COMPARISON OF FOOT-STRETCHER FORCE PROFILES BETWEEN ON-WATER AND ERGOMETER ROWING

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The purpose of this study was to compare the reaction forces at the foot stretcher of a Concept2 ergometer with and without slides to those of the boat in single scull rowing. Four male elite rowers were tested at rates of 20 and 30 strokes per minute on the ergometer with and without slides as well as in a single scull. The coefficient of multiple determination showed a high consistency about five time-normalised successive strokes in all conditions (about 0.99). Cross-correlation calculations between on-water force curves and force curves obtained under both ergometer conditions showed higher similarities for the ergometer on slides.

KEY WORDS: rowing technique, ergometers, land-based training.

INTRODUCTION: Rowing ergometers are used for land-based training in periods of bad weather conditions, biomechanical analysis of rowing, technique coaching, crew selection and performance tests (Lyttle, Elliott, & Birkett, 2001; Smith & Loschner, 2003; Soper & Hume, 2004; Nowicky, Burdett, & Horne, 2005). Opinions on the effectiveness of ergometers in simulating on-water rowing are controversial. Studies of Lamb (1989) and Eliott, Little, & Birkett (2002) indicate high levels of consistency, findings of Martindale & Robertson (1984) and Kleshnev (2005) question their usefulness.
One of the most commonly used ergometers is the Concept2 (Concept2, Vermont, USA). Two modes of application can be distinguished. In the static mode, the foot stretcher is stationary and the rower moves relative to the static ergometer. If the ergometer is put on slides (a construction that is attached to the legs) the ergometer itself rolls back and forth during the rowing stroke.
The rower applies force against the foot stretcher in order to exert force on the handle of the ergometer or to produce forward propulsion of the boat. Investigations by Körndle & Lippens (1988) indicate that experienced rowers show a typical pattern ("footwriting") in the reaction forces at the foot stretcher. If the ergometer is a good simulator for on-water rowing, one would expect that similar force curves can be observed. Force profiles have therefore been compared between on-water and both modes of Concept2 rowing.

METHOD:

Subjects: Four Austrian male elite rowers aged between 19 and 27 years participated in the study.

Data Collection: Measurements on the ergometer (Concept2 Indoor Rower Model D) and in the boat were performed within the same day. All subjects were tested at rates of 20 and 30 strokes per minute. Reaction forces at the foot stretcher were measured using two identical constructions (Baca, Kornfeind & Heller, 2006) based on load cells (HBM, type HLC220) and strain gages (HBM, type XY91-6/120). These constructions, one for the left and one for the right foot, were attached to the foot stretcher of the boat and of the ergometer. Force components normal (load cell; F_N) and parallel to the platform (strain gages; F_P) were acquired. From the data recorded and the angle of the foot stretcher horizontal (F_H) and vertical (F_V) reaction forces were calculated for the left and right foot as is illustrated in Figure 1. Start (catch) and end (finish) of the pulling phase (drive) were determined from synchronously recorded high-speed video sequences (100 Hz).

Data Analysis: Five consecutive strokes were considered for the statistical calculations. A procedure similar to that applied by Lyttle, Elliott & Birkett (2001) was used to compare the shapes of the force curves. All force-time curves were normalised in time to a uniform length of 200 samples per stroke. The adjusted coefficient of multiple determination (CMD; Kadaba, Ramakrishnan, Wootten, Gainey, Gorton & Cochran) was calculated to quantify each rower's motion variability within cycles. Cross-correlation coefficients of the averaged normalized curves between ergometer forces and boat forces were used as measure of similarity. They were also calculated considering the time-normalised pulling phases (from catch to finish; 100 samples) only.

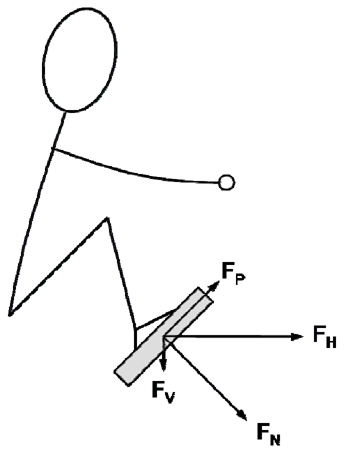

Figure 1: Reaction force components normal and parallel to foot stretcher and corresponding horizontal and vertical forces.

RESULTS AND DISCUSSION: Horizontal reaction force curves at the foot stretcher for one stroke of one of the rowers are exemplarily shown in Figure 2.

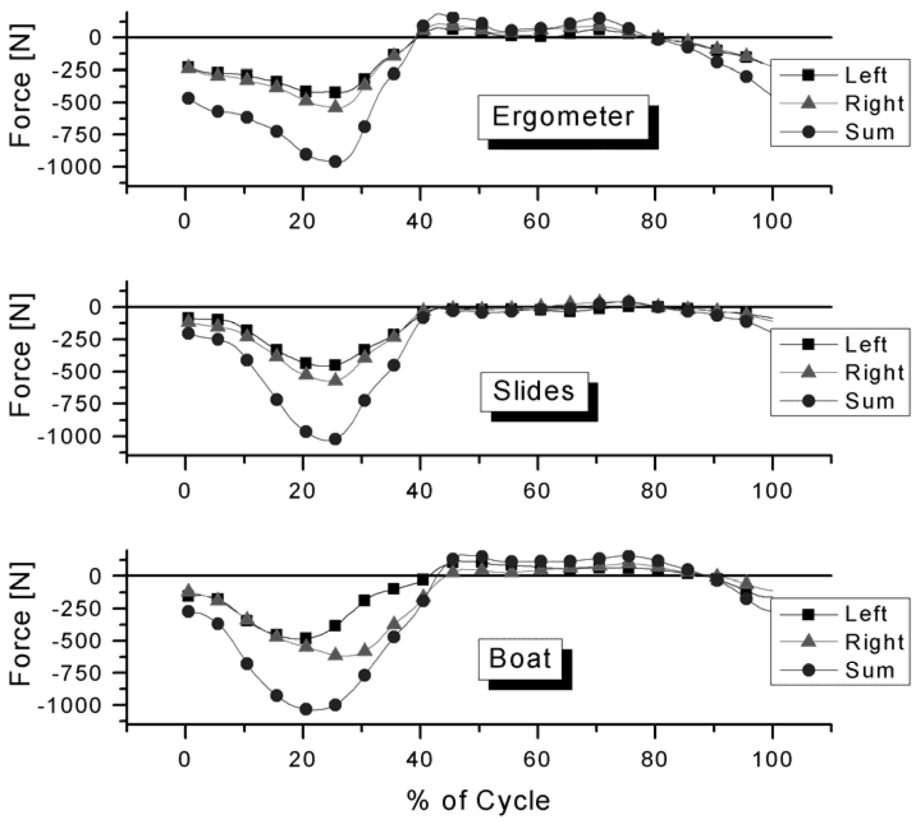

Figure 2: Horizontal reaction forces at the foot stretcher. Upper chart: static ergometer, middle: ergometer on slides, lower chart: boat. 30 strokes/min.

The durations of the pulling phase relative to that of the full cycle, the maximum horizontal reaction forces and the differences of the maximum horizontal reaction force for each rower at the left and right foot are listed in Table1.

Table 1: Relative Durations of Pulling Phase and Maximum Reaction Forces for Boat and Ergometer Trials (4 subjects A-D; 5 trials per subject)

	SR	**Duration of Pulling Phase (%)**	**Max. force Horizontal Total (N)**	**Diff. Max. Hor. Force Left-Right (N) for Rowers A - D**			
				A	B	C	D
Static Ergo.	20	31±1	886±120	-26	-51	-96	-12
Slides Ergo.	20	32±3	912±134	-115	-29	-129	5
Boat	20	35±1	904±65	-118	-200	-186	118
Static Ergo.	30	41±4	942±68	-21	-39	-116	20,6
Slides Ergo.	30	37±1	984±75	-66	-53	-117	30
Boat	30	45±2	1030±32	-116	-192	-133	151

The results indicate longer durations of the pulling phase in the boat. Force asymmetries in the boat could also be observed under ergometer conditions. They were, however, smaller in magnitude on the ergometer on slides and even smaller on the static ergometer.
As can be seen from Table 2, a high inter-stroke consistency could be observed.

Table 2: CMD values to quantify inter-stroke consistency

	SR	**Horizontal Left**	**Horizontal Right**	**Horizontal Total**
Static Ergo.	20	0,98±0,02	0,98±0,02	0,98±0,02
Slides Ergo.	20	0,99±0,01	0,99±0,00	0,99±0,01
Boat	20	0,97±0,01	0,97±0,01	0,98±0,01
Static Ergo.	30	0,99±0,01	0,99±0,00	0,99±0,00
Slides Ergo.	30	0,99±0,01	0,99±0,00	0,99±0,01
Boat	30	0,99±0,01	0,99±0,01	0,99±0,00

Cross-correlation values between the mean normalised force curves obtained from both types of ergometer trials and the boat are listed in Table 3. Comparisons based on the total strokes as well as the pulling phase only are given.

Table 3: Cross-correlation coefficients to quantify similarity

		Whole cycle			**Pulling Phase**		
	SR	**Left**	**Right**	**Total**	**Left**	**Right**	**Total**
Static Ergo./Boat	20	0.82±0.09	0.81±0.02	0.82±0.04	0.78±0.09	0.74±0.12	0.77±0.09
Slides Ergo./Boat	20	0.91±0.07	0.92±0.05	0.92±0.05	0.93±0.03	0.93±0.06	0.94±0.03
Static Ergo./Boat	30	0.80±0.12	0.81±0.09	0.81±0.11	0.79±0.09	0.84±0.08	0.83±0.10
Slides Ergo./Boat	30	0.89±0.08	0.90±0.07	0.90±0.07	0.85±0.14	0.95±0.04	0.92±0.05

Both comparisons show higher similarities for the ergometer on slides. These results can partly be explained by different initial conditions. At the beginning of the pulling phase the rower in the boat and at the ergometer on slides decelerates/accelerates the scull/ergometer whereas at the static ergometer the body of the rower has to be decelerated/accelerated.

The differences in the durations of the pulling phases are assumed to be one important reason for the deviations observed when comparing whole cycles. It should therefore also be noted, that different correlation coefficients would have been obtained for the whole cycle, if another key position (e.g. finish) had been chosen as starting (and end) point of one stroke.

CONCLUSION: From the results it can be concluded that rowing on the slide ergometer compares better to on-water rowing than exercising on the static ergometer. In the present investigation this was not initially expected, since only two of the rowers, who took part in the study, used the ergometer on slides for a small part of their land-based training.

Asymmetries between the reaction forces at left and right foot can be identified under all conditions. If they occur on the static ergometer they might be more visible on the ergometer with slides and much more visible in the boat.

The technique used on the ergometer on slides appears to be similar to that for on-water sculling. This agrees with the findings of Elliott, Little & Birkett (2002) for the RowPerfect ergometer. However, different durations of the pulling phases were observed (Table 1). Changes in the setting of the resistance of the Concept2 ergometer could reduce this difference.

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