KINEMATICS OF WOMEN'S SPRINT CANOEING TECHNIQUE

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Little is known about the biomechanics of sprint canoeing, especially for women's canoeing, and a quantitative kinematic description of the motion would help coaches to develop valid technique coaching models. Five highly-trained female canoeists were filmed at 150 Hz while undertaking a 50 s maximal effort on a canoe ergometer, whose trolley motions were taken to represent those of the boat. Selected boat, body and paddle kinematics were evaluated at three key stroke cycle events (Contact, Paddle Vertical, and End of Drive) and their patterns monitored across the stroke cycle. While no clear trends between the kinematics and power output emerged, a range of strategies were identified and the data represent an initial step in the construction of detailed technique models that can be used to evaluate and monitor individual athletes.

KEYWORDS: women's canoeing, canoeing biomechanics

INTRODUCTION: It is expected that women's canoeing will be introduced into the Olympic programme in Canoe Sprint for the Olympic games in Tokyo in 2020. While women's canoe has only been raced at World Championships level since 2010, men's canoeing has been a part of the Olympics since 1948. In the current Olympic programme men race over 200m (C1) and 1000m (C1 and C2), and it is proposed for women to race over 200m (C1) and 500m (C2). There have been few studies investigating the biomechanics of men's sprint canoeing, and to the authors' knowledge there exist no studies reporting the biomechanics of women's sprint canoeing.

Toro (1986) provided a mechanical description of technique for coaching purposes and identified 6 key positions: reach, entry, vertical, control, exit, and check, which were interspersed by 5 phases: set up, catch, power, steering, and air transfer. Two styles of sprint canoeing technique were identified: rigid lower frame or stationary hip technique, and dynamic lower frame technique, with the latter technique exhibiting a greater involvement of the hip and lower limbs in the overall body movement. Toro's mechanics-based description of technique provided excellent guidance for coaches but did not provide sufficient information upon which to base a quantitative analysis of technique. More recently Zahalka et al. (2011) studied differences in the kinematics of a male high-level canoeist at different paddling intensities as a case study. Little variance was observed in maximum and minimum vertical displacements of the left and right hands at different paddling intensities but changes in velocity between strokes were noted. However, the displacement and velocity of the hands, head and boat were the only measures reported quantitatively.

Due to the lack of study, there exists little biomechanical information specifically on sprint canoeing to assist coaches in the development of their 'technical paddling model' and for technique coaching. It is also unknown whether it is appropriate to use a technique model based on men's canoeing for coaching technique for women's canoe. The purpose of this study was to report the key kinematics of women's sprint canoeing technique in a group of highly-trained female canoeists to establish key aspects of the movement pattern that were similar across the group, and also those that differed between participants. An additional aim was to provide the group's coach with kinematic data that was important and meaningful to his technique coaching model.

METHODS: 5 highly-trained competitive female canoeists (mean ± SD: age, 21.6 ± 2.5 years; C1 200m personal best, 56 ± 6 s) gave written informed consent before participation in the study, which was approved by the institutional ethics committee. The participants comprised 3 right-sided and 2 left-sided paddlers. A canoeing-specific ergometer (WEBA sport, Austria) with a moving trolley was used to collect the data. After a period of warm-up and stretching, each participant customised the ergometer set-up using their own knee block. She then completed a 50 s maximal effort to replicate an on-water race from which an average race power output was determined from the ergometer that sampled data at 100 Hz. Participants were instructed to paddle with their normal on-water paddling style. Kinematic data were collected using twelve Raptor cameras sampling at 150 Hz through Motion Analysis Cortex (v. 5.3, Motion Analysis Corporation, Santa Rosa, CA). The global reference frame was defined with the positive X-axis horizontal and pointing forwards along the length of the ergometer, the positive Y-axis pointing horizontally to the athlete's left, and the positive Z-axis vertical. During the paddling trials, a total of 50 reflective markers were attached to the athlete's head, trunk, pelvis, feet and cluster pads on the upper and lower arms, thighs and shanks. Four further markers were attached to the paddle, and four to the ergometer trolley (to represent the motion of the boat). During static trials, an additional 24 markers were attached to allow reconstruction of the positions of the shoulder, elbow, wrist, hip, knee and ankle joint centres. Coordinate data were exported to Visual3D (v. 4.96, C-Motion, Germantown, MD) for further analysis. From the trial, 20 time-normalised full strokes, starting at stroke 5, were analysed for each participant. The athletes' coach had identified key positions during the stroke that were used in the coaching process and these were used in the analysis to determine key phases of the stroke and to report data that was meaningful to the coach and athlete. These positions were contact (CO), defined as the maximum forward displacement of the tip of the paddle in the X direction; paddle vertical (PV), defined as the instant when the paddle reached a vertical position as viewed from the sagittal plane; and end of drive phase (ED), defined as the maximum backward displacement of the tip of the paddle in the X direction. To allow direct comparison between left and right-sided paddlers, all data were angle direction normalised.

RESULTS: Average power outputs for the 50 s trials and performance ranking during on-water trials (provided by the coach) for the participants are shown in Table 1.

Table 1
On-water performance ranking and average power output recorded during the 50 s trials.

	P1	P2	P3	P4	P5
On-water performance ranking	4	3	1	2	5
Power output (W)	75	145	146	121	78

Tables 2 to 4 show the individual and mean group data for the following kinematic measures at the three key positions of CO, PV and ED: Bv - Boat velocity, $P\theta_1$ - Paddle angle frontal plane, $P\theta_2$ - Paddle angle sagittal plane, CM - Centre of Mass displacement in the X direction relative to the rear knee, $T\alpha$ - Trunk flexion, $T\gamma$ - Trunk internal/external rotation (trunk twist), $L_k\alpha$ - Lead leg knee flexion/extension, $R_h\alpha$ - Rear leg hip flexion/extension. The changes during the stroke cycle are shown for selected variables in Figure 1.

Table 2
Boat, paddle and participant kinematics at Contact (mean ± SD)

	Bv (m/s)	$P\theta_1$ (°)	$P\theta_2$ (°)	CM (m)	$T\alpha$ (°)	$T\gamma$ (°)	$L_k\alpha$ (°)	$R_h\alpha$ (°)
P1	-0.50 ± 0.10	83 ± 2	49 ± 1	0.43 ± 0.01	16 ± 2	-36 ± 2	-100 ± 2	-36 ± 2
P2	-0.65 ± 0.09	76 ± 3	58 ± 2	0.42 ± 0.01	4 ± 2	-24 ± 2	-91 ± 3	-34 ± 2
P3	-0.49 ± 0.09	81 ± 1	48 ± 2	0.44 ± 0.01	-3 ± 2	-42 ± 2	-100 ± 2	-30 ± 1
P4	-0.46 ± 0.07	79 ± 1	46 ± 1	0.42 ± 0.01	12 ± 2	-26 ± 1	-90 ± 1	-25 ± 1
P5	-0.45 ± 0.06	80 ± 3	51 ± 2	0.45 ± 0.01	10 ± 2	-14 ± 2	-93 ± 2	-28 ± 1
Group	-0.51 ± 0.07	80 ± 2	50 ± 4	0.43 ± 0.01	8 ± 7	-28 ± 10	-95 ± 4	-31 ± 4

Table 3

Boat, paddle and participant kinematics at Paddle Vertical (mean ± SD)

	Bv (m/s)	$P\theta_1$ (°)	$P\theta_2$ (°)	CM (m)	Tα (°)	Tγ (°)	$L_k\alpha$ (°)	$R_h\alpha$ (°)
P1	3.77 ± 0.11	82 ± 2	91 ± 0	0.45 ± 0.01	-6 ± 2	-23 ± 1	-77 ± 3	-3 ± 3
P2	2.72 ± 0.14	85 ± 2	91 ± 0	0.47 ± 0.02	-11 ± 2	-15 ± 2	-90 ± 3	-26 ± 3
P3	3.63 ± 0.08	87 ± 1	90 ± 0	0.44 ± 0.02	-20 ± 2	-20 ± 1	-85 ± 3	-12 ± 1
P4	3.41 ± 0.10	87 ± 2	91 ± 0	0.44 ± 0.01	-8 ± 1	-9 ± 1	-70 ± 2	-4 ± 2
P5	2.83 ± 0.16	85 ± 3	90 ± 0	0.51 ± 0.01	-7 ± 2	-3 ± 1	-89 ± 2	-23 ± 1
Group	3.27 ± 0.42	85 ± 2	91 ± 0	0.46 ± 0.03	-10 ± 5	-14 ± 7	-82 ± 8	-14 ± 9

Table 4

Boat, paddle and participant kinematics at End of Drive (mean ± SD)

	Bv (m/s)	$P\theta_1$ (°)	$P\theta_2$ (°)	CM (m)	Tα (°)	Tγ (°)	$L_k\alpha$ (°)	$R_h\alpha$ (°)
P1	0.24 ± 0.12	35 ± 4	145 ± 2	0.17 ± 0.01	-21 ± 3	-5 ± 3	-21 ± 2	0 ± 2
P2	0.26 ± 0.18	15 ± 5	172 ± 3	0.14 ± 0.01	-24 ± 3	3 ± 2	-28 ± 5	-6 ± 3
P3	0.05 ± 0.11	43 ± 6	158 ± 2	0.17 ± 0.01	-19 ± 2	-4 ± 1	-57 ± 3	-13 ± 2
P4	0.27 ± 0.10	54 ± 4	150 ± 1	0.18 ± 0.01	-26 ± 1	5 ± 1	-33 ± 2	0 ± 1
P5	0.51 ± 0.15	17 ± 6	170 ± 2	0.20 ± 0.03	-27 ± 3	7 ± 2	-28 ± 5	-11 ± 3
Group	0.27 ± 0.14	33 ± 15	159 ± 11	0.17 ± 0.02	-23 ± 3	1 ± 5	-33 ± 12	-6 ± 5

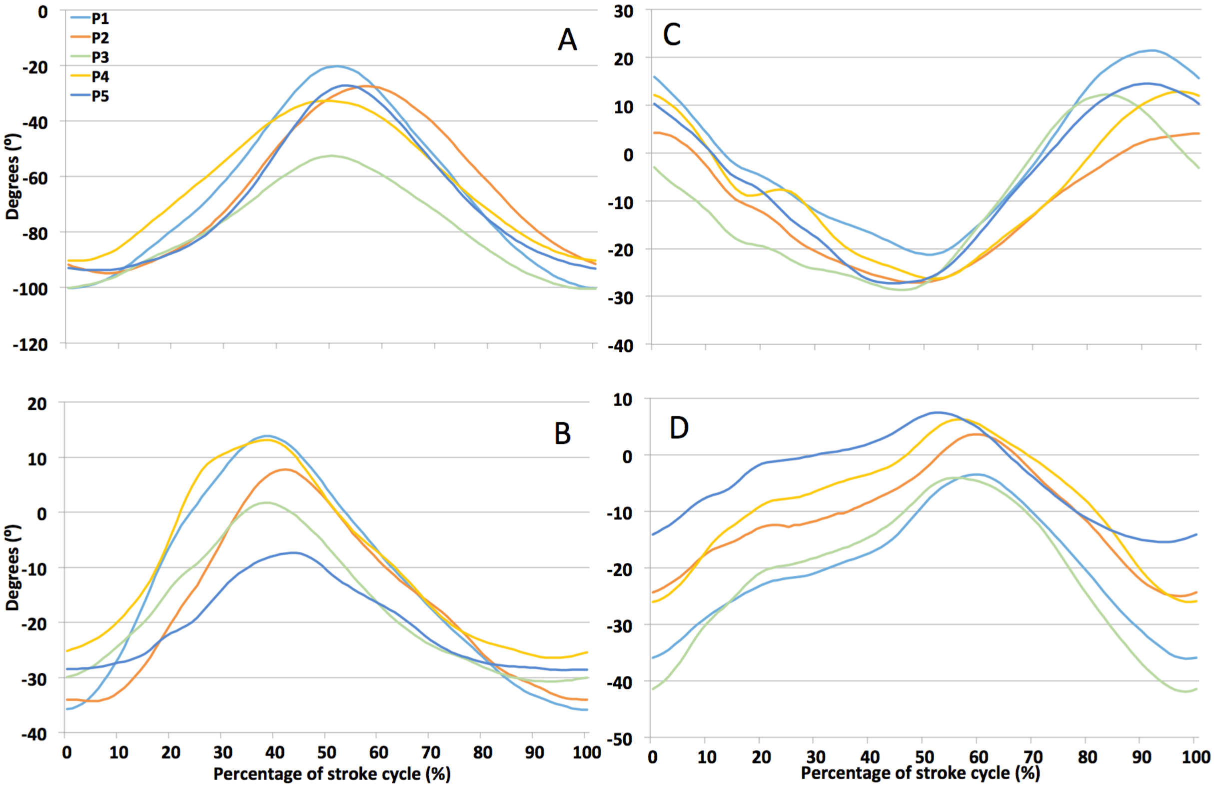

Figure 1: The pattern of changes through the stroke cycle for Participants 1 to 5 for the Front knee flexion (A), Rear leg hip flexion (B), Trunk to pelvis flexion (C) and the Trunk to pelvis internal/external rotation (trunk twist) (D). Individual participant data are mean values. The stroke cycle runs from Contact to Contact.

DISCUSSION: The cohort demonstrated a range of power outputs that were generally in line with their on-water performance ranking. P3 and P2 produced power outputs that were nearly twice the power outputs of P5 and P1. The kinematics in Figure 1 show a similar core pattern of variation at the lead leg knee, rear leg hip and trunk though clear differences were observed in magnitudes across the stroke and, as Tables 2-4 demonstrate, differences in magnitudes at key events. While P3 and P2 produced similar power outputs, different strategies for developing the power were observed as well as differences in the effect of that power on boat velocity. At CO P2 has the largest negative boat velocity and orientated the paddle in a different way to the rest of the cohort. P3 was the only athlete to show trunk flexion at CO and had the greatest trunk twist relative to the pelvis. At PV P2 demonstrated similar paddle orientation to the rest of the cohort but again had the lowest boat velocity following the most important part of the stroke for increasing boat velocity (Zahalka et al., 2011), perhaps showing an ineffective start of the stroke. P2 and P5 showed little change in magnitude for knee flexion and hip extension from CO to PV, relying on greater contribution of trunk flexion and twist. P3 and P4 were able to demonstrate a combination of changes in knee extension, hip flexion, trunk flexion and trunk twist. The coordination of changes across these four kinematic variables may explain the performance ranking of both these athletes. Interestingly P1 had the greatest boat velocity at PV yet produced one of the lowest power outputs. P1 actually showed similar patterns of variation in the kinematics to P3 but demonstrated greater knee extension, hip flexion and trunk flexion from CO to PV. Although Figure 1 shows similar patterns of trunk twist in P1 and P3, Tables 2 and 3 highlight that P1 did not exhibit the same change in trunk rotation between CO and PV as P3. At the ED, P3 paddled with minimal changes in magnitude of hip flexion and trunk flexion from PV and the least amount of knee extension. P4 also demonstrated a pattern of low knee extension and minimal change in hip flexion but, in line with the rest of the cohort, showed an extension of the trunk. All of the cohort show a similar change in magnitude of trunk twist from PV. Unfortunately, due to a lack of literature found on the kinematics of canoeing, no published data have been found with which these patterns can be compared.

CONCLUSION: The results do not demonstrate any clear generic trends in the kinematics in relation to the power outputs and generated boat velocities. Participants did, however demonstrate individual strategies in coordinating the kinematics through the stroke to produce the output power where trunk and pelvis mechanics appeared to play a key role in producing an effective stroke. An individual case study approach analysing the data using a sport specific deterministic model (Wainwright et al., 2015) will allow for athlete specific recommendations to be made for performance improvement as well as an improved understanding of technique in relation to canoeing performance. It should be noted that differences between ergometer and water-based canoeing technique may exist and may influence the applicability of these findings to paddling on-water. This novel study has identified and quantified key aspects of ergometer-based canoeing kinematics that can be used by coaches, athletes and practitioners to evaluate and monitor progressions in performance-related technique.

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