2D KINEMATIC AND KINETIC CHARACTERISTICS OF THE DRAGON BOAT PADDLING STROKE

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The aim of this study was to combine 2D force measurements on a dragon boat paddle with synchronised 2D video data, establish the main kinetic and kinematic parameters for key paddle events and measure the paddle displacement between entry and exit points on the surface of the water. A custom built strain gauged paddle and a stationary high speed video camera was used to collect synchronised data at 200 Hz. Results for skilled versus club level paddlers were significant with a large effect size for propulsive impulse, impulse workload, maximum paddle force, average paddle force, force development, stroke length, paddle displacement, and, paddle angles at maximum force, zero force, exit and minimum force. Paddle displacement at the water interface is in the direction of boat movement and this may indicate a breaking force during part of the paddling stroke.

KEY WORDS: paddle, force, angle, displacement, inertia, technique.

INTRODUCTION: Dragon boat racing consists of teams of 20 paddlers sitting in pairs on 10 fixed wooden benches in a long narrow boat (12.4m long, 1.14m wide), with a drummer at the front urging the paddlers on and a helm at the rear steering the boat via a long sweep oar. To maintain the heritage and traditions of dragon boat racing, the International Dragon Boat Federation (IDBF) specifies the use of standard boats and paddles so that races are won by the efforts of a crew and not by the technical superiority of the equipment used. Thus performance in dragon boat racing is determined by the skill and fitness of team members and the importance of effective paddling technique is paramount to success.

Literature on the biomechanics of dragon boat paddling is limited. Pease (1997) compared large and small framed paddlers at a world championship. Smaller framed paddlers had higher stroke rates per minute, shorter stroke lengths and shorter boat travel distance per stroke, with a larger angle of paddle entry than the large framed paddlers. No numerical data, apart from stroke rates (reported as ~95 versus low 80's), were supplied.

Ho, Smith and O'Meara (2006) evaluated an instrumentation system to measure dragon boat paddling forces and reported data (average of 10 strokes) for two male subjects paddling at moderate intensity (65 strokes per minute, peak force 263-267N, mean force 132-140N, rate of force development 5100-6100N/s and drive stroke time ratio 43-53%). In Ho, Smith and O'Meara (2007), six elite (3male, 3 female) and six sub-elite paddlers (2 male, 4 female) were compared at high intensity paddling (80-90 strokes per minute) via ten consecutive strokes selected from 250m radomised paddling trials. Significant differences between elite and sub-elite paddlers were found at $p<0.01$ for average peak force (306±12N versus 203±12N), mean force (150 ±-5N versus 98±5N), and stroke impulse (55±3N.s versus 34±3N.s). Elite results were higher but not significant at $p<0.05$ for paddling efficiencies (76±4% versus 67±10%), rate of force development (3300 ±340N/s versus 2800 ±330N/s) and drive to stroke time ratio (55 ±2% versus 51 ±2%). The Ho et al (2007) data is of similar magnitude to the Ho et al. (2006) data except for the rate of force developement which was nearly 50% less. Ho, Smith and O'Meara (2009) reported the kinetic data from Ho et al. (2007) in body mass normalised form along with kinematic data for the same subjects. The kinetic data was normalised (divided by body mass raised to the power of two-thirds) to overcome the confounding effects of gender and strength. Large variations in kinematic data were observed but no significant differences were noted. Average angles for elite and sub-elite groups were as follows: trunk flexion at entry 41 ±8° versus 48 ±3°; trunk flexion at exit 21 ±4° versus 23±3°; shoulder angle at entry 114 ±7° versus 119 ±4°; shoulder angle at exit 0 ±30° versus -13±6°; elbow flexion at entry 16 ±2° versus 16 ±8°; elbow flexion at exit 71 ±19° versus 59±33°; paddle angle at entry 40 ±7° versus 39 ±4°; and, paddle angle at exit 63

±4° versus 63 ±4°. Average stroke length was reported as 1.3 ±0.1 m for elite and 1.2 ±0.1 m for sub-elite. Small sample size, gender combined data and normalised reporting of kinetic variables limits the usefulness of Ho et al. (2006; 2007; 2009) studies.
Gomory, Ball and Stokes (2011a) described a system to measure kinematics, kinetics and effort of dragon boat paddling, and provided data for two international paddlers for stationary versus dynamic paddling (average impulse per stroke - male 347 versus 136 N, female 156 versus 86 N; maximum force - male 465 versus 366 N, female 268 versus 263 N). In Gomory, Ball, Stokes and Cucsa (2011b) the relationship between stationary and dynamic dragon boat paddling was examined for a group of paddlers via two tailed paired t-tests ($p<0.01$). Average maximum force (285 ±94 N versus 302 ±82 N) and rate of force development (1260 ±630 N/s versus 1580 ±660 N/s) did not differ significantly but stroke rate per minute was significantly lower (40 ±5 versus 64 ±3) and impulse per stroke was significantly higher (236 ±77N.s versus 113 ±30N.s) for stationary paddling ($p<0.01$).
None of the above studies examined the basis of propulsion – paddle-water interaction in the global reference frame. The aims of this study was to combine 2D force measurements on the paddle with synchronised 2D video data, establish the main kinetic and kinematic parameters for key paddle events (entry and exit points; max, min and zero paddling forces) and determine the paddle displacement between entry and exit relative to the water surface.

METHODS: Twenty two paddlers (11 male [7 club, 4 skilled], 11 female [7club, 4 skilled], aged 27-65, skill level club to international) participated in the study. Each paddler performed a 30 second maximum effort paddling task in a simulated dragon boat race (starting ~80m from the camera), using a custom built strain gauged paddle. The stationary video camera (Sony HDR-HC7) was set up for 2D analysis and recorded a three second video clip of the paddling stroke(s) for each subject at 200 Hz frame rate as the boat entered the camera's field of view (set at 6m). Paddlers were allowed to sit in their preferred positions and were given adequate rest periods between tests. The strain gauged paddle recorded the paddling forces at 200 Hz via a laptop data collection system (Gomory et al., 2011a). Calibration of the paddle was via a 10cm loading strap at the hand grip position (mid-point of paddle) with fixed standard weights (0-40-0Kg in 5Kg steps), using a water cushion support on the blade surface and a fixed support on the handle. A manually operated LED torch, interfaced with the laptop data collection system, was used to synchronise the force and video data. The video recording for each paddler was analysed using Siliconcoach Pro 7 software (Silicon Coach, NZ) to measure the time, paddle angle and boat displacement for key paddle events (entry and exit points; max, min and zero paddling forces). Distance calibration was obtained from tape marked reference points on the sides of the boat. The paddle angles were measured using the paddle handle and paddle-water intercept as the construction points for the Siliconcoach angle measurement tool and the coordinates of these points were recorded for subsequent use in a custom made Excel spreadsheet. Force and video data were combined in the Excel spreadsheet to produce the statistics for the kinetic and kinematic parameters reported in Table 1. Student's two-sample unequal variance t-test with one-tailed distribution was used to calculate p values and significance was set at $p<0.05$. For effect size Cohen's d and criteria were used (small <0.2, medium ~0.5, large >0.8).

RESULTS AND DISCUSSION: Results for the combined force video study is summarised in Table 1 and a representative paddling force curve is shown in Figure 1. Average stroke rates were 68-72 strokes per minute which was less than the 80-90 strokes per minute reported by Ho et al (2009) for high intensity paddling. The average boat displacement per stroke was 3.01-3.32 m. For female paddlers (skilled versus club level) ten parameters were found to be significant; propulsive impulse (44 versus 31 N.s, range 29-75 versus 20-45), impulse workload (3170 versus 2170 N.s/min, range 2060-3570 versus 1350-3190), maximum paddle force (221 versus 157 N, range 161-252 versus 115-237), average paddle force (107 versus 74 N, range 78-124 versus 46-108), force development (2250 versus 1100 N/s, range 1240-2790 versus 640-1830), stroke length (1.76 versus 1.47m, range 1.58-1.89 versus 1.26-1.63), paddle displacement (see below), and, paddle angle at zero force in water (-57 versus -41°, range -53 to -62° versus -33 to -46°), paddle angle at exit (-61 versus -50°, range -56 to

-66° versus -41 to -59°) and paddle angle at minimum force (-63 versus -50°, range -55 to -70° versus -28 to -66°). All these parameters had a large effect size (Cohen's d>0.8). For male paddlers (skilled versus club level) only two parameters were significant; stroke length (1.81 versus 1.59m, range 1.68-1.97 versus 1.32-1.86) and paddle angle at maximum force (9 versus 0°, range 3-18° versus -11-11°). However these two parameters for male paddlers along with propulsive impulse, impulse workload, maximum paddle force, average paddle force and force development had a large effect size indicating that with a larger sample size or a more representative skilled sample, these parameters may also have been significant.
The average paddle displacement as measured between water entry and exit points was not significant for males (-0.28 versus -0.32 m, range -0.01 to -0.68 versus -0.16 to -0.49) but was significant with a large effect size for females (-0.07 versus -0.25m, range -0.04 to -0.10 m versus -0.11 to -0.46 m). Paddle movement was in the same direction as boat movement. However movement was expected to be in the opposite direction since dragon boat paddles work on the principle of drag force. Visual examinations of the video clips appear to indicate an initial backward movement of the paddle followed by a forward movement for skilled paddlers and a forward movement only for club level paddlers as the water phase of the stroke is completed. This appears to indicate that a breaking force was being applied by the paddle during the latter part of the stroke. The available data is not sufficient to provide an explanation for the observed results. Tracking of the blade movement through the water is required to define the blade path of the paddle in the global reference frame.

Table 1: Dragon boat test parameters for club versus skilled male and female paddlers.

TEST PARAMETERS	Club Male		Skilled Male		Club Female		Skilled Female	
Force & video derived data	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Stroke rate per minute	69	4	68	6	70	2	72	3
Propulsive impulse, N.s	59	14	75^{L}	21	31	9	44^{*L}	10
Impulse workload, N.s/min	4080	950	5010^{L}	1260	2170	680	3170^{*L}	740
Maximum paddle force, N	252	58	323^{L}	91	157	44	221^{*L}	43
Average paddle force, N	134	23	159^{L}	28	74	22	107^{*L}	20
Minimum paddle force, N	-43	17	-62	34	-36	12	-28	9
Force curve efficiency, %	54	7	50	7	47	7	48	2
Force development, N/s	1570	407	2620^{L}	1090	1100	380	2250^{*L}	690
Stroke reach, m	1.27	0.17	1.34	0.07	1.27	0.09	1.31	0.10
Stroke length, m	1.59	0.17	1.81^{*L}	0.12	1.47	0.15	1.76^{*L}	0.15
Paddle displacement, m	-0.32	0.13	-0.28	0.31	-0.25	0.12	-0.07^{*L}	0.03
Boat displacement, m	3.18	0.19	3.32	0.21	3.01	0.36	3.22	0.16
Water entry angle, deg	34	6	34	6	33	4	31	3
Maximum force angle, deg	0	7	9^{*L}	7	7	4	6	4
Zero force angle, deg	-51	8	-52	9	-41	5	-57^{*L}	5
Water exit angle, deg	-54	9	-58	4	-50	6	-61^{*L}	5
Minimum force air angle, deg	-50	13	-57	7	-50	14	-63^{*L}	6
Zero force air angle, deg	27	11	23	7	19	13	28	4

'Cohen's d' effect size criteria ^{L}=Large (>0.8). Significance *$p<0.05$.

The representative force curve in Figure 1 shows that on entry the force on the paddle increases rapidly to a maximum. Synchronised video data confirms that this maximum force is reached near the end of the entry phase of the stroke. During the drive phase for a brief period (less than 0.1 s) the paddle force remains near the maximum and then declines almost as rapidly as it rose. Exit occurs at zero paddle force and is confirmed by video data. A subsequent negative force arises on the paddle as it changes direction and accelerates forward towards the entry point. The negative force at first increases and then reduces to zero as the paddle moves forward. This initial negative force may be increased by paddle-water interaction if a paddler fails to have a 'clean exit' (paddle moves forward whilst still immersed). During the latter part of recovery (air phase of the stroke), a positive force arises on the paddle as it moves forward to the entry point. This inertial air-force increases from zero prior to entry to a peak value at entry (confirmed by video data) as the paddle accelerates and plunges into the water. Whatever forces a paddler applies to the paddle via body movement, regardless of whether the paddle is in the water or the air, that force is measured by the strain gauged paddle. Force measurement is an indicator of paddling technique, both in the air and the water. Paddlers and coaches can use the force curve to assess quality of the paddling stroke in conjunction with video data. Effort can be assessed by the impulse workload parameter (defined as stroke rate multiplied by stroke impulse).

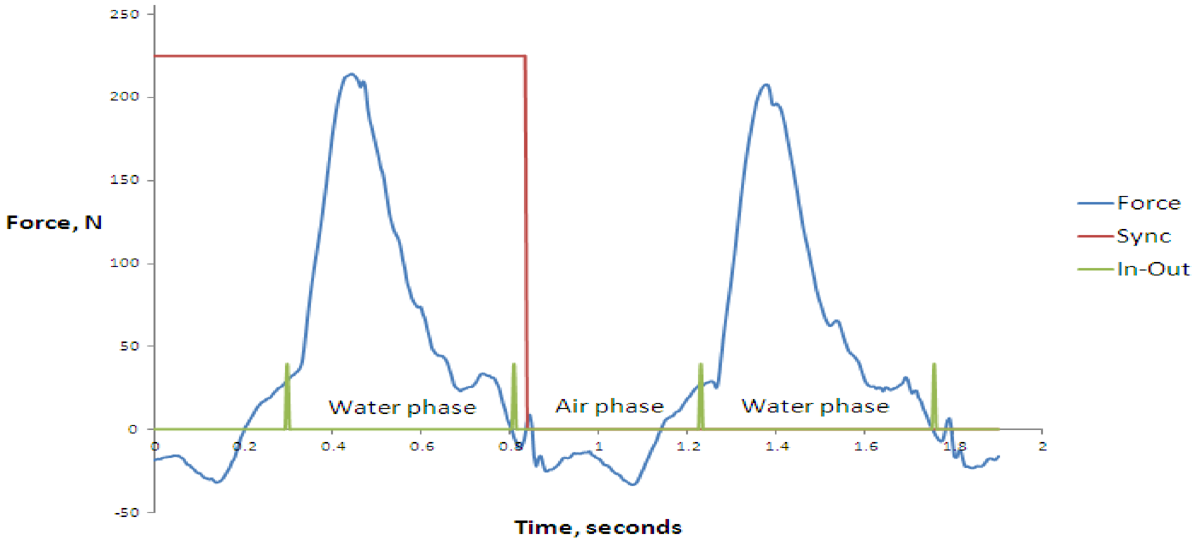

Figure 1: Force curve of videoed paddling strokes for 42 year old female international paddler showing entry [In] and exit [Out] of paddle, and synchronising light signal for video analysis.

CONCLUSION: This study combined 2D force measurements on a dragon boat paddle with synchronised 2D video data, established the main kinetic and kinematic parameters for key paddle events and determined the paddle displacement between entry and exit points on the water surface in the global reference frame. Parameters that were found to be significant for club versus skilled paddlers with a large effect size (combined results) included propulsive impulse, impulse workload, maximum paddle force, average paddle force, force development, stroke length, paddle displacement, and, paddle angles at maximum force, zero force, exit and minimum force. Other key findings of the study were that the max paddling force occurs at the end of the entry phase of the paddling stroke prior to vertical paddle position and the overall blade displacement relative to the water is in the direction of boat travel indicating that a possible breaking force exists during part of the paddling stroke.

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