 15-18 October 2009

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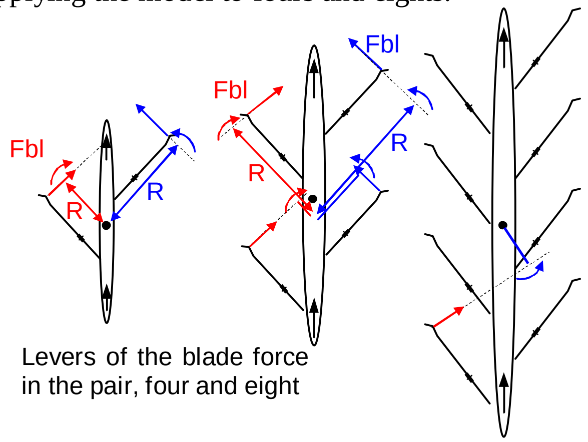
Recently, a paper on the **positioning of rowers** was published by John Barrow of Cambridge University (1) and received quite wide response in media. John wrote: *“We consider the optimal positioning of crew members in a (sweep) boat in order to avoid a sideways wiggle. We show that the traditional (alternate port and starboard) rig always possesses an oscillating non-zero transverse moment and associated wiggling motion. … We find the one zero-moment rig for a Four and show there are four possible such rigs for an Eight, of which only two (the so called 'Italian' and 'German' rigs) appear to be already known….”*

We already discussed the boat wiggle in a pair (RBN 2002/04, 2008/01-2) and found that the model proposed by Einar Gjessing (where the moment of the blade force is considered) is the most appropriate method to analyse this problem. Now we will look at applying the model to fours and eights.



Levers of the blade force in the pair, four and eight

Levers of the blade forces were calculated for the most common range of oar angles in sweep rowing from -55 deg at the catch to 35 deg at the finish. As it was expected, in the four with the normal rig the sum of the levers was found non-zero and equal to 0.47m (Fig. 1), which turns the bow to the port side. In the Italian rig the sum was zero, so the boat goes straight at the equal application of force. Similarly, in the eight with normal rig the sum of the levers was found 0.93m. In the eights with the Italian, German and other two rigs proposed by Barrow the sum was zero.

It is interesting that the stroke in the eight with any rig has a negative lever from the catch to the oar angle -40 deg. This means **the stroke rower turns the eight during the catch to the same side.** This happens because the line of the blade force passes the centre of the boat from the stern side and the blade reaction force pushes the stern in the opposite direction.

What sort of boat wiggle can be created by the above non-zero levers? The blade force ***Fbl*** was modelled as a typical front-loaded curve with maximum magnitude 350N (800N at the handle). Rotating torque ***T*** was calculated for each rower as:

$$T = Fbl * R \qquad (1)$$

This torque creates angular acceleration ***a***

$$a = T / I \qquad (2)$$

where ***I*** is the mass moment of inertia of the boat with rowers, which was defined as a sum of the mass-moments of the boat and rowers, which were modelled as a product of rower's mass 90kg by square of the distance between their CM from the centre of the boat (Table 1). The angular acceleration ***a*** was integrated twice and it was found that **each stroke with synchronous force application creates the boat yaw angle of 0.37 deg in a pair, 0.076 deg in the normally rigged four and 0.015 deg in the eight**. This yaw must be compensated by a side force applied by the fin and rudder, which creates the wiggle of the boat. In bigger boats the wiggle is smaller, which is explained by the square increase of the mass moment of inertia.

How can rowers compensate for the wiggle? In RBN 2008/01 we found that a pair goes straight if the stroke rower applies 5% higher average force. For simplicity, we modelled the same difference between stroke and bow sides in all seats and surprisingly found that this difference should be similar in big boats. Fig. 1c shows the model of force curves, which keeps straight the normally rigged four. Stroke-side rowers (closer to the stern, doesn't matter which side) in both the four and the eight should apply force earlier, so the average value should be 5% higher. **It is preferable to put the stronger stroke-side rowers closer to the bow**, because these seats have the longest levers: 5% higher force (at the same curve) of 2 seat of the eight makes the wiggle 10% smaller, 4 seat – 7.5%, 6 seat – 5% and the stroke seat can make it only 2.5% smaller.

Alternation of the oar length, inboard and span could have very small effect on the wiggle. E.g. in the normally rigged four the stroke side must have 55 cm longer oars and proportionally 18cm longer inboard and span to compensate the wiggle at the same forces.

Concluding, **Italian, German and two other zero-moment rigs are the optimal solution if you have rowers of similar strength. Boats with the normal rig can be kept straight if stronger rowers are placed on the stroke side closer to the bow.**

References

1. Barrow J.D. 2009. Rowing and the Same-Sum Problem Have Their Moments. DAMTP, Centre for Mathematical Sciences, Cambridge University. http://arxiv.org/abs/0911.3551

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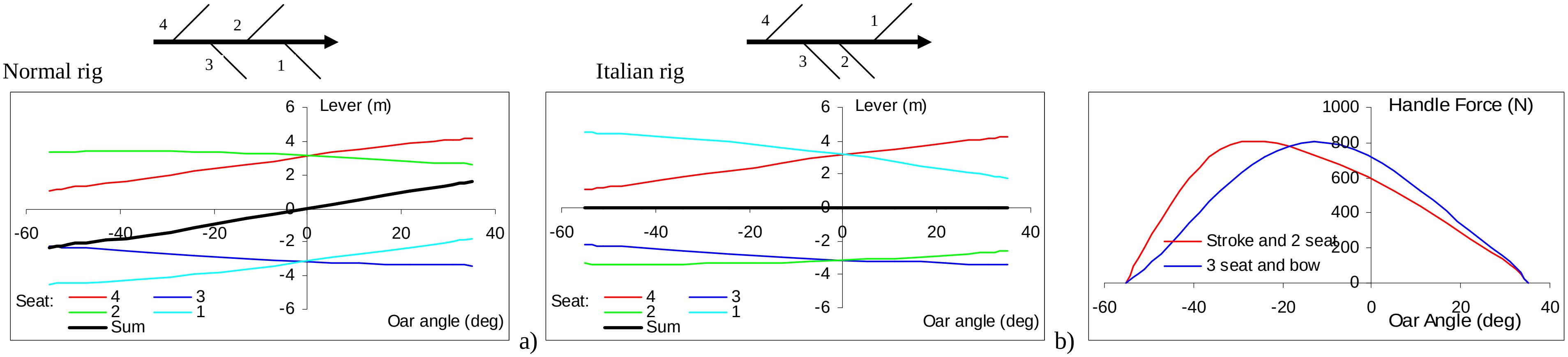
Appendices

Table 1. Mass moments of inertia in various boat types (kg m^2)

	Boat	Rowers	Total
Pair	15	88	103
Four	243	882	1125
Eight	3360	7400	10760



a) b) c)

Fig. 1. Levers of the blade force in the normal (a) and Italian (b) fours (positive lever turns the boat towards the bow side, clock wise on the pictures and vise versa). Model of the forces, which creates even moments in the normal four (c).

Table 2. Average levers in fours (m)

Seat	Stroke	3	2	Bow	Sum
Normal rig	2.66	-2.90	3.13	-3.36	-0.47
Italian rig	2.66	-2.90	-3.13	3.36	0.00

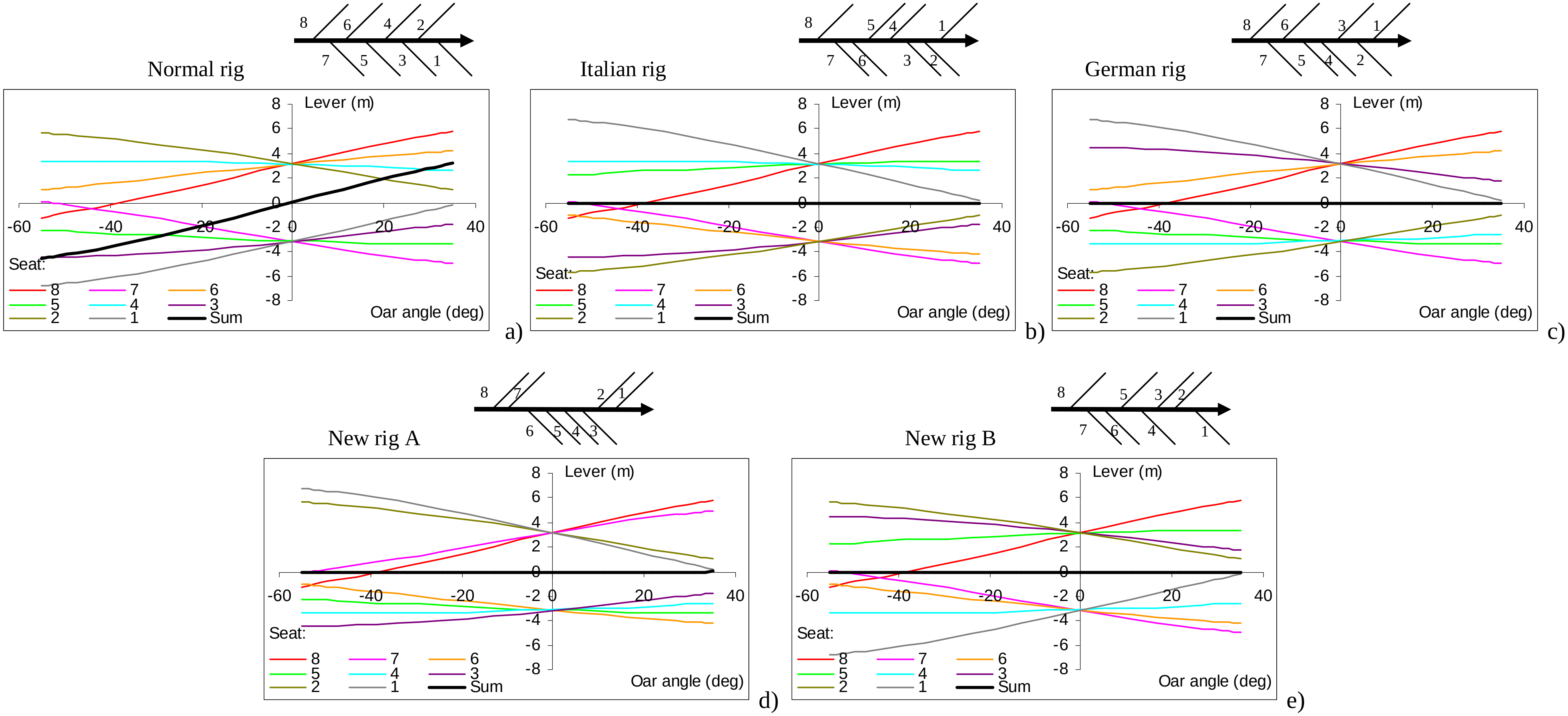


Fig. 2. Levers of the blade force in eights with the normal (a), Italian (b), German (c) and two new (d, e) riggs

Table 3. Average levers in eights (m)

Seat	8	7	6	5	4	3	2	1	Sum
Normal rig	2.20	-2.43	2.66	-2.90	3.13	-3.36	3.60	-3.83	-0.93
Italian rig	2.20	-2.43	-2.66	2.90	3.13	-3.36	-3.60	3.83	0.00
German rig	2.20	-2.43	2.66	-2.90	-3.13	3.36	-3.60	3.83	0.00
New rig A	2.20	2.43	-2.66	-2.90	-3.13	-3.36	3.60	3.83	0.00
New rig B	2.20	-2.43	-2.66	2.90	-3.13	3.36	3.60	-3.83	0.00

Weather and boat speed

It's an obvious fact that the boat speed depends on the wind speed, direction and water temperature. Thanks to Klaus Filter (1) we can analyse experimental data, which was obtained in 1970-s in DDR. Klaus wrote: "The physical property or water changes depending on the temperature. … The mobility of water molecules decrease at lower temperatures", which increases the frictional resistance. Fig. 1 shows that **the boat speeds decrease by 1.3% (~4s over 2k), when the water temperature drops from 20^{o} C down to 5^{o} C**. If the water gets warmer, up to 30^{o}, then the boat goes 0.6% faster (~1.8s over 2k). The power trend fits very well to the experimental data (R^2 = 0.99).

The wind resistance data was obtained using a wind tunnel. Klaus wrote: "The system crew-boat above the waterline causes a resistance of approximately 13% of hydrodynamic resistance." This means that the wind resistance comprises 11.5% of the total resistance. Boat and riggers contribute 15% to the wind resistance (1.7% of the total resistance), rowers' bodies – 35% (4.0%) and oars – 50% (5.7%). "These shares can increase up to 4 times under headwind conditions and decrease to zero with a sufficient tailwind."

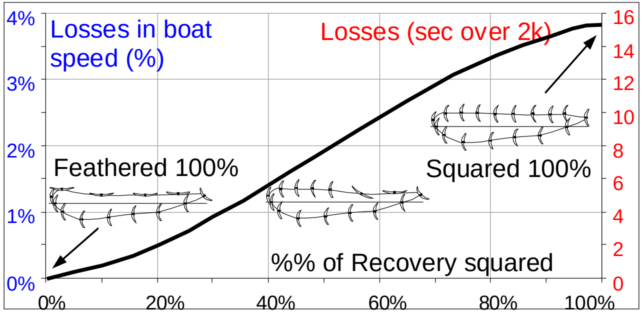
Fig. 2 shows that straight winds and winds at an angle of 30 deg to the boat have a higher effect on smaller boats: 5 m/s head wind makes singles 17.4% slower and eights 12.2% slower, tail wind of the same speed makes singles 7.5% faster and eights 5.1% faster. According to Klaus's data, a cross-head wind at 60 deg has a similar effect on all boat types (about 10% slower at 5 m/s) and a cross-tail wind of the same speed is more favourable to smaller boats. Cross winds have a higher effect on bigger boats: 5 m/s cross wind makes singles 1.6% slower and eights 4.1% slower. The second order polynomial trends fit quite well to all experimental data (R^2>0.99) except 60 deg and cross winds in eights (R^2=0.93 and 0.53 respectively).

How can we check above data using results of World regattas? Fig. 3 shows that the winners' speed normally lie within the range of ±5% from the average speed in the event. The slowest speeds (typically 8% slower than average) and the fastest speeds (3.9% faster) correspond to head/tail wind of 3-4 m/s according to Klaus's data. Unfortunately, statistical data on weather conditions is not available, but we could estimate that the strongest winds had higher speeds (e.g. 5m/s wind is classified only as "a gentle breeze" n=3 on Beaufort scale). Therefore, it is possible that the presented charts slightly overestimate the influence of the wind. It is noticeable that the head wind has the highest effect on lightweight events, which is understandable due to their lower mass and power. Also, it looks like doubles are less affected by wind than pairs.

Above data allows us to build a model, which can predict the boat speed at various wind and water temperature conditions. The model was implemented as a Web application in combination with a rigging chart (http://www.biorow.com/RigChart.aspx).

What we can do to decrease wind resistance? Klaus recommends the following: "In crews where the height of the sitting athletes noticeably is different, the tallest should be in the bow to give the best coverage. … Crews should wear caps where they can cover their hair under stronger headwind conditions. The clothing has no influence as long as it does not flutter."

We can add that **the technique of the blade squaring/feathering is very important**. During recovery the blade moves with a speed of up to 15 m/s (50 km/h), which is a sum of the boat velocity (it has the highest value during recovery and could be up to 7 m/s in M8+) and handle velocity (up to 3 m/s) multiplied by gearing ratio (2.3-2.4). The air drag of the blade is very significant because it increases with the square of the speed. If a rower squares the blade early during recovery, it increases the area affected by wind, which creates extra loss of the boat speed. The chart below shows the losses at various shares of recovery passed with squared blades:



If the blade squared early at the middle of recovery, a crew can lose up to 10 s over 2k race at calm conditions and up to 30 s at head wind 5 m/s.

References

1. Filter K.B. 2009. The System Crew – Boat. Lecture during FISA juniors' coaches' conference, Naples, 15-18 October 2009 (also on http://www.scribd.com/doc/21984934/klaus-Filter)

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Appendices.

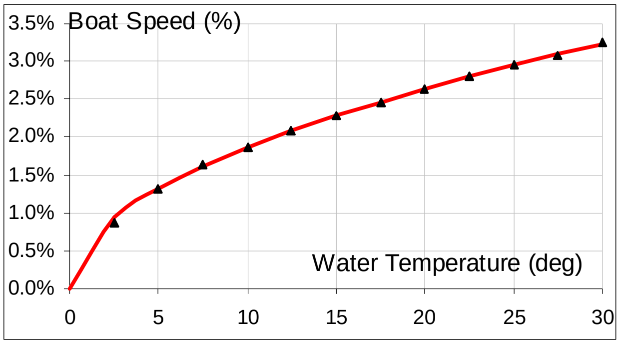


Fig. 1. Dependence of the boat speed on water temperature. Points – experimental data of Klaus Filter (1), line – fitted power trend.

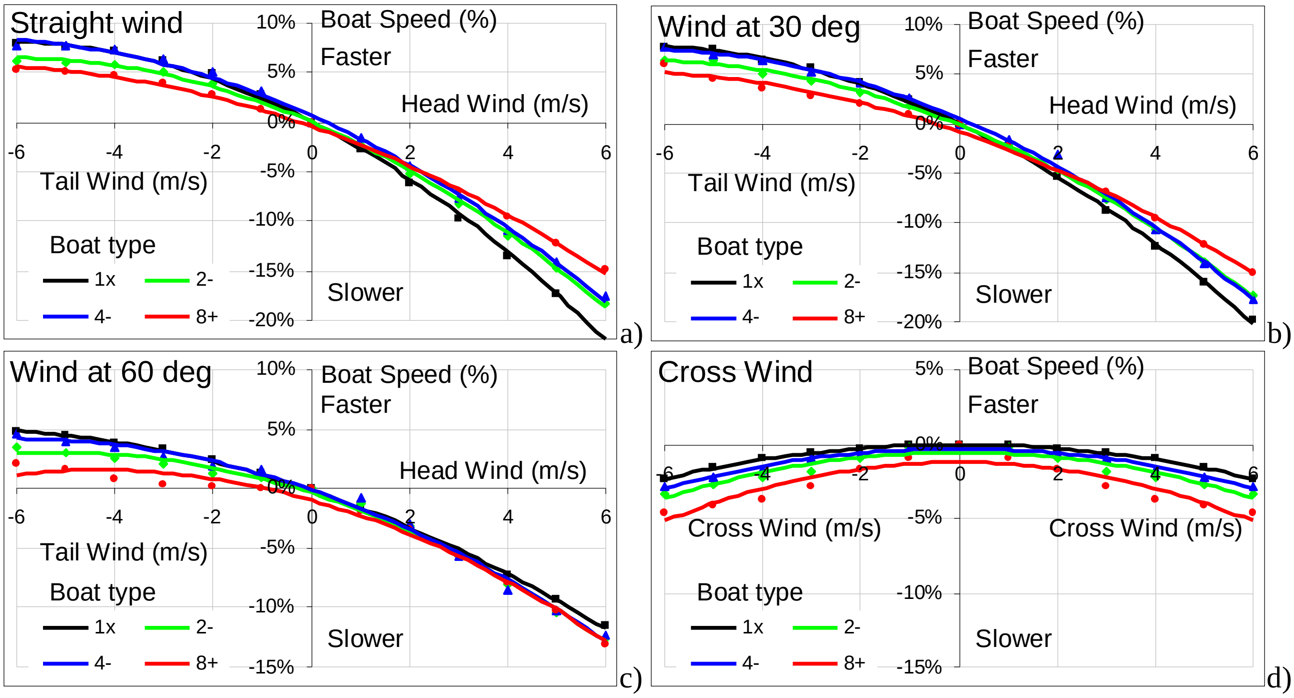
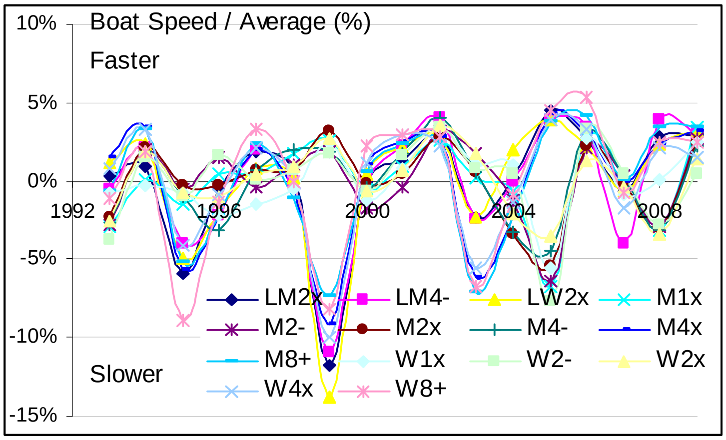


Fig. 2. Dependence of the speed of various boat types on wind direction and speed. Points – experimental data of Klaus Filter (1), lines – fitted second order polynomial trends.



Boat	Min	Max	Range
LW2x	-13.8%	3.9%	17.8%
LM2x	-11.8%	4.5%	16.3%
LM4-	-10.9%	4.1%	15.0%
W8+	-8.8%	5.3%	14.2%
W4x	-9.9%	3.9%	13.9%
M4x	-9.2%	4.2%	13.4%
M8+	-7.3%	4.1%	11.4%
W2-	-7.7%	3.5%	11.2%
M1x	-6.8%	3.4%	10.2%
M2-	-6.4%	3.1%	9.6%
W1x	-5.5%	3.5%	9.0%
M2x	-5.5%	3.2%	8.6%
M4-	-4.5%	4.0%	8.5%
W2x	-3.6%	3.5%	7.1%
All boats	**-8.0%**	**3.9%**	**11.9%**

Fig. 3. Variation of the boat speed relative the average in the boat type in the winners of World Championships and Olympic Games during 1993-2009.