FORCE AND SPEED OF PARTIAL MOTIONS IN ON-WATER AND SIMULATED ROWING

Kanta Tachibana
Nagoya University, the Japan Society for the Promotion of Science and National Institute for Health and Nutrition, Japan

Rowers try to provide power as much as possible to the boat using oars. Because the power is defined by the product of force and speed, infinite combinations of force and speed produce a certain value of power. The aim of this study is to clarify force and speed of three main partial motions, i.e. leg drive, trunk swing and arm pull, during drive phase. Handle force is measured and then, shoulder, hip and foot forces are calculated with a one dimensional model. The speed of joints is calculated from position data obtained with video. Data of male university rowers showed that force and speed of the partial motions were different between on-water sculling and RowPerfect rowing. Another finding was that the force and the speed of trunk swing tended to decrease during 2000 meter simulated race on RowPerfect for the university scullers.

KEY WORDS: rowing, power patterns of partial motions, patterns of force and speed, difference between on-water and simulator, change during a race.

INTRODUCTION: Rowers try to optimize their motions so that they provide power as much as possible to the boat using oars. Sources of the power are muscle contractions for leg drive, trunk swing and arm pull during the drive phase. Share and time-series patterns of the three motions were studied (Kleshnev 2000, Tachibana et al. 2001). Because power is defined as the product of speed and force, infinite combinations of force and speed produce a certain value of power. And, force and speed of muscle contraction are contradictory. For example, trying to apply excessive force causes loss of relax, which decreases the speed of motion. Supposing that the power of a partial motion differs at a certain time point in the drive phase between two rowers, which of the two factors, force or speed, makes the difference?. The aim of this study is to specify the factor that makes the difference of the power patterns between groups. Two pairs of groups are compared: (1) on-water sculling vs. RowPerfect simulator rowing; and (2) the first half vs. the second half of a 2000m simulated race on the RowPerfect. The RowPerfect is said to be a better simulator of on-water rowing than static rowing ergometer (Buck et al. 2000, Lyttle et al. 2001). The first comparison of this study is to assess the similarity between on-water and the RowPerfect. The second comparison is to specify the factor that relates with a decrease of power during a race. The component to the boat direction of force, acceleration and velocity affects the boat speed directly (Anderson et al. 2001). This study utilizes a simple model that analyzes one dimensional movement. Joint positions are projected to the boat direction to calculate the power, the force and the speed of each partial motion.

METHOD: *Subject and measurement:* Eighteen male scullers from a university club participated. Eight of them rowed a few pieces of 100m with a single scull on water. They were directed to row at 26 – 28 strokes per minute. Seventeen strokes of their sculling were analyzed. Data collection was the same as reported in (Tachibana et al. 2001). The force and the angles of the oar were measured by strain gage and electronic goniometer, respectively. The sampling frequency was set at 30 Hz. Fifteen scullers rowed a 2000m simulated race on RowPerfect. The RowPerfect software records the handle force accurately (Lyttle et al. 2001). The handle force ($f_1(x)$) of every 20 strokes was recorded as a function of x, handle position relative to the flywheel, in every 2 cm. Time-series of handle force ($f_1(t)$) was calculated by Piecewise Cubic Hermite Interpolating Polynomial (PCHIP), included in MATLAB package, as $f_1(t) = \mathrm{PCHIP}(x(t), f_1(x))$, where $x(t)$ was time series of the handle position. The stroke rate of the simulated races on the RowPerfect were 32.0 ± 2.6 (average$\pm$SD) for 176 analyzed strokes. Five scullers participated in both the on-water sculling and the RowPerfect rowing.
One-dimensional model to calculate power, speed and force: This study assumed a simple model of rower's body to analyze one dimensional movement along "start to goal" direction. Figure 1 shows the axis on the pictures of simulated rowing. During both on-water sculling and RowPerfect simulation, positions of handle (x_1), shoulder (x_2), hip (x_3) and foot stretcher

(x_4) were videotaped and digitized at 30 frame/sec. The position data were low-passed by Butterworth filter with cutoff frequency of 7.5 Hz. Velocities (v_1 to v_4) and accelerations (a_1 to a_4) were calculated.

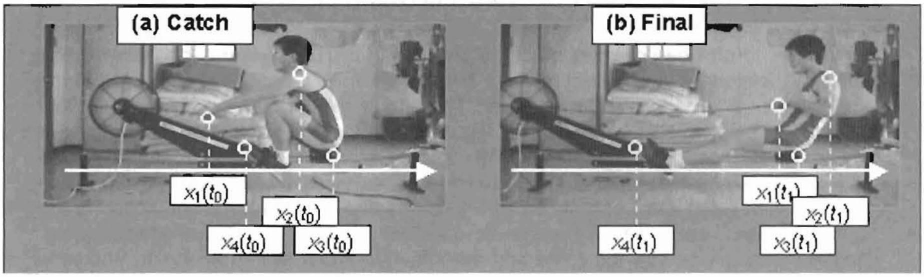

Figure 1. X-Axis and Digitizing Points That Are Projected to the X-Axis.

The force at shoulder (f_2) was calculated from the handle force (f_1) and accelerations (a_1 and a_2) as $f_2 = f_1 + m_{ARM}(k_{ARM}a_1 + (1-k_{ARM})a_2)$ (1), where m_{ARM} was mass of arm, which was calculated from body weight and weight proportions. k_{ARM} was ratio of center of mass to the length of arm, which was set at 0.5 for simplicity. The forces at hip (f_3) and the force at foot stretcher (f_4) were calculated in the same way.

The product of handle force and handle velocity stands for rate of energy outgo from the arm, so $E_{OUT\_ARM} = f_1v_1$ (2). The product of shoulder force and shoulder velocity stands for rate of energy intake to the arm, $E_{IN\_ARM} = f_2v_2$ (3). The arm produced the difference of energy outgo and energy intake. The power of arm pull (P_{ARM}) was given by

$$P_{ARM} = E_{OUT\_ARM} - E_{IN\_ARM} = f_1v_1 - f_2v_2 \quad (4).$$

The power of trunk swing (P_{TRUNK}) and the power of leg drive (P_{LEG}) were calculated in the same way.

The speed of arm pull (v_{ARM}) was relative velocity of the hand to the shoulder, $v_{ARM} = v_1 - v_2$ (5). The force of arm pull (f_{ARM}) was the tension of the arm segment:

$$f_{ARM} = \begin{cases} \min(f_1, f_2) & (f_1 > 0 \wedge f_2 > 0) \\ \max(f_1, f_2) & (f_1 < 0 \wedge f_2 < 0) \\ 0 & (f_1 f_2 \le 0) \end{cases} \quad (6).$$

The speed and force of trunk swing (v_{TRUNK} and f_{TRUNK}) and those of leg drive (v_{LEG} and f_{LEG}) were calculated in the same way.

The total power was calculated by $P_{TOTAL} = P_{ARM} + P_{TRUNK} + P_{LEG} = f_1v_1 - f_4v_4$ (7). Speed and force of the whole body motion were calculated by $v_{TOTAL} = v_{ARM} + v_{TRUNK} + v_{LEG} = v_1 - v_4$ (8)

and $f_{TOTAL} = \begin{cases} \min(f_1, f_4) & (f_1 > 0 \wedge f_4 > 0) \\ \max(f_1, f_4) & (f_1 < 0 \wedge f_4 < 0) \\ 0 & (f_1 f_4 \le 0) \end{cases}$ (9), respectively.

Comparison of power patterns: Power, speed and force patterns of each stroke were normalized to 0 – 100% of drive phase time. Compared groups were defined as follows:

(1) The 176 strokes on RowPerfect vs. the 17 strokes on-water, by university scullers.

(2) 27 strokes during the first half vs. 34 strokes during the second half of the simulated race by the worst 5 university scullers. The other scullers (the best 10 out of the 15 scullers) rowed in even pace.

Then, t-test was applied to test the difference of power between the two groups for each time point. The difference of force and the difference of speed between the two groups were also tested for each time point.

RESULTS AND DISCUSSIONS: *On-water vs. RowPerfect simulator:* Figure 2 (a), (b), (c) and (d) show force and speed of arm pull, trunk swing, leg drive and total body motion, respectively. The thick solid curves show force - speed relationships of RowPerfect. The broken curves show those of on-water. A pair of open circles connected by a thin line shows each 10% drive phase time. A closed circle shows that the power of each partial motion on RowPerfect was significantly larger than that of on-water at the time point. A square shows that the power of each partial motion on water was significantly larger than that of RowPerfect. Arm pull, trunk swing and leg drive power of RowPerfect were larger from the beginning to the middle of the stroke and at the final part of the stroke. On the other hand, the arm pull power and leg drive power of on-water sculling were larger when the normalized time was from 0.60 to 0.76 and when it was from 0.55 to 0.66, respectively. Table 1 and table 2 show the results of the *t*-tests at 0.40 and 0.70 drive phase time, respectively. Possible reasons of the different force-speed relationships are:

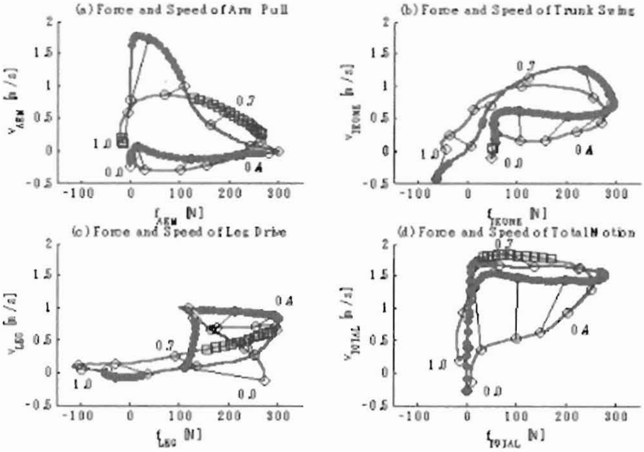

Figure 2. Force-Speed Relationships (On-Water and RowPerfect).

Table 1. *t*-tests at 0.40 drive phase time.

	Power [W]	*Force* [N]	*Speed* [m/s]
TOTAL	431 ± 118 200 ± 50 15.41*	267 ± 52 202 ± 47 5.34*	1.45 ± 0.23 0.93 ± 0.20 10.37*
ARM	-16 ± 62 -31 ± 40 - 1.36	283 ± 44 214 ± 27 9.24*	-0.04 ± 0.20 -0.07 ± 0.17 0.76
TRUNK	178 ± 71 43 ± 44 11.33*	279 ± 53 219 ± 46 5.08*	0.60 ± 0.21 0.29 ± 0.18 6.80*
LEG	269 ± 94 188 ± 61 4.99*	294 ± 81 256 ± 76 1.98	0.89 ± 0.17 0.71 ± 0.17 3.97*

Upper: Average ± SD of RowPerfect; Middle: On-water; Lower: *t*-value; *: significantly different ($\alpha = 0.01$);

Table 2. *t*-tests at 0.70 drive phase time.

	Power [W]	*Force* [N]	*Speed* [m/s]
TOTAL	276 ± 98 391 ± 134 -3.44*	136 ± 70 88 ± 64 2.96*	1.64 ± 0.22 1.84 ± 0.50 -1.59
ARM	64 ± 48 129 ± 56 -4.62*	161 ± 48 201 ± 34 -4.34*	0.41 ± 0.27 0.58 ± 0.26 -2.66*
TRUNK	188 ± 102 228 ± 97 -1.60	124 ± 76 110 ± 60 0.91	1.14 ± 0.30 1.00 ± 0.33 1.67
LEG	24 ± 45 34 ± 30 -1.25	136 ± 101 92 ± 72 2.29	0.09 ± 0.21 0.25 ± 0.12 -4.83*

Upper: Average ± SD of RowPerfect; Middle: On-water; Lower: *t*-value; *: significantly different ($\alpha = 0.01$);

Difference of load-speed characteristics between chain – gear – flywheel – air load, in the case of RowPerfect, and oar – pin – boat – water load, in the case of on-water rowing.

- Different path of the handle. RowPerfect allows moving the handle straight backward. On-water sculling requires rower to move the hand in an arc path. It makes rower more difficult to lean back on water.

- Different stroke rate. It largely affected the absolute value of power (250±45 [W] vs. 169±45 [W]). So, it might affect the force-speed relationship of body motions.

These possible reasons need to be separated in further study.

First half vs. second half of 2000m simulated race: Figure 3 shows the result. The thick solid curves show the 1st half of race. The broken curves show the 2nd half of race. A closed circle shows that power of each partial motion in the 1st half was significantly larger than that in the 2nd half. The trunk swing power became smaller when the normalized time was from 0.36 to 0.65. Arm pull power differed at 0.71 and 0.72 drive phase time between the 1st half and the 2nd half. There was not significant difference of leg drive power. Table 3 shows results of *t*-tests at 0.50 drive phase time.

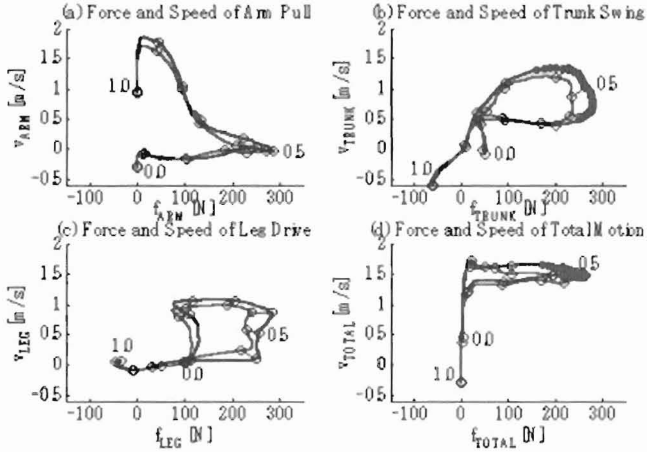

Figure 3. Force-Speed Relationships (1st Half and 2nd Half of 2000m Simulated Race).

CONCLUSIONS: The force and the speed of three main motions in the drive phase were different between on-water sculling and RowPerfect rowing. Possible reasons are load-speed characteristics and structure of hardware, and different stroke rate. These possible reasons need to be detected separately in further study. Changes of force and speed during a 2000m simulated race were also investigated. Leg drive and arm pull power were kept in the 2nd half of the simulated race, but trunk swing power became smaller, for rowers with bad scores.

Table 3. *t*-tests at 0.50 drive phase time

	Power [W]	*Force* [N]	*Speed* [m/s]
TOTAL	428±87 360±94 2.91*	257±42 221±46 3.18*	1.54±0.16 1.46±0.20 1.62
ARM	-17±35 - 2±45 -1.48	288±36 252±35 3.85*	0.02±0.12 0.02±0.18 -1.09
TRUNK	307±83 229±51 4.28*	266±47 233±51 2.64*	1.03±0.21 0.87±0.14 3.43*
LEG	138±62 133±54 0.31	257±46 228±57 2.17	0.53±0.19 0.57±0.15 -0.97

Upper: Average±SD in 1st half; Middle: 2nd half; Lower: t-value; *: significantly different ($\alpha = 0.01$);

REFERENCES:

Anderson, R., Harrison, A.J. & Lyons, G.M. (2001). Body Accelerations as Predictors of Power Output on a RowPerfect Boat Simulator, *ISBS 2001*, 255 – 258.

Buck, D.P., Smith, R.M. & Sinclair, P.J. (2000). Peak ergometer handle and foot-stretcher force on concept II and RowPerfect rowing ergometers. *ISBS 2000*, 622 – 625.

Kleshnev, V. (2000). Power in Rowing, *ISBS 2000*, 662 – 666.

Lyttle, A., Elliott, B. & Birkett, O. (2001). Comparison of force curves between on-water single scull rowing and the RowPerfect ergometer. *ISBS 2001*, 259 – 262.

Tachibana, K., Furuhashi, T., Shimoda, M., Kawakami, Y. & Fukunaga, T. (2001) Suggestion to rowers obtained by inverse dynamics and fuzzy modeling, *ISBS 2001*, 272 – 275.