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EFFECTS OF NON-OARSIDE-ARM PULL ON THE FORCES AT THE HANDLE AND FOOT-STRETCHER IN SWEEP-ROWING

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ABSTRACT

In sweep-rowing the rotational movement of the oar-handle around the swivel is executed by the arm and shoulder and results in an asymmetry between the body sides. The non-oarside-hand (-arm, -shoulder and -leg) pulls with a longer lever and more tangentially at the handle than the oarside-arm. Aim of the study was to examine the non-oarside-arm-force and its effect on the longitudinal, normal force at the oar-handle, and on the stretcher-force of the non-oarside- and oarside-leg. Twenty-six male elite rowers of the German Rowing Federation participated in coxless-fours. Normal, longitudinal, non-oarside-arm force on the oar-handle, and stretcher-force of the oarside- and non-oarside-leg were measured with a mobile measuring system. Normal two-handed rowing (Baseline), one-handed oarside-arm, non-oarside-arm, and dominant two-handed non-oarside-arm pull were compared using an analysis of variance. The results showed that the non-oarside-arm pull produced higher propulsion compared to the oarside-arm because the torque on the oar is greater and the stretcher-force reduced with lower differences between the oarside- and non-oarside-leg. Main reason is the longer lever and in addition the more tangential pull direction at the handle of the oarside-arm. A dominant non-oarside-arm pull should be practiced for increased performance and reduced leg asymmetry, but increases trunk asymmetry.

Keywords: biomechanics, technique optimization, rowing technique, sweep-rowing, propulsive efficiency

INTRODUCTION

In rowing, the athlete can apply force effectively to the boat at three points: the oar-handle, the stretcher and the sliding seat. Propulsion for the overall system rower/boat is produced during the drive phase only when the oar blades are in the water and their propulsive force exceeds the air and water resistance forces, as well as the forces of inertia of the moving masses (boat, athlete or crew) (3, 4, 5, 11, 12, 13, 16, 19, 20, 27, 29, 30, 32). A simplified model of the forces acting on the oar-handle, the swivel, the stretcher and oar blade are shown in Figure 1. In comparison to Mattes et al. (25), this study considered the force on the oar-handle for both arms and the non-oarside-arms separately.

The racing shell is propelled forwards by the oar acting as a lever of the second order with the fulcrum on the blade and the point of force application at the oar-handle. Thereby, the oar-handle rotates around the swivel. The force on the oar-handle is converted to a proportionally greater swivel force by the relationship of the inboard and outboard lever, which acts directly on the boat. To generate the force on the oar-handle and the swivel, an opposing reaction force of equal magnitude on the stretcher is necessary. The forces acting on the sliding seat were neglected.

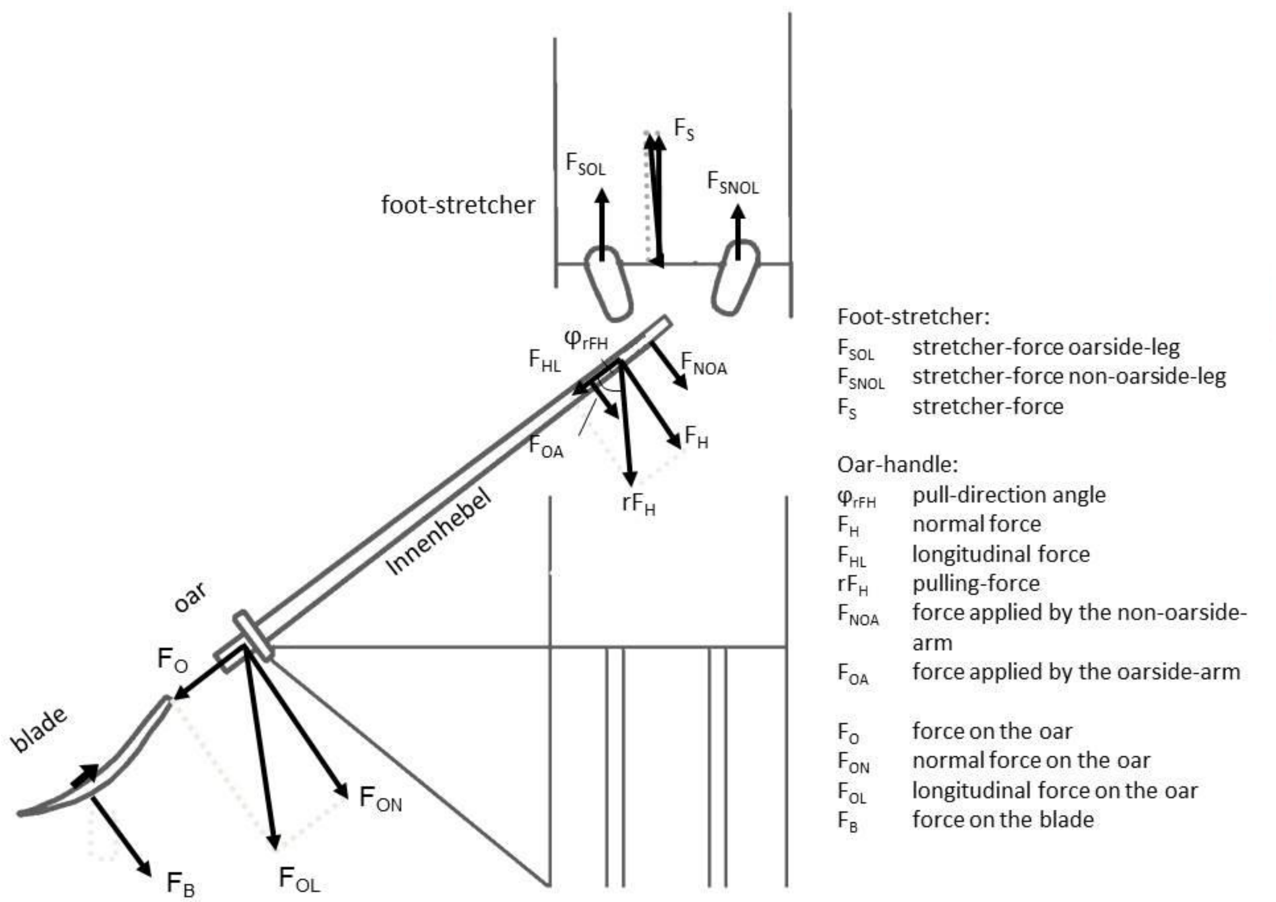

Figure 1 Forces on the oar-handle, the swivel, the blade and the stretcher, as well as the pull direction angle during sweep-rowing.

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To produce a large torque, the force on the oar-handle must act as normally as possible (tangential to the arc of the oar-handle) and with a long lever. Because the force cannot be fully applied normally to the handle, there is a longitudinal force-component (along the oar-handle) that pushes statically against the swivel and produces no torque but enhances the reaction force at the stretcher. With non-tangential force application, the longitudinal component increases. A certain longitudinal force component is always necessary to keep the oar in the swivel because an opposing water force can be assumed. These aspects have already been described from Schwanitz (29) and on the basis of models from other authors (19, 23).

During sweep-rowing, the hands hold the oar-handle at different distances. Accordingly, a distinction between the oarside-hand, which holds the handle further inboard and closer to the swivel, and the non-oarside-hand, that holds the handle further outboard. This term is adopted for the respective body side, i.e. non-oarside-hand, arm, shoulder and leg. According to the rowing technical concept (24), the distance between both hands should be 2.5 hand widths, which corresponds to a lever difference of 20 cm to the advantage of the non-oarside-arm.

Owing to the rotational movement of the oar-handle around the swivel, its position deviates from the boat's center line especially in the forward position and at the first part of the drive. The legs and shoulders jointly perform the rotational movement with the result that asymmetries between both body sides occur because the pull direction angles of the oarside and non-oarside-arm and the stretcher-forces of the oarside and non-oarside-leg, in particular, during the forward position and the early phase of the drive are different (14, 15, 18, 22, 30).

In the forward position, the stretched non-oarside-arm is located between the knees and the knee of the oarside-leg is more flexed than the knee of the non-oarside-leg (22). The pull direction of the non-oarside-arm in this position is approx. 10° more tangential compared to that of the oarside-arm (19). This more advantageous pull direction of the non-oarside-arm prevails throughout the first part of the drive phase. Because the non-oarside-arm pulls on the longer lever and has a more tangential pull direction during the first part of the rowing stroke compared to the oarside-arm, a double physical superiority of the non-oarside-arm occurs to produce rotational and leverage effects during the first part of the drive.

Owing to a stronger compression of the oarside-leg and the trunk rotation in the forward position, a tendency exists to start the leg drive more with the oarside-leg. Different stretcher-forces by oarside and non-oarside-leg have been already described by several authors. However, there are contradictory statements regarding asymmetry during sweep-rowing (1, 5, 21, 30). Smith and Loschner (30) found for the coxless pair that the stretcher-force by the oarside-leg starts the drive with greater amplitude and achieves the maximum force earlier than the non-oarside-leg. In contrast, the stretcher-force by the non-oarside-leg reaches an approx. 20% greater maximum during the drive. This result was valid for stroke and bowman.

In a first study (25, 26) the magnitudes of the longitudinal component force and the pull direction angle on the oar-handle, as well as the separate stretcher-forces of the oarside and non-oarside-leg have been described. Results showed static longitudinal force components from the first part of the drive phase to 100° rowing angle with high values during the first part of the drive phase (118-

285 N), and a percentage of 77.2-88.5% of the resultant force on the oar-handle. The pull direction angle differed between 52-64° inter-individually among athletes. In congruence with Smith and Loschner (30), asymmetric stretcher-forces were found with higher values for the oarside-leg during the first part of the drive phase, but higher values of the non-oarside-leg during the second and third part of the drive. With increasing stroke frequency, the force application on the oar-handle deteriorated owing to increases in the static longitudinal force component and the stretcher-force of the oarside-leg. With increasing performance class, the pull direction angle was increased and, therefore, the effectiveness of the force output on the oar-handle. These findings underline the high relevance of the longitudinal force component and the pull direction angle as a further reserve capacity in sweep-rowing. On the other hand, the expected effect of the pull direction on the stretcher-force could not be shown because it was not possible to differentiate between the forces of the oarside and non-oarside-arm.

OBJECTIVES

Hitherto, the amount of the non-oarside-arm-force, its relation to the normal and longitudinal force components, as well as the stretcher-force was unknown for sweep-rowing. Furthermore, information about the influence of non-oarside and oarside-arm pull on the forces and pull direction angle at the oar-handle, and the stretcher-force, were missing. The study examined the forces and pull direction angle in sweep-rowing (4-) by measuring the non-oarside-arm-force and longitudinal component force on the oar-handle in addition, as well as the separate stretcher-force of the oarside and non-oarside-leg. It was aimed to expand the scientific and practical training knowledge about the effectiveness of the force application on the oar-handle for reducing the reaction forces at the stretcher and to increase the propulsion of the boat.

HYPOTHESIS

First, it was assumed that during one-handed sweep-rowing with only the non-oarside-hand, the normal and non-oarside-arm-forces on the oar-handle would be proportional to each other but with the normal force having greater values. Second, when pulling one-handed with only the non-oarside-arm, in contrast to pulling one-handed with only the oarside-arm, owing to different lever lengths a higher normal force would result with a comparable or lower longitudinal force component on the oar-handle and a lower stretcher-force by the oarside-leg, with a resulting lower sum of the oarside and non-oarside-leg-forces. Third, it was expected that when pulling two-handed with a dominant non-oarside-arm pull, the pull direction angle and, therefore, the proportion of normal force due to the non-oarside-arm pull during the beginning of the drive would increase.

METHODS

Study Design and participants

The dependent variables: normal force, longitudinal force component, non-oarside-hand-force and pull direction angle, as well as the stretcher-force for the oarside and non-oarside-leg were analysed for training stroke frequency (20 strokes per min). The movement variants one-handed oarside-arm and non-oarside-arm pull, as well as two-handed dominant non-oarside-arm pull during the beginning of the drive phase (independent variables) were compared to the baseline (two-handed normal rowing).

The field studies were carried out with twenty-six male elite athletes of the German Rowing Federation in a coxless four (4-). The sample was divided in three performance classes: juniors (JM), male lightweight seniors (LM) and male heavy-weight seniors (M). The athletes of all three performance classes were capable of performing successfully in their age-groups at high-ranking national and international regattas. Two athletes participated at the World Championships in 2014 in the German eight. The anthropometric data for the LM differed from that for JM and M in body height and mass. JM showed the same body height, but a lower body mass compared to M (Table 1).

Testing Procedures

The data for basic endurance cadence (20 strokes per min) was collected as part of a standardised stroke frequency incremental test (20, 24, 28, 32 strokes per minute) for 15 rowing strokes followed by the movement variants test in the order baseline, oarside or non-oarside-arm pull (randomised) and dominant non-oarside-arm pull. The test included the following sections to which the athletes were instructed as follows:

1. Familiar, normal rowing (10 strokes), (baseline)
2. Pull only with the non-oarside-arm (10 strokes), (NOAP)
3. Pull only with the oarside-arm (10 strokes), (OAP)
4. Dominant use of the non-oarside-arm during the beginning of the drive phase, (dNOAP). Task 4 was carried out two times (10 rowing strokes each).

Between the sections, the athletes stopped rowing to separate clearly the phases for the subsequent analysis. Before each set, a transition of five rowing strokes was performed to pick up speed. Weather and water conditions were comparable between the tests and did not disturb the procedure (water temperature 16-17°, air temperature 18-22°, wind speed 0-2 Beaufort).

Measuring devices

The mobile measurement system by FES (Institut fuer Forschung und Entwicklung von Sportgeraeten) and a set of four instrumented oars were used for data acquisition. The sensor-equipped oar measured the normal and longitudinal component force (24, 25), as well as the separate non-oarside-arm-force with strain gauges affixed 21 cm from the end of the oar-handle. The measuring accuracy of the forces on the oar-handle and the stretcher was 1.5% and the sampling rate 50 Hz.

Statistical Analyses

Table 2 provides the means and standard deviations, the upper and lower level of the 95%-confidence interval, as well as minimum and maximum values for the submaximal stroke frequency (basic endurance cadence).

Table 2 Parameters of the rowing performance and rowing technique during training stroke frequency (20 strokes/min), Mean ± SD, upper and lower level of the 95% confidence interval (UL, LL), during the drive, *N*=26.

Table 1 Overview of the sample, performance class (PC), juniors (JM), male lightweight seniors (LM) and male heavyweight seniors (M), body height (B_H), body mass (B_M); *N*=26.

PC	Number	B_H [m]	B_M [kg]	Squad level	Results 2014
JM	12	1.93 ± 0.04	84.8 ± 8.7	D/C and JA	1. Place JWM. 4-; 1.Place DJM 2-. 8+
LM	8	1.86 ± 0.05	74.3 ± 2.8	B. C. D	4. Place U23 WM. 4-. 2-
M	6	1.93 ± 0.02	91.5 ± 6.1	A	2. Place WM. 8+; 4. Place U23 WM. 8+

Table 2 Parameters of the rowing performance and rowing technique during training stroke frequency (20 strokes/min), Mean ± SD, upper and lower level of the 95% confidence interval (UL, LL), during the drive, *N*=26.

Parameter	Abbreviation [Dimension]	MW ± SD	UL	LL	Min	Max
stroke frequency	S_F [1/min]	19.5 ± 0.7	19.1	20.0	18.7	20.7
non-oarside-arm force	F_{NOA} [N]	215 ± 35	201	229	166	305
normal force	F_H [N]	387 ± 57	363	410	309	517
longitudinal force	F_{HL} [N]	145 ± 31	132	157	85	215
resulting force on the inner part of the oar	rF_H [N]	412 ± 61	387	436	327	544
amount of normal force on the resulting force on the inner part of the oar (percent)	$F_{H\%}$ [%]	94 ± 2	93	95	87	98
pull-direction angle	φ_{rFH} [°]	57.1 ± 2.9	56.0	58.3	51.0	64.0
Stretcher-force sum	F_S [N]	555 ± 81	520	589	427	734
stretcher-force applied by the oarside-leg	F_{SOAL} [N]	250 ± 49	228	271	170	363
Stretcher-force applied by the non-oarside-leg	F_{SNOAL} [N]	305 ± 48	284	326	215	371
amount of the stretcher force of the non-oarside leg (percent)	$F_{SNOAL\%}$ [%]	54.9 ± 5.3	52.6	57.2	47.7	64.9

Verification of the relation between the normal and non-oarside-arm-force during one-arm pull with the non-oarside-arm only was analysed with a regression analysis (Table 3 and Figure 2).

The effect of the movement variants was evaluated with a repeated measures analysis of variance with the intersubjective factor movement variant (Table 4). Partial eta-squared (η_p^2) was taken as measure of effect size (small effect ≥0.08, medium effect ≥0.20, big effect ≥0.32, (9). Normal distribution and variance homogeneity was assessed with the Kolmogorov-Smirnov-Test and Levene Test. SPSS 20.0, (Chicago, IL, USA) was used for all statistical calculations.

Table 3 Mean ± SD, and parameters of the regression analysis of the non-oarside-arm-force (FNOA) as function of the normal force (FOA), *N*=26.

Phase	Force	MW ± SD	$F_{NOA}=m*F_H+n$		
			m	n	R^2
Drive	F_H [N]	246 ±47	0.8915	-0.314	0.99
	F_{NOA} [N]	219 ±42			
First part of the Drive	F_H [N]	241 ±57	0.9224	8.8799	0.981
	F_{NOA} [N]	231 ± 3			
Second part of the Drive	F_H [N]	315 ±64	0.8243	4.2069	0.9679
	F_{NOA} [N]	264 ± 4			
Third part of the Drive	F_H [N]	111 ±	0.8179	-3.709	0.9491
	F_{NOA} [N]	87 ±25			

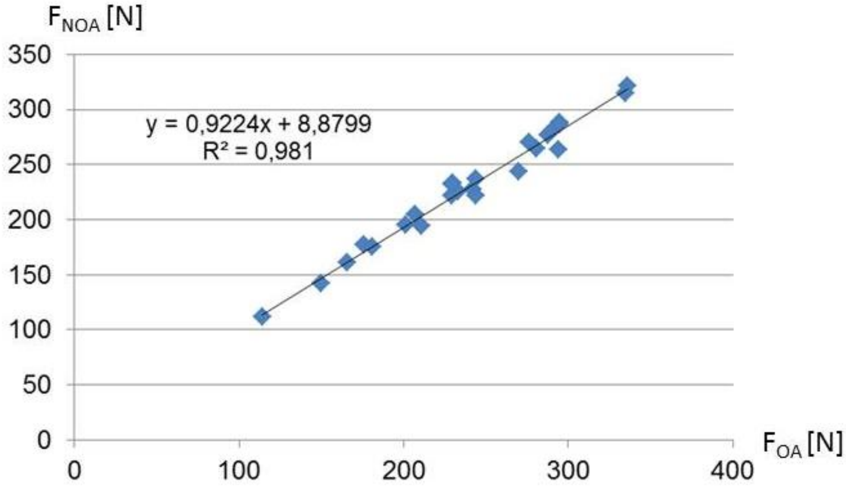

Figure 2 Regression of the non-oarside-arm-force (FNOA) as function of the normal force (FOA) on the oar-handle during the first part of the drive phase, *N*=26.

RESULTS

Pull direction angle and forces on the oar-handle and stretcher during sub-maximal stroke frequency

During the drive, the non-oar side-arm force and the longitudinal force component obtained 55.6 ± 9.0% and 37.4 ± 8.0% of the normal force on the oar-handle (387 ± 57 N), respectively. The pull direction angle during the first part of the drive phase was 57.1 ± 2.9°, so that 94 ± 2% of the resultant force on the oar-handle (of longitudinal component and normal force) acted as normal force. The stretcher-force of the non-oarside-leg was with 54.9 ± 5.3% of the sum of the stretcher-force greater than that of the oarside-leg. Data varied between individuals (Table 2) depending upon the different performance levels (seniors and juniors, light- and heavy-weight rowers).

Relation of normal and non-oarside-arm force during one-handed non-oarside-arm pull

On the basis of the movement variants, non-oarside-arm pull only, the relation of normal and non-oarside-arm force was described by means of the linear regression analysis, whereas a high coefficient of determination was achieved for the different phases of the drive from 0.95 to 0.99 (Figure 2 and Table 3).

Influence of the movement variants one-handed oarside and non-oarside-arm pull

The movement variants showed significant differences in the structure of the rowing stroke. In detail, stroke frequencies, oar-handle power and the normal and longitudinal force components, as well as the stretcher-force, were reduced proceeding from baseline to non-oarside-arm pull to the oarside-arm pull. The greatest stroke arc-length was measured during the oarside-arm pull, followed by the baseline and the non-oarside-arm pull, and reflected the differences in the angle in the forward position. The differences in the angle in the finish position were in total smaller, with significantly longer finish position during baseline compared to the oarside-arm pull and non-oarside-arm pull (Table 4).

Table 4 Stroke frequency (S_F), power (P_H), normal force (F_{HT}), longitudinal force component (F_{HL}), non-oarside-arm force (F_{NOA}), stroke width (SW), sum stretcher-force (F_S) and oarside-leg (F_{SOL}), forward position angle (φ_i), backward position angle (φ_x), percentage of the normal force to the resultant force on the oar-handle ($F_{H\%}$), pulling direction angle (φ_{rFH}) as well as percentage of the stretcher-force of the non-oarside-leg ($F_{SNOL\%}$) during drive of the movement variances Baseline, non-oarside-arm (NOAP) and oarside-arm pulling (OAP), dominant non-oarside-arm pulling (dNOAP), *N*=26.

Section	Stroke Level	Drive Phase									First part of the Drive								
	S_F [1/min]	P_H [W]	F_{IH} [N]	F_{HL} [N]	F_{NOAL} [N]	SW [°]	F_S [N]	F_{SOAL} [N]	φ_i [°]	φ_x [°]	F_H [N]	F_{HL} [N]	F_{NOA} [N]	$F_{H\%}$ [%]	φ_{rFH} [°]	F_S [N]	F_{SOAL} [N]	F_{SNOAL} [N]	$F_{SNOAL\%}$ [%]
Baseline	19.5±0.7	676±138	365±62	139±35	202±39	85.1±4	524±84	235±51	37.2±3.7	122.0±2.2	327±73	201±47	225±60	83±3	56.8±3	521±111	261±65	259±53	50.1±4.2
NOAP	18.7±0.6	365±79	246±46	94±21	219±41	81.4±3.9	301±52	116±27	40.1±3.6	120.8±2.1	239±56	134±32	228±54	85±2	59.9±2.6	337±82	141±40	196±52	58.4±7.1
OAP	17.9±0.8	282±62	195±35	90±21	-	90.3±3.5	338±49	201±40	31.4±3	121.2±2.2	217±37	132±29	-	84±3	58.7±3.5	415±70	264±54	151±40	36.4±8.1
pHE	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00
η_p^2	0.66	0.90	0.90	0.80	-	0.66	0.90	0.75	0.83	0.44	0.79	0.80		0.23	0.31	0.79	0.72	0.82	0.77
p_1	0.05	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.00	0.00	0.00
p_2	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.01	0.04	0.00	0.65	0.00	0.00
p_3	0.00	0.00	0.00	0.34	-	0.00	0.00	0.00	0.00	0.32	0.01	0.95		0.36	0.02	0.00	0.00	0.00	0.00
dNOAP1	19.3±0.6	705±135	384±64	145±28	245±39	85±3.2	526±82	217±50	37.2±3.7	122.3±2.3	357±74	209±42	278±58	84±2	57.7±3.1	538±109	249±61	289±58	53.9±4.6
dNOAP2	19.6±0.7	701±150	381±70	143±32	238±50	84.7±3.2	529±88	223±57	37.2±3.7	122.3±2.2	349±78	206±46	269±62	83±3	57.3±2.7	534±105	251±67	282±49	53.4±5.4
pHE	0.18	0.03	0.01	0.01	0.00	0.83	0.36	0.00	37.2±3.7	122.4±2.3	0.00	0.01	0.00	0.01	0.05	0.04	0.21	0.00	0.00
η_p^2	0.21	0.11	0.14	0.14	0.40	0.01	0.03	0.16	0.778	0.495	0.26	0.14	0.40	0.22	0.09	0.10	0.05	0.38	0.41
p_4	0.16	0.06	0.02	0.02	0.00	0.22	0.71	0.00	0.01	0.02	0.00	0.03	0.00	0.00	0.08	0.09	0.08	0.00	0.00
p_5	0.69	0.16	0.10	0.08	0.00	0.65	0.53	0.15	0.315	0.409	0.03	0.11	0.00	0.05	0.62	0.26	0.35	0.00	0.00

pHE = p-value of the main effect movement variant. η_p^2 = partial eta-squared.
p_1 = Baseline vs. NOAP.
p_2 = Baseline vs. OAP.
p_3 = NOAP vs. OAP.
p_4 = Baseline vs. dNOAP1.
p_5 = Baseline vs. dNOAP2

During the first part of the drive phase, a significant main effect was found for the movement variants on the forces, the pull direction angle on the oar-handle, as well as the stretcher-force (large effect sizes). The pairwise comparisons of the movement variants during the first part of the drive revealed the following significant differences:

- Baseline vs. non-oarside-arm pull: the normal and longitudinal component forces on the oar-handle, as well as the stretcher-forces with lower values during non-oarside-arm pull, but larger pull force angle, as well as greater percentages of the normal force of the resultant force on the oar-handle and greater percentages of the stretcher-force of the non-oarside-leg of the sum of the stretcher-force during non-oarside-arm pull.

- Non-oarside vs. oarside-arm pull of the normal force and the pull direction angle with greater values during non-oarside-arm pull and greater percentage of the stretcher-force of the non-oarside-leg of the sum of the stretcher-force. On the other hand, a smaller stretcher-force by the oarside-leg and sum of the stretcher-force were registered (Table 4).

Influence of the movement variant: dominant non-oarside-arm pull

The movement variants baseline and dominant non-oarside-arm pull showed no significant differences for stroke frequency and stroke arc-length. In contrast, there was higher power, normal force, longitudinal component force and non-oarside-arm-force, but reduced stretcher-force by the oarside-leg with comparable sum of the stretcher-force during the drive phase (Table 4).

At the first part of the drive phase, the dominant non-oarside-arm pull in-creased the normal, longitudinal and non-oarside-arm pull forces with non-significant increased pull direction angle, but with higher percentage of the normal force of the resultant force on the oar-handle. In addition, the dominant non-oarside-arm pull increased the stretcher-force by the non-oarside-leg (i.e. the same side) and reduced the stretcher-force by the oarside-leg (i.e. the opposite side), so that despite higher normal force on the oar-handle, the sum of the stretcher-force did not increase.

DISCUSSION

The present study examined primarily the normal and longitudinal handle forces, and in addition the separate non-oarside-arm-force to examine its influence on the forces on the oar-handle, the pull direction angle and the stretcher-force. In theory, when the oar blade is immersed (lever of the second order with the fulcrum on the blade) the boat is levered in the propulsive direction by the normal force on the oar. The non-oarside-hand is further away from the swivel with a longer leverage than the oarside-hand. Owing to the rotational move-ments of the oar-handle around the swivel, the position of the oar-handle deviates from the boat's center-line, particularly at the forward position and during the first part of the drive. The arms and shoulders create the rotational movement so that different pull direction angles with varying longitudinal force component, as well as asymmetric stretcher-forces of oarside and non-oarside-leg during the first part of drive were expected (19, 23, 24, 25, 29).

A first data-driven description of the longitudinal force component, the pull direction angle and the stretcher-force separately for the oarside and non-oarside-leg has previously been given (24) and confirmed with the present study. The data was in agreement for:

- a comparably high longitudinal force component during the beginning of the drive phase, even though during the second part of the drive there were higher normal and non-oarside-arm forces,

- inter-individual differences in the pull direction angle (52-64°), as well as

- systematic differences in stretcher-force between oarside and non-oarside-leg with higher values for the oarside-leg during the beginning of the drive, but higher non-oarside-leg forces during the entire drive phase.

Hitherto, the non-oarside-arm-force has not been measured in other projects. The parameter values found differed inter-individually between athletes which underlines their performance diagnostic relevance because the data were clearly above measurement uncertainty (ca. 1.5%).
For one-handed rowing with only the non-oarside-arm, it was assumed that owing to different lever lengths (12 cm lever difference) the normal and non-oarside-arm-force on the oar-handle were proportionally related with higher values of the normal force compared to the non-oarside-arm-force. This assumption was verified with the regression function with good estimation of the non-oarside-arm-force as a function of the normal force with a measure of de-termination of 0.99 for the drive. The quality of the fit diminished from the first part of the drive, over the second, to the third part of the drive (measure of determination 0.98, 0.96, 0.94). One reason for the deviations is assumed to be caused by the connection between the handle and the loom. The handle is firmly glued to the loom, so that minimal differences be-tween the four oars existed. In addition, changes in the normal force after calibration can occur in individual cases. For the measurement of the normal force, a sensor is buckled on and firmly screwed onto the oar to measure the bending torque. If the sensor is not fixed optimally, mechanical transmission errors of the bending of the oar to the stylus, as well as the bending bar with sensor may occur and lead to measurement errors.

The comparison of the movement variants confirmed the following hypotheses:

- contrary to one-handed oarside-arm pull, one-handed non-oarside-arm pull acts with higher normal force with a comparable or lower longitudinal force component on the oar-handle and lower stretcher-force of the oarside-leg, as well as the sum of oar side and non-oarside-leg;

- the dominant use of the non-oarside-leg enhances the effectiveness of the force output on the oar-handle and reduces the sum of the stretcher-force.

Therefore, both movement variants (only non-oarside-arm pull and dominant non-oarside-arm pull) showed the advantages of the non-oarside-arm pull vs. oarside-arm pull. The advantage of the non-oarside-arm pull was theoretically expected because firstly, the non-oarside-arm pulls with a longer lever and, secondly, with an advantageous pull direction during the first part of the drive; that is more tangentially to the oar-handle compared to the oarside-arm. Be-sides the dominant use of the non-oarside-arm, the movement direction of non-oarside-arm and shoulder determines the resulting pull direction on the oar-handle. Pulling with the non-oarside-arm is a necessary, but not a sufficient condition, for a propulsive force application because the non-oarside-arm force may act more or less tangentially on the oar-handle.

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The measured differences of the stretcher-force of oarside and non-oarside-leg can be traced back to the asymmetry during sweep-rowing, especially in the forward position and during the early phase of the drive phase (14, 15, 18, 22, 30). The rowing stroke is characterised by a lateral trunk rotation. During recovery, a rotation in the direction towards the swivel with flexed pelvic, knee and ankle joints exists during the preparation for water contact to transfer the stretcher-force with extended lower extremities over the trunk, arms and legs onto the oar-handle (28, 30). Because of the trunk rotation towards the swivel during the first part of the rowing stroke, the oarside-knee is a little more flexed than the non-oarside-knee (22). There is a tendency to begin the leg push more strongly with the oarside-leg due to its strong compression (30).

Further studies provided evidence for the existence of relevant asymmetries of the stretcher-forces of the left and right side at the concept II ergometer rowing (2, 6, 7, 17), as well as in single scull (2, 10) in highly trained and experienced rowers. The bilateral asymmetries of the stretcher-forces during ergometer rowing influence the kinematics of the pelvic, the lumbar spine and pelvic rotation in the sagittal plane (8) and are associated with pain in the pelvic and lumbar spine region. Due to the closed chain (handle, seat and stretcher), asymmetric stretcher-forces should be balanced with a compensating movement pattern of the pelvic and/or spine or a stabilising co-contraction of the pelvic and trunk muscles in order to keep the movement of the handle in the sagittal plane (8). A dominant non-oarside pull at the handle influences the bilateral asymmetry of the stretcher force as our study showed.

The movement variants used in this study implied two substantial advantages: During single-arm pull, the effect can directly be traced back to the respective arm. The measured force of the oar-handle was lower compared to the two-handed pull, nevertheless, deviations in the stroke structure resulted. One-handed rowing has higher coordinative demands, but it is not unusual as it is a regular training exercise. It remains open if mastering the non-oarside-arm pull dominates the oarside-arm pull. Since the oarside-arm performs the feathering of the blades above the water during sweep-rowing (31), it can be assumed that during training, rowing only with the oarside-hand is performed more frequently than rowing only with the non-oarside-hand and, thus, it is executed better. During the two-handed dominant non-oarside-arm pull, the stroke structure was near those of the baseline, which enhanced the validity of the results for two-handed rowing.

In the study, the longitudinal force component and for the first time the non-oarside-arm-force was separately measured. Technically, this was only possible because four oars were equipped with sensors. The same four oars were used for all tests. Oars of the same type are currently used also in training and for regattas, where they can be adjusted (lever setting) individually. However, the athletes have had acceptance problems using the measuring oars because during performance testing the measurement sensors are attached to the individual oar of the athlete.

CONCLUSION

Until today, no comparable multidimensional measurements exist with the separation of the non-oarside-arm force in a racing boat. Thus, the results of this study have a new value to provide information about the pull direction and effectiveness of force application on the oar-handle and the necessary reaction force at the stretcher. It was shown that

- during the first part of the drive, pulling with the non-oarside-arm produced a higher propulsive force than pulling with the oarside-arm because the torque at the oar increases and, at the same time, the stretcher-force of the oarside-leg and the sum of the stretcher-force decreased. In addition, it was shown that

- pulling with the non-oarside-arm was necessary, but not a sufficient condition for an effective propulsive force application be-cause the non-oarside-arm-force can pull more or less tangentially at the oar-handle,

- the stretcher-force showed a characteristic asymmetry with higher values of the oarside-leg during the first part and over the entire drive.

The following principle can be deduced for on-water training:

- By using the non-oarside-arm dominantly and applying the force tangentially during the first part of the drive phase, the torque on the oar-handle can be increased and the longitudinal component force and stretcher-force of the oarside-leg decreased (enhanced propulsion).

For increased performance, one-handed rowing should be used only with the non-oarside-hand; the dominant non-oarside-arm pull should be used during two-handed rowing for training exercise. Due to differences of the stroke structure, a methodical order of one-handed rowing only with the non-oarside-hand followed by two-handed rowing with the dominant non-oarside-arm pull is recommended.

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