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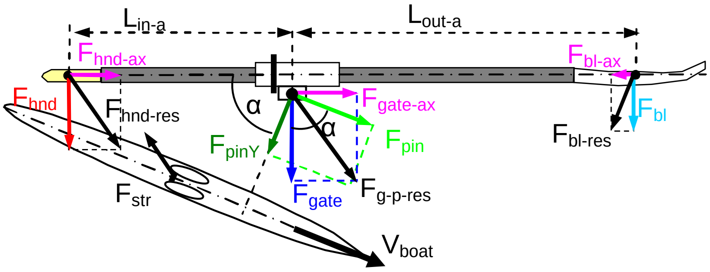
Q&A

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.

References

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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
4. WEBA Sport. RowX Outdoor. www.weba-sport.com/weba/rowx_outdoor.html

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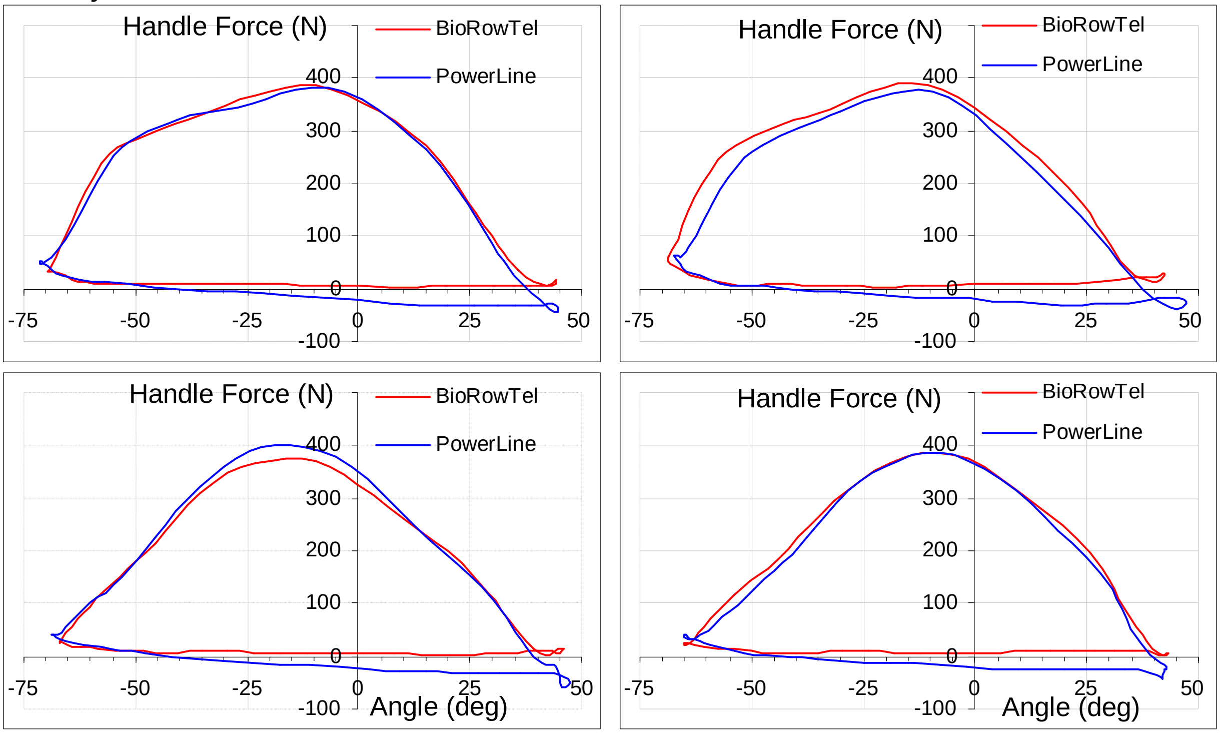
Appendix 1. Comparison of the measurements of the handle and pin forces in sculling

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.



Seat 2

Seat 1

Left

Right

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.

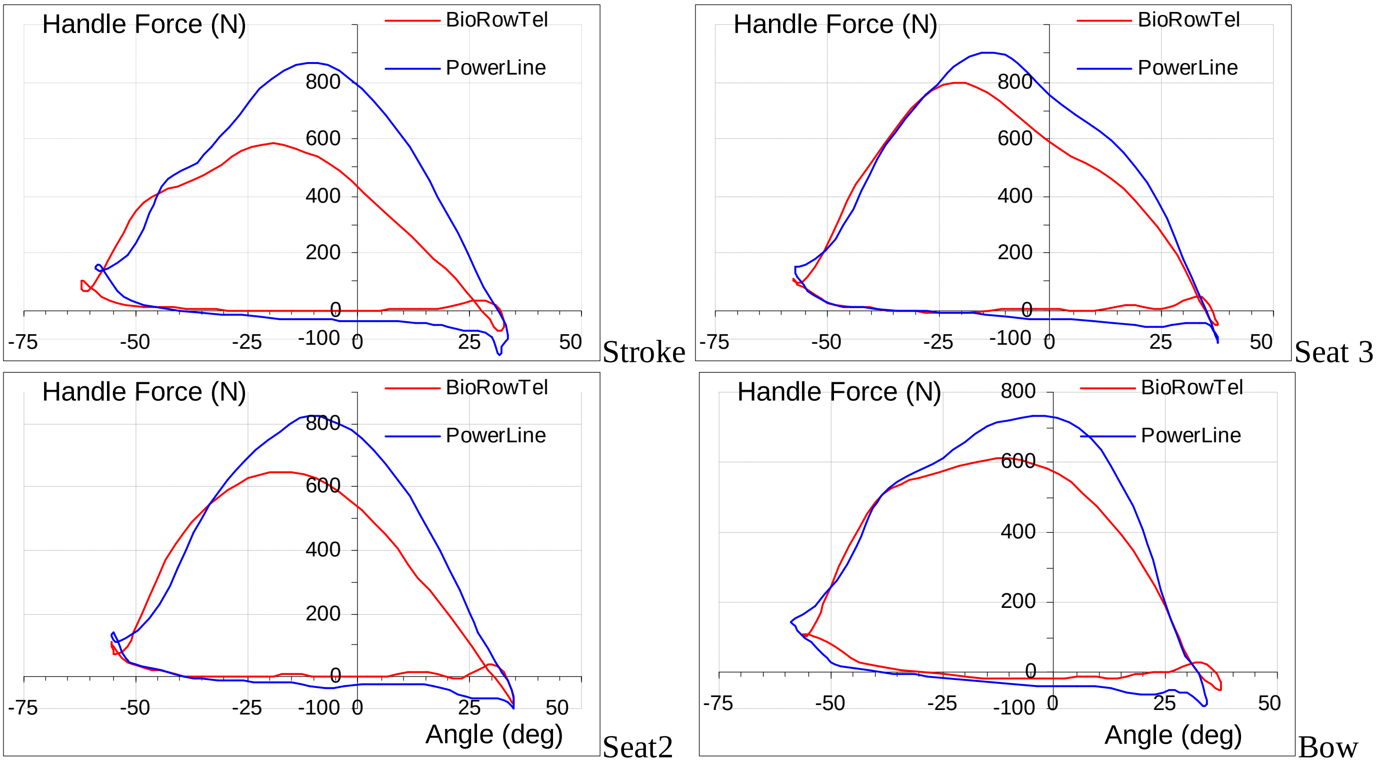


Figure 2. Comparison of the force/angle curves in a four at stroke rate 34 str/min

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%**