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**New technologies**

**NEW MEASURING AND ON WATER COACHING DEVICE FOR ROWING**

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**ABSTRACT**

This article presents a new measuring and on water coaching device for rowing called “Accrow” which measures the boat acceleration with an acceleration sensor (50 Hz) and boat velocity with GPS (4 Hz). The data were analysed with the special software “Regatta”, based on scientific criteria and broad knowledge in biomechanical analysis of rowing training and races. In particular, “Regatta” performs three special analysis routines including every stroke: the boat motion for on-water training or tests, a race analysis over 2000m, 1000m or 500m to improve the race profile and an improvement of the rowing start. The device supports the rowing training and facilitates the answering of numerous trainings questions. Thus, Accrow is well suited for the analysis of water training sessions and rowing races for athletes and coaches as well as for scientific studies with interest in information regarding the boat acceleration, boat velocity, stroke rate and propulsion per stroke with high accuracy.

**Key words:** biomechanics, rowing, rowing performance, rowing technique, on-water training, measuring device, analysis system, coaching device, boat acceleration, boat velocity.

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## INTRODUCTION

The Department of Human Movement Science of the University of Hamburg has a long tradition in biomechanical diagnostics in rowing performance and rowing technique. Currently a mobile measuring system is used which records the forces at the shaft (the inboard part of the oar) and at the foot stretcher, furthermore the movement of the oars and the seat as well as the boat velocity and acceleration. Therefore, the mobile measuring system is mounted into the respective racing boat in order to measure the parameters during a training session as well as during a race in the athletes own boat. On the basis of this procedure, precise conceptions were generated regarding the functional rowing technique and its control in on-water training sessions as well as for the mechanical- and biological-energetic functional structuring/conception of a rowing race (Mattes, 2007).

The main disadvantages of this system consist in its high personal effort which is necessary for the professional installation of the complex measuring system in the respective racing boat. A coach cannot combine the requirements of the complex measuring system with his regularly daily activities. That requires a technician special skilled in measurement technology. The use of special equipped measuring boats was not an alternative to the mobile measuring system. Thus, the acceptance of the measured results would be reduced by athletes and coaches.

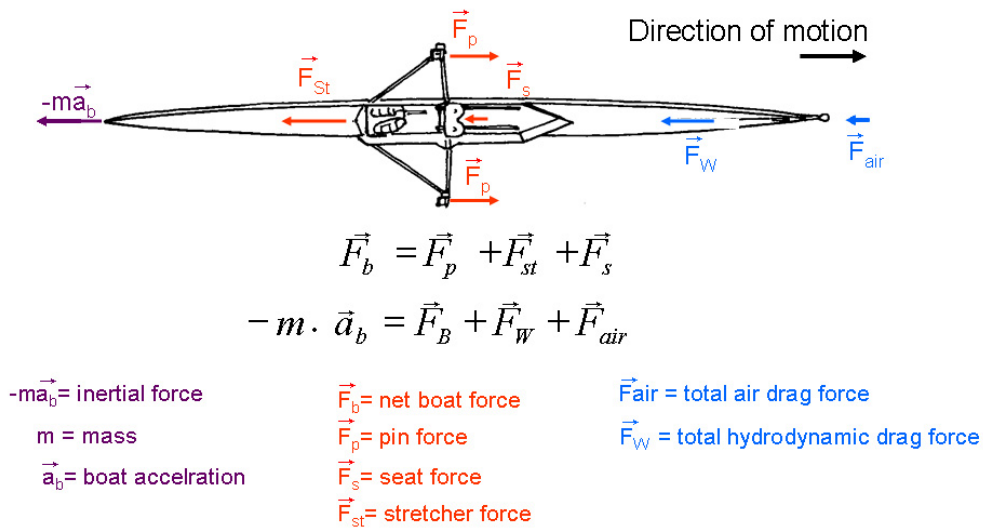
The idea for a measuring device for the analysis and control of the important factors of the boat movement (boat acceleration  $a_B$ , boat velocity  $v_B$  and stroke rate  $S_R$ ) for on-water training sessions or as well for tests was based on this background. It was considered to design a measuring device which is easy to use and can be implemented from coaches into their daily training without extra effort. The development was realized in cooperation of the University of Hamburg and the BeSB GmbH Berlin, Sound & Vibration Engineering. The hard- and software was produced from the engineers of BeSB whereas the movement scientists of the University of Hamburg provided the sport scientific design and realized the practical testing in racing rowing. The outcome is an easy to use measuring-, testing and analysing device to determine the boat motion which combines recent measuring technique with broad knowledge in biomechanical performance diagnostics and training control in racing rowing (Mattes, 2001).

The device supports the rowing training and facilitates the answering of numerous trainings questions. It analyses the rowing race according to scientific criteria and is well suited for the precise measuring of the boat motion in the frame of performance diagnostics or for scientific studies in racing rowing. This article presents the new measuring device Accrow, its functionality and some application possibilities.

### *Theoretical basics for measuring the boat acceleration*

The goal of a rowing race is to cover the 2000 meter race distance in the shortest time possible (and under the psychological stress of competitive performance). Consequently, the measurement of average boat velocity describes the main target size of the race performance (Schneider & Hauser, 1981; Sanderson & Martindale, 1986, Millward, 1987; Smith & Spinks, 1995; Baudouin & Hawkins, 2002). The acceleration trace of the boat is the result of all forces acting external on the boat which are aerodynamic and water forces as well as the muscle forces

of the rowers (Figure 1). The acceleration trace and the distance travelled by the boat were measured with Accrow.



**Figure 1.** Forces acting on the boat and the resulting boat acceleration during the drive phase of the rowing stroke.

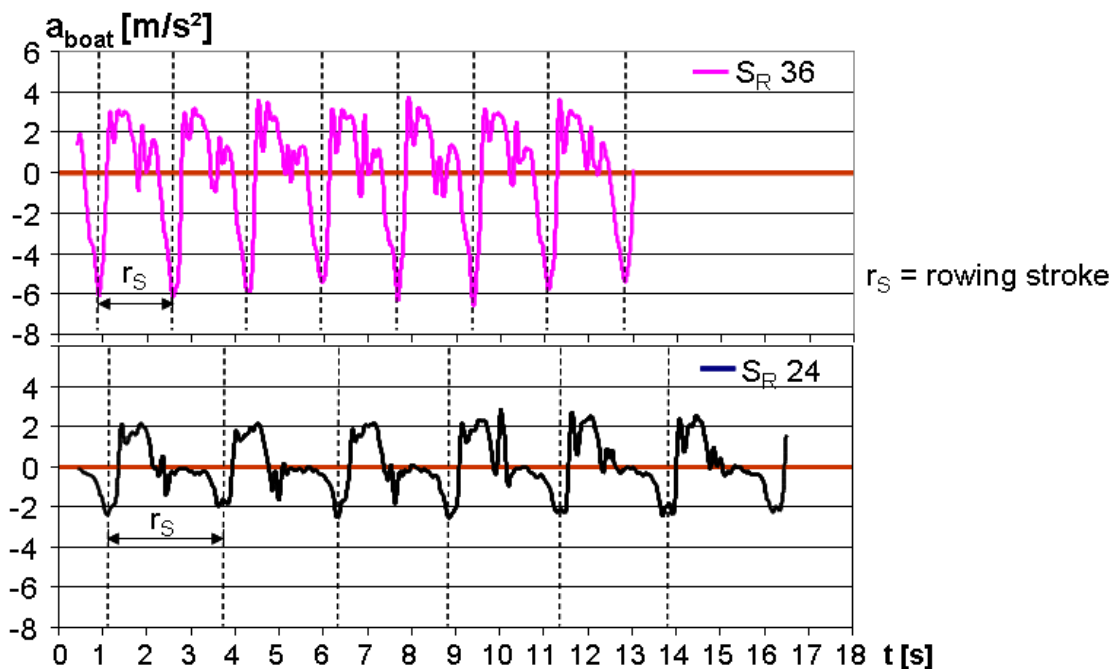
The rowing motion is divided into the drive and the recovery phase. During the drive, the oar-blades were below the water surface and the rower produces an action of force on the boat as a result of the interaction of his forces given on oarlock, foot-stretcher and seat and the forces of the exterior force of the blades. The resulting propulsive force accelerates the whole system (boat and rower) in the target direction. In that process, the external acting forces (air and water resistance) were overridden.

Metaphorically spoken, the whole system crew/boat is pulled forward using the oar-blade as a single-arm lever where the pivot point is in the water. That pivot point changes its position during the drive phase and results in a characteristic movement of the oar-blade which was described several times (Affeld, 1993; Hofmijster, Landman, Smith & van Soest, 2007). The resulting force on the oar-blade consists of the resistance force and the dynamical transverse force depending on the water flow around the oar-blade (Baudouin & Hawkins, 2002; Caplan & Gardener, 2007). Figure 2 shows the characteristic boat acceleration trace in two different stroke frequencies.

During the recovery phase, where the oar-blades are out of the water, the whole system rower/boat produces no propulsion. But the boat velocity is influenced as a result of the movement of the rowers within the boat towards the stern of the boat because of the principle of momentum conservation. The movement impulse of the rower has a strong influence on the boat

velocity because the mass of the rower is much greater than that of the boat (Baudouin & Hawkins, 2004; Celentano et al., 1971; Zatsiorsky & Yakunin, 1991).

At the beginning of the recovery phase the rower pulls at the footstretcher and therewith he pulls the boat below himself. The boat is accelerated in the direction of propulsion if the drag force at the footstretcher exceeds the water and air resistance. But at the same time, the whole system rower/boat is caused to slow down. The conditions change at the end of the recovery phase when the rower pushes against the footstretcher to start the front reversal. The footstretcher force acts against the direction of propulsion and decelerates the boat. Additionally, the water and air resistance causes the boat to slow down. As a result of this, the front reversal is characterized by a distinctive peak in the boat acceleration. This reproductive acceleration trace is typical for all boat categories and increases with increasing stroke rate. Accrow uses this repetitive peak of negative acceleration to detect the single strokes (Figure 2).

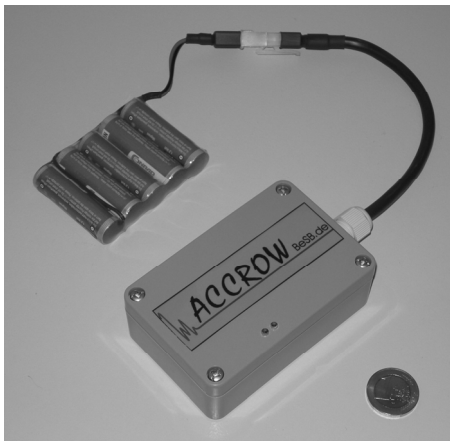


**Figure 2.** Characteristic boat acceleration traces in two different stroke rates (36 and 24 strokes per minute) measured with Accrow and stroke detection on the basis of negative acceleration peak during the front reversal.

## MATERIAL AND METHOD

### *Materials and Methodology: technical and functional description of Accrow*

The term Accrow means “acc” for acceleration and “row” for rowing. The device consists of two parts: an unobtrusive grey small box including high tech electronic for the measuring and storage of position and acceleration data of the boat motion during the rowing trip. Accrow measures the boat velocity and the distance travelled by receiving data on the speed over ground without causing resistive forces with the environment (Figure 3), compared with an impeller which is used to measure the boat velocity with the SpeedCoach from Nielsen & Kellermann. Accrow causes no additional water resistance. The evaluation software “Regatta” analyses the measured data and calculates several evaluation routines. The data transfer between Accrow and the computer proceeds via WLAN.



#### Technical Data

##### Acceleration sensor:

- ±2 g measuring range
- 50 Hz sampling rate

##### GPS-Sensor:

- Positions UP-DATE Rate: 4 Hz
- Velocity: 0,1 m/s

##### Power supply:

- 5 V – 32 V co-flow (accumulator)

##### Dimensions:

- 98 x 64 x 34 mm

**Figure 3.** Accrow and its technical data.

To start the measuring process, Accrow is fixed on top of the boat surface with a velcro strip. Shortly after the accumulator is connected, a control lamp displays the beginning of the measurement process. The data was stored on a SD-card and can be transferred wireless via WLAN to a notebook. Optional, the measured data can be transferred in real-time via WLAN to a PDA, iPod or notebook into the motorboat of the coach. Therewith, the coach receives precise measurement data for the boat velocity, stroke rate and the propulsion per stroke already during the on-water training session. That opens the possibility to execute a training load analysis during the training unit. Special stroke series can be analysed instantly regarding its effects on the boat velocity, for example with a modified rowing technique or with a different stroke rate. As a consequence of this, the quality of the on-water training is augmented.

Furthermore, the analysis software Regatta is provided which defines the boat velocity, stroke rate, propulsion per stroke as well as the distance travelled (sB) by the boat and the required running times. Therefore, Regatta identifies every single rowing stroke on the basis of the boat acceleration trace. The calculated values were exported to Excel (diagrams and tables). Accrow

offers ease of operation without the need for special knowledge of measurement techniques or knowledge of software. It is quick to use and thus, well suited for daily use.

The software Regatta performs three special analysis routines:

- the boat motion for on-water training or tests
- a race analysis over 2000m, 1000m or 500m to improve the race profile
- improvement of the rowing start

## RESULTS

### **Analysis for the boat motion in on-water training or tests**

Essential attributes of the external load were identified to analyse on water-training or tests: intensity (boat velocity, stroke rate, propulsion), volume (distance travelled, number of strokes) and time duration. Thus, it is possible to plan, monitor and control on-water training precisely. Furthermore, performance in tests can be rated on the basis of the boat motion.

The distance travelled is measured with GPS which makes it possible to measure the training load independently of buoys or markers on both lakes and race courses. When a PDA, iPod or notebook is used it is possible to adjust the training or tests directly on the basis of the measured data.

Generally, on water training units consists of different sections beginning with a start-up program, followed by the main training section. The contents of the main training section consist of different stroke series and distances and differ in every training unit depending on the goal of the training. Certainly, every training unit involve short breaks for example to drink something, control the heart rate or, depending on the rowing area as well turning breaks. Even during basic/extensive endurance training units the rowers do not row without interruption. Training units with higher load intensities regularly involve defined distances in which primarily the stroke rate and possibly the section-times are used to control the training load. This flexible procedure is supported by Accrow since the entire training unit is measured and stored and special analysis intervals were defined weather prior to the training unit or afterwards using the software Regatta. The analysis intervals can be alternatively defined by time, number of strokes or by distance travelled. The resulting data were exported to Excel as mean-values for the selected analysis interval (Table 1).

**Table 1.** Results measured with Accrow taken in an on-water training unit with different training intervals. Depending on the training interval the data were calculated for the driving distance (sGPS, interval 1), the driving time ( $t_{\text{interval}}$ , interval 2) or the number of rowing strokes (RS) (interval 3-6).

Interval	$t_{\text{interval}}$ [s]	sGPS [m]	Number of RS	$S_r$ [1/min]	$v_b$ [m/s]	$S_d$ [m]
1	241.7	1000	79	19.7	4.14	12.6
2	120	476	40	20	3.97	11.9
3	26.8	137	10	23.3	5.12	13.2
4	21.8	119	10	28.7	5.46	11.4
5	18.7	107	10	32.2	5.71	10.6
6	16.8	99	10	35.6	5.89	9.9

Using Accrow regularly facilitates monitoring of the training. For example, increases in the boat velocity in dependency of the load amount (distance), the load duration (rowing time) and load intensity (stroke rate) were documented. As a result of Accrow's exact definition of the stroke rate and boat velocity, coaches can easily find the optimal stroke rate of their crews for the training process as well as for rowing races using stroke rate step tests. Furthermore, Accrow facilitates the decision for the boat crew and eases the optimization of the boat rigging or the selection for the appropriate type of oar-blades. The effect of several factors on the boat velocity and stroke rate can be examined by a test for example over a defined distance. To contain influences of different weather conditions it is advisable to row with and against the wind direction. Dreissigacker choose a comparable approach with the intervention of new shapes of oar-blades (Dreissigacker & Dreissigacker, 2010).

Accrow is well suited for field investigations on physiological performance because it provides the characteristics of the internal load (heart frequency, lactate and/or  $VO_{2\text{max}}$ ) by detecting the factors of the external load as essential corresponding factors for the internal load. Thus, it is possible to verify the load intensities from ergometer tests in field investigations to specify the adjustments of the ergometer results.

For scientific investigations the mean-values for the respective sections as well as the raw data of the GPS and acceleration sensor are available and exportable into other software applications.

### Race analysis with Accrow

It is crucial for the success in rowing races to orientate the boat velocity and stroke rate adequately to the stage of development of conditional and rowing technical performance conditions as well as to external environmental conditions and tactical requirements. A successful race design includes these three influence factors.

In rowing, it is tactically and psychologically advantageous to gain the lead from the start. In this position it is possible for the rowers to notice position changes of other racing boats which give them the chance to react adequately (Garland, 2005). This is especially the case in rowing

because of the position of the rowers in the boat: the viewing direction is against the driving direction. In other words: the rowers sit with the back to the front. If they want to know what is in front of them they have to turn their head.

The hydrodynamic drag force acting on a racing boat increases with the square of velocity which corresponds to a 3.2 power increase in energy expenditure. However, the metabolic cost increases with only approximately 2.4 power function of the boat velocity (Secher, 1993). Consequently, a mechanical effective race profile should be characterized by low variations in the boat velocity: equal driving time but lower variation results in a lower water resistance. But even in international high-level races the measured boat velocities are not constant but rather vary. Race analysis shows a characteristic profiling (Garland, 2005; Kleshnev, 2001; Kennedy & Bell, 2003). The completion of a 2000m distance with a constant mean boat velocity is contrary to the bio-energetic laws and tactical requirements for rowing races. An optimal exploitation of the different energy supply processes (anaerobic-alactacid, lactacid and aerobic) with its different variation in time and capacities for the rowing performance (short driving time) requires load intensities which increases from aerobic to aerobic-alactacid (Secher, Volantis & Jürimäe, 2007).

The main problem in racing rowing consists in a precise control of intensity to exploit the existing energy capacities completely but avoiding at the same time negative interactions between these factors. High load intensities in the time frame of a dominant lactacid energy supply between the 10<sup>th</sup> to the 90<sup>th</sup> second of a rowing race for example, would result in an early stage lactacidose with an impaired aerobic metabolism. As a consequence of this, performance declines dramatically in the following race section. Thus, actual existing conditional performance conditions would not be realized effectively for a short driving time over 2000m. Consequently, it is necessary to consider mechanical effectiveness (low variations in the boat velocity) as well as anaerobic and aerobic capacities of the rowers by profiling the boat velocity and stroke rate.

On the basis of a separated evaluation routine, Accrow describes the external kinematic structure of a rowing race. Therefore, the 2000-m-race is decomposed in sub-sections and sub-phases for which mean boat velocities, stroke rates, propulsions per rowing stroke as well as the distances travelled respectively driving times are provided. The analysis of the travelled distance is comparable to a typical race analysis (Kleshnev, 2001; Garland, 2005) who divided the rowing race in 500-m-sections. The distinction of the analysis with Accrow and Regatta is a refined grading scale (Table 2).



**Table 2.** Analysis of a rowing race by distance travelled where the sub-sections were measured with GPS.

<b>Distance</b> <b>[m]</b>	<b>t<sub>distance</sub></b> <b>[s]</b>	<b>Number of strokes</b>	<b>S<sub>R</sub></b> <b>[1/min]</b>	<b>v<sub>B</sub></b> <b>[m/s]</b>	<b>s<sub>B</sub></b> <b>[m]</b>	<b>t<math>\Sigma</math></b> <b>[s]</b>
<b>0-100</b>	19.1	13	41.3	5.22	7.6	19.1
<b>0-250</b>	43.7	29	40.3	5.72	8.51	43.7
<b>250-500</b>	42.5	27	37.5	5.89	9.42	86.2
<b>500-750</b>	43.2	26	36.3	5.79	9.57	129.4
<b>750-1000</b>	43.4	26	35.9	5.76	9.63	172.8
<b>1000-1250</b>	43.3	26	35.9	5.77	9.65	216.2
<b>1250-1500</b>	43.7	26	36.1	5.72	9.52	259.9
<b>1500-1750</b>	43.5	27	37.3	5.74	9.23	303.5
<b>1750-2000</b>	42.2	28	39.5	5.93	9	345.6
<b>Total</b>		215	37.3	5.79	9.3	345.6

*t = time*

Although a time-dependent structure of the characteristic race phases gains an improved relation to bio-energetic and tactical requirements for rowing races. The different phases offer different tasks to the rower to control the boat velocity which are covered differently from a bio-energetically point of view. It is differentiated between the start, mid-race distance and final sprint phases, whereas the start phase has further sub-phases:

- start acceleration, to accelerate the boat from a stationary position to maximum velocity
- phase of the maximum boat velocity
- transition phase in which the boat velocity yields into the level of a mean distance (Mattes & Draper, 2003).

During the mid-race distance, which represents the longest section of a rowing race, it is advised to realize a constant boat velocity to minimize the water resistance. Though, it is possible to implement short sprints if it is tactically meaningful. In this case, an equal stroke rate is realized by an increase in force input. This so called stroke rate spurts, are advantageous if it results in an increased boat velocity to influence other competitors or the own crew psychologically. From a mechanic-energetical point of view it is ineffective to implement those mid-spurts.

The final spurt at the end of the race represents the fight for the line in which the remaining performance capacities were mobilized to increase the force input and stroke rate with a stable rowing technique at the same time. If the boat velocity increases together with the stroke rate, it is possible to verify the effectiveness of the final spurt. Table 3 shows the division into different race phases dependent on time which is realized by Accrow. Results for the main- and sub-phases of a rowing race are provided as mean values analog to the results of the analysis by distance travelled.

**Table 3.** Characteristic phase-division of a 2000-m-rowing race including time duration, bio-energetic supply and dominant required conditional abilities.

<b>Race phase</b>	<b>Start acceleration</b>	<b>Maximum boat speed</b>	<b>Transition</b>	<b>Mid-race phase</b>	<b>Finish</b>
<b>Time structure</b>	0.-15. s	10.(15.)-30.(45.)s	30.(45.)-90.s	90.s-5.(7.)min	last 30-60s
<b>Energy supply dominant:</b>	anaerobic-alactacid	anaerobic, lactacid	lactacid:	aerobic	aerobic
<b>Partial:</b>			aerobic	lactacid	lactacid, alactacid
<b>Conditional abilities</b>	Fs, Fmax, s	se partial: s, Fe	se, s, Fe	Fe, e	Fe, e, se, s

*Fs = speed strength; Fmax = maximum strength; Fe = strength endurance; s = speed; se = speed endurance; e = endurance*

The results are provided as absolute values as well as in relation to the mean values of the boat velocity and stroke rate to analyse the variations over the distance. Furthermore, the comparison of different races is facilitated.

### Start analysis with Accrow

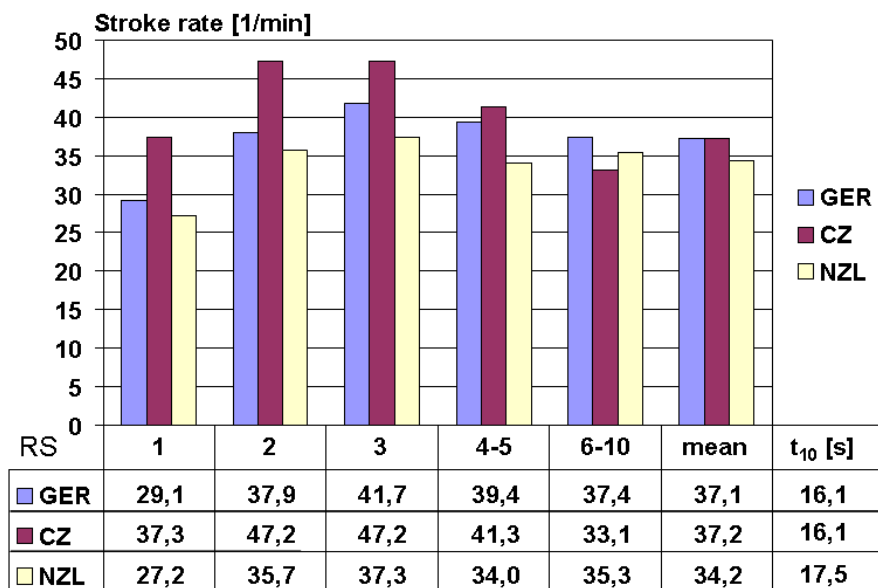
The start of a rowing race often forms the basis for the victory. Race analysis of international races showed that successful crews dominated the race from the start position to the end of the race. Currently, most crews choose an offensive manner of driving (Garland, 2005). The priority of the rowing start increases with the boat category: the higher the boat velocity (for example in the eight), the more difficult it is to regain lost distance. In this process the energy expenditure increases to a less efficient level because of the water resistance which increases squared with increasing boat velocity.

Starts at international races show a high variety in the first rowing strokes. Great differences consists in the starting position and the question how far the leg-extension for the first stroke can be exploited in a meaningful way (Figure 4).



**Figure 4.** Starting position in the skiff final of the world championship 2006 in Munich, Germany.

Furthermore, the stroke frequencies differ over the first start strokes. As a result, the starts differ between the crews due to the individual status of the conditional and rowing technical conditions (Figure 5).



**Figure 5.** Comparison of the starting position and stroke frequencies during the first ten rowing strokes in a skiff at the final of the world championship 2006 in Munich, Germany.

In contrast to that, the rating of a rowing start follows precise external criteria which consist of:

- the time travelled over a defined distance (for example the first 100m)
- realized start acceleration (increase of the boat velocity over the first start strokes) and maximum boat velocity.

Accrow detects those external criteria and specifies them for the first 15 rowing strokes. Therewith the pre-conditions were given to find the optimal start variant for the own crew by testing different start variants. Table 2 compares two start variants (I and II) of one crew (lightweight 4), which differ dependent on the stroke rate.

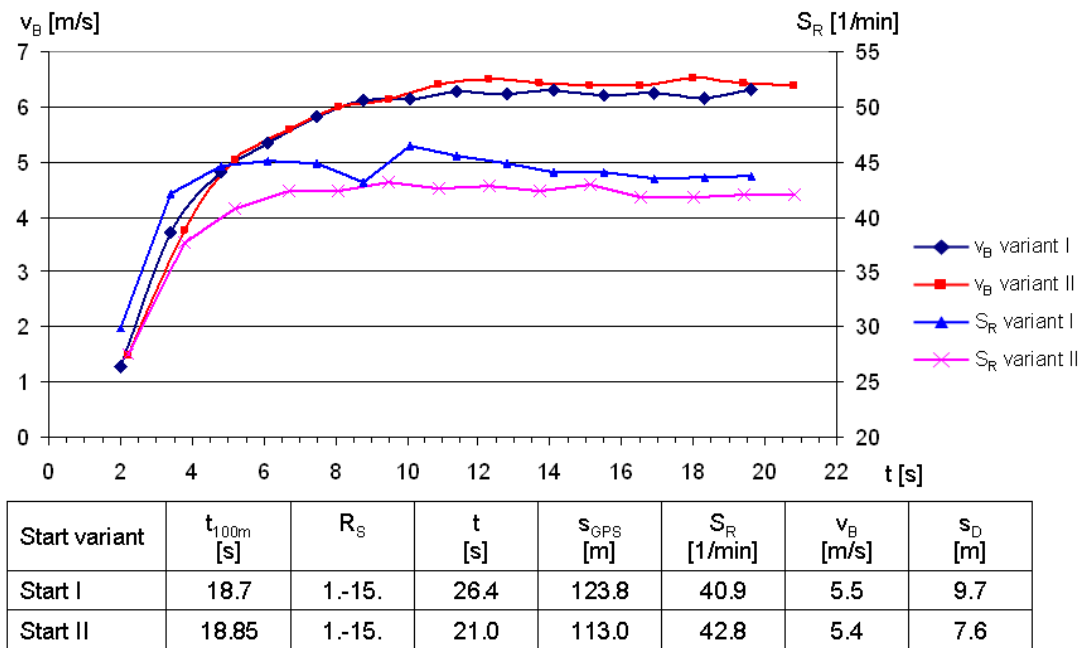


Figure 6. Comparison of two start variants (I and II) with different stroke frequencies on the basis of the results measured with Accrow.

Start variant II was realized with approximately two strokes per minute higher than start variant I. Both variants differ in the start acceleration, whereas in variant II a higher acceleration from a stationary position was realized. In variant I a higher maximum boat velocity was realized and, furthermore, the first 100m were covered in a shorter driving time.

**CONCLUSION**

Accrow supports the rowing training and facilitates the answering of numerous trainings questions. It is easy to use from every coach without extra knowledge of measurement techniques or software. The provided evaluation software “Regatta” analyses the rowing race or training session according to scientific criteria for three special analysis routines: the boat motion for on-water trainings or tests, the race over 2000m, 1000m or 500m to optimize the race profile and the rowing start. Thus, Accrow is well suited for the precise measuring of the boat motion in the frame of performance diagnostics or for scientific studies in racing rowing.

For further information please follow the link: <http://www.accrow.com/>

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