TEMPORAL ANALYSIS OF STROKE CYCLE IN ROWING

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Analysis of the temporal structure of the cycle is versatile and valuable method in many cyclic sports. Biomechanical measurements were conducted in competitive rowing boats. Boat acceleration, velocity, handle force, oar angles and the segments velocities were measured. Accelerations of whole system and the rower's CM were derived and used for definition of the temporal structure of the cycle. Six micro phases were derived during the drive and three during recovery phase. It was found that emphasis on acceleration of the boat and rower's CM switches twice during the drive. Presence of the micro-phase D3 initial boat acceleration was defined as the most important indicator of efficiency of rowing technique. It creates faster moving platform on the stretcher for acceleration of the rower's CM.

KEY WORDS: Rowing, temporal analysis, boat acceleration, technique.

INTRODUCTION:

Temporal or phase analysis plays important role in modern sport biomechanics. It is the most versatile biomechanical method of analysis across different sports, because it is based on time only and can represent different motions as a sequence of phases and sub-phases. The phase analysis can play integrating role for other biomechanical methods, such as kinematics and kinetics analysis using video or instrumentation measurements. It can decrease complexity of many sporting techniques and helps their better understanding by the coaches and athletes, which essential for learning and improving of efficient technique (Bartlett, 1999). Each phase should have clearly defined biomechanical function and easily identified phase boundaries, often called key moments or key events.

Phase analysis is well developed area in a number of cyclic sports. The most common is definition of two main phases of the cycle:

- Support phase (drive, stroke, stride), when athletes have a contact with support substance (ground, water, snow, ice, etc.) and execute effort to propel themselves forward;
- Non-support phase (recovery), when resistance forces decrease speed of the athlete's center of mass (CM).

In many sports these phases divided on sub- or micro-phases. For example, support phase in running is divided on foot strike, mid-support and take-off. Recovery phase is divided on follow-through, forward swing and foot descent (James and Brubaker, 1973).

Phase analysis in rowing is not as well developed as it is in other cyclic sports. The purpose of this study is to define sub-phases of the rowing cycle using acceleration patterns of two main masses in the rowing system: rowers and boat.

METHODS:

The main part of the measurements was conducted during the period 1999-2005 as a part of regular biomechanical service of elite athletes of Australian Institute of Sport and Australian National Team. Total number of 294 crews, both male and female, was measured in their own competitive boats. A radio telemetry system was used for data acquisition (12 bit, 25 Hz sampling frequency).

The following mechanical parameters were measured:

- Boat velocity (Vb) was measured using an electromagnetic impeller (Nielsen-Kellerman Co., accuracy ±1.0%).
- Boat shell acceleration (Ab) along horizontal axis was measured using an accelerometer (Analog Devices, accuracy ±1%).

- The oar angles in horizontal (θ) and vertical (β) dimensions were measured using conductive-plastic potentiometers (Bourns, accuracy ±0.1%) connected to the oar shaft with a light arm and a bracket.
- The force applied to the oar handle (Fh) was measured using custom made strain-gauged transducer attached to the oar shaft (±0.5%). Each oar was dynamically calibrated before each session using a precision load cell (Applied Measurement) attached at the middle of the handle (0.15m for sweep oar, 0.06 for sculling oar). Also, more detailed measurements were conducted on eight male singles, where gate and stretcher forces (*Fgate, Ffoot*) were measured. This data is used here for illustration purpose only (Figure 1) and is not involved in definition of micro-phases.
- Seat position (Ls) was measured using spring loaded 10-turn potentiometer (Bourns) connected to the seat. Legs (seat) velocity *Vleg* was derived from Ls. Trunk position was measured on small boats; trunk and arms velocities (*Vtrunk, Varm*) were derived.

The data collected during one sample period was normalized, i.e. converted into a form, which represents one typical stroke cycle for this sample (Kleshnev, 1995, 2004).
The blade *Fbl* force was derived from measured handle force *Fh* and actual inboard *Lin_a* and outboard *Lour_a* length:

$$Fbl = Fh * (Lin\_a / Lout\_a) \qquad (1)$$

,where actual inboard *Lin_a* and outboard *Lour_a* were derived as:

$$Lin\_a = Lin - Wh / 2 + Wg / 2 \qquad (2)$$

, where *Wh* is the handle width (0.12m for sculls and 0.30m for sweep oars, *Wg* = 0.04m is the gate width. *Lout_a* was calculated as:

$$Lout\_a = (Loar - Lin) - Lbl / 2 - Wg / 2 \qquad (3)$$

,where *Loar* is the oar length, *Lbl* is the blade length.
The drag force *Fdrag* applied to the boat shell was derived as:

$$Fdrag = Kdrag * Vb^2 \qquad (4)$$

,where *Kdrag* was calculated as a ratio of integrals of the blade propulsive force and square of boat speed during the stroke cycle:

$$Kdrag = \left(\int Fbl \cdot \cos(\theta)\right) / \int Vb^2 \qquad (5)$$

Then the system propulsive force *Fsys* was defined as:

$$Fsys = Fbl * \cos(\theta) - Fdrag \qquad (6)$$

The system centre of mass acceleration *Asys* was calculated as:

$$Asys = Fsys / m_{sys} = Fsys / (m_b + m_{row}) \qquad (7)$$

,where m_{sys}, m_b and m_{row} are masses of the system, boat and rower, correspondingly. The rowers' centre of mass acceleration *Arow* was calculated as:

$$Arow = Frow / m_{row\_a} \qquad (8)$$

,where m_{row_a} is actual mowing mass of the rower equal to rower's mass m_{row} minus a mass associated with the boat, which we assumed equal to 12% of the rower's mass (feet 4% and shins 8%, Zatsiorsky and Yakunin, 1991). The force *Frow* applied to the rowers' CM was derived as:

$$Frow = Fsys - Fb = Fsys - Ab * m_{b\_a} \qquad (9)$$

,where boat acceleration *Ab* was measured, and m_{b_a} is actual boat mass equal to the boat mass m_b plus associated mass m_{acc}.

RESULTS AND DISCUSSION:

We used the boat, rowers' CM and the system CM accelerations as well as the oar and seat velocity for definition of the micro-phases of the stroke cycle, Figure 1 shows typical biomechanical parameters of a single sculler obtained during detailed measurements.
We defined six micro-phases of the drive phase D1 to D6 and three micro-phases of the recovery R1, R2, R3 (Table 1).
Only D3 significantly increases its relative duration at higher stroke rate (Table 2). The trend of D3 time share is non-linear: it achieves its maximum at the stroke rates 32-36 and then decreases slightly.

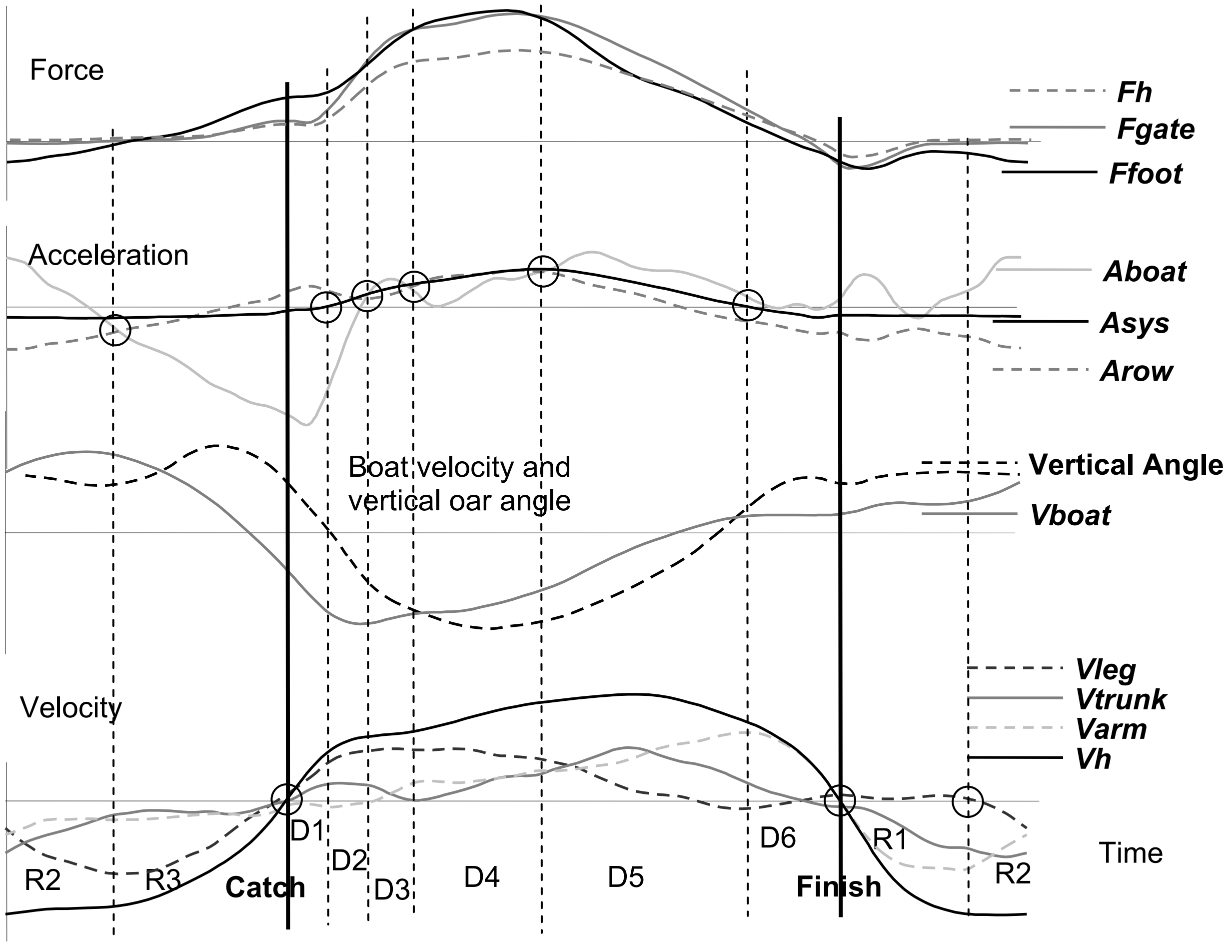

Figure 1: Typical biomechanical parameters and micro-phases of the stroke cycle (M1x, rate 32 str/min). Key events are marked with circles

Table 1 Characteristics of micro-phases of the stroke cycle

ID	Micro-phase	Start event	Description
D1	Blade Immersion	Catch, beginning of the drive. *Vh* changes sign to positive.	*Asys* and *Aboat* are negative, but *Arow* is positive. Fast increase of handle and legs speed.
D2	Initial rowers' acceleration	*Asys* became positive. The centre of the blade crosses the water level downwards.	Handle force and *Aboat* increases, but *Aboat* is still negative and lower than *Arow*
D3	Initial boat acceleration	*Aboat* became higher than *Arow*	First positive peak of *Aboat*, which became higher than *Arow*. Maximum of *Vleg*
D4	Rowers' acceleration	*Aboat* decreases and became lower than rower's acceleration	Forces, *Arow* and *Asys* increases slowly. *Vleg* decreases.
D5	Boat acceleration	*Aboat* again became higher than *Arow*	All forces, *Arow* and *Asys* decrease, but Ffoot is decreasing faster than Fgate which produces the highest *Aboat*.
D6	Blade removal	*Asys* became negative. The centre of the blade crosses the water level upwards.	*Arow* is negative and *Aboat* close to zero. *Vh* is still positive. *Varm* is maximal.
R1	Arms and trunk return	Release, end of the drive. *Vh* changes sign to negative.	A quick positive peak of *Aboat* and negative *Arow*, caused by transfer of

			moment of inertia from rower to boat.
R2	Legs return	Seat starts moving toward the stern. Increasing of *Aboat* and decreasing of *Arow*.	*Aboat* is positive (depending on the stroke rate), but *Arow* and *Asys* are negative. *Vleg* towards the stern increasing.
R3	Catch preparation	*Ffoot* increases, which causes the *Vleg* decreasing and *Aboat* became negative.	*Aboat* deceleration, but *Arow* became positive. Arms and oars prepare to catch the water.

Some inefficient crews don't have D3 phase at all. The duration of the D3 must be optimal at the period of 0.08-0.12s. This means that the switching from push into the stretcher during D2 to pull the handle during D3 and back to push during D4 must be present, but it must be done quickly.

Table 2. Average ratio of each micro-phase to the drive time, its standard deviation, minimal and maximal values, and correlation with the stroke rate.

	Sweep rowing						Sculling					
Micro-phase	D1	D2	D3	D4	D5	D6	D1	D2	D3	D4	D5	D6
% of drive time	13.3	11.6	13.7	20.9	28.1	12.5	10.4	9.8	18.0	24.5	21.8	15.5
STDev (%)	2.5	3.1	5.3	6.2	7.4	5.3	1.9	2.6	6.8	4.9	4.6	3.4
Min	6.1	4.0	0.0	0.0	11.2	0.5	5.0	2.8	0.0	11.5	11.0	6.2
Max	20.0	20.3	25.0	37.2	46.8	23.5	14.9	17.4	31.6	37.6	36.5	25.1
Corr. w. stroke rate	0.13	-0.15	0.43	-0.02	-0.23	0.02	-0.11	0.06	0.35	-0.10	-0.28	0.04

CONCLUSIONS

Coordination of the handle/gate and foot-stretcher forces during the drive phase was found quite complicated. More push (higher foot-stretcher force, legs work) means greater acceleration of the rower's mass; more pull (higher handle/gate force, upper body work) means greater boat acceleration. The rower's CM acceleration is the most important, which determines amount of kinetic energy accumulated during the drive and, hence, average speed of the rowers-boat system.

During micro-phase D3, "initial boat acceleration", rowers accelerate the boat to create faster moving support on the foot-stretcher to further accelerate their bodies, which is extremely important for performing effective drive phase. Fast increasing of the handle force is the main condition of its presence.

During micro-phase D4, "rowers' acceleration", rowers push the stretcher again to accelerate themselves and accumulate the main part of kinetic energy. This push-pull-push-pull sequence during the drive requires significant coordination and "boat feel" from rowers.

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