EFFECT OF STROKE RATE ON KINEMATIC CHARACTERISTICS OF SIMULATED ON-WATER DRAGON BOAT PADDLING

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The purpose of this study was to determine the effect of stroke rate on the 3D kinematics of simulated on-water dragon boat paddling. Twenty dragon boat paddlers (female=12, male=8) ranging in experience level, paddled in a simulated on-water dragon boat condition in a motion laboratory at stroke rates of 40, 50 and 60 strokes·min^{-1}. With an increase in stroke rate, there was a significant decrease in stroke length and increase in drive time to total stroke time ratio (p<0.05). Increases in stroke rate also resulted in changes in lumbar, hip, shoulder and elbow joint angles at paddle entry, exit and joint range of motion from paddle entry to exit (p<0.05). These changes in kinematics should be considered by coaches when selecting the optimal stroke rate for a crew.

KEY WORDS: paddling technique, gender, biomechanics.

INTRODUCTION: There have been few studies in scientific literature to describe the kinematics of dragon boat paddling. Ho, Smith & O'Meara (2009) reported the shoulder, trunk and elbow sagittal movements during on-water paddling at high-intensity between stroke rates of 80 and 90 strokes·min^{-1}. It was found that paddlers showed similar patterns of joint movements during corresponding phases of the stroke, however there were variations in joint angles at paddle entry and exit and joint range of motion. It is not known whether technique changes occur in dragon boat paddling with an increase in stroke rate. Previous studies have found that stroke rate is correlated with a decrease in stroke length (Standon, Evans, Dascombe & Peddle, 2001; Sealey, Ness & Leicht, 2011), trunk flexion at entry (Standon et al, 2001) and trunk range of motion in the sagittal plane (Sealey et al, 2011) during both ergometer and on-water paddling. The aim of this study was to compare the 3D kinematics of paddling at different stroke rates to determine whether paddlers modify their technique in response to an increase in stroke rate. These findings will have important implications for understanding what technique aspects should be focused on at higher stroke rates and determining race strategy in dragon boat racing.

METHODS: Twenty dragon boat paddlers (female=12, male=8) ranging in experience from novice to competitive, volunteered to participate in the study. Paddlers were recruited from local, Australian dragon boat clubs.

In order to replicate the conditions of on-water dragon boat paddling, a simulator was constructed based on the structure and dimensions of a BuK 20-crew dragon boat (BuK, Luebesse, Germany). The simulator included gunnels and footrests and was designed to represent the physical constraints of a dragon boat. The simulator was placed in a motion analysis laboratory and allowed the paddler to paddle on the right or left. A Concept 2D rowing ergometer (Concept 2, Victoria, Australia) with a paddling adaptor (Vermont Waterways, VT, USA) was used to provide resistance during paddling.

A 14-camera motion analysis system (EVaRT 5.0, Motion Analysis Corporation, CA, USA, 100 Hz) was used to measure the 3D kinematics of the paddler and paddle. Prior to data capture, the experimental space was statically and dynamically calibrated to ensure accurate marker tracking and reconstruction in accordance with EVaRT calibration guidelines. A full-body market set was created using 44 reflective markers (diameter 15 mm): forehead, right head, left head, acromion processes, sternum, C7, T10, right scapula, sacrum, medial and lateral epicondyles, radial and ulnar styloid processes, iliac crests, anterior superior iliac spines, greater trochanters, mid-thighs, medial and lateral femoral condyles, upper and lower anterior shanks, lateral shanks, medial and lateral malleoli, calcanei and heads of metatarsal

1. The greater trochanter and medial malleoli markers were removed during the paddling trials as these markers were obstructed by the simulator during paddling. Prior to testing, a static trial was collected to obtain an anatomical reference position to define joint centres and segment coordinate systems using KinTrak software (v. 6.2, University of Calgary, Canada). Four markers were placed on the ergometer paddle (top paddle, left and right anterior paddle blade and posterior paddle blade) and 2 markers were placed on the paddle adaptor rope to define the motion of the paddle and direction of pull. The marker set defined 13 segments and 12 joints of the paddler and paddle angle. Joint angles analysed included lumbar, hip, shoulder and elbow joints. For the hip, shoulder and elbow joints, left and right segments were converted to inside (side of the body towards the midline of the boat) and outside (side of the body away from the midline of the boat) segments and only the joint angles for the outside segments were analysed.

The procedures of the study received ethical approval from the institutional Human Ethics Review Committee. On arrival to the motion analysis laboratory, participants were familiarised with the dragon boat simulator and allowed time to warm up. Participants were instructed to replicate their on-water paddling technique during the trials and were allowed to paddle on their preferred side. For all participants, the outside foot was placed forward and the inside foot was placed underneath or behind the seat during paddling. Participants paddled at stroke rates of 40, 50 and 60 strokes·min^{-1}. The order of stroke rate was randomised and participants were given sufficient rest time in between each trial. Participants were given feedback on their stroke rate and upon reaching the desired stroke rate another 10 strokes were collected.

Ten consecutive strokes from each participant were selected for analysis. A stroke was defined as paddle entry of one stroke (the point at which the paddle blade markers were in the most anterior position) until paddle entry of the next stroke. Each stroke was divided into the drive phase (the period from paddle entry to paddle exit, the point at which the paddle blade markers were in the most posterior position) and recovery phase (the period from paddle exit to paddle entry of the next stroke). Custom-built software written in MATLAB (Mathworks, v.7.1.0, 2005, MA, USA) was used to normalise each time point to percentage of stroke. Means and standard deviations were calculated of the ten strokes for each participant at each stroke rate and then means were calculated for male and female groups.

Variables measured included stroke length (horizontal distance travelled by paddle blade markers from paddle entry to paddle exit), drive time (time from paddle entry to exit) as a percentage of total stroke time (time from paddle entry of one stroke to paddle entry of the next stroke), lumbar transverse, hip sagittal, shoulder sagittal and elbow sagittal joint angles at paddle entry and exit and joint range of motion (maximum joint angle minus minimum joint angle during the drive phase).

To test for significant differences, a three-way ANOVA was carried out with one between-subjects factor of sex and two within-subjects factors of stroke rate (40, 50 and 60 strokes·min^{-1}) and stroke number (stroke 1 to 10). Post-hoc pairwise comparisons with a Bonferroni correction were conducted to identify where significant differences occurred. Statistical analyses were conducted using SPSS (SPSS Inc., Chicago, IL, USA) and significance level was set at $p<0.05$.

RESULTS AND DISCUSSION: Results for stroke length and drive time to total stroke time ratio are shown in Table 1. Results for lumbar, hip, shoulder and elbow joint angles at entry and exit and range of motion are shown in Figure 1. As there was no effect of sex on any of the joint angle variables, all results are shown as grouped means for the stroke rates.

There was a significant decrease in stroke length when stroke rate increased from 40 and 50 strokes·min^{-1} to 60 strokes·min^{-1} ($p<0.05$) (Table 1), supporting findings of previous studies (Sealey et al, 2011; Standon et al, 2001). Stroke length reported in this study was higher than results reported for on-water dragon boat paddling at 80 to 90 strokes·min^{-1} (1.2 m; Ho et al, 2009), but similar to results reported for ergometer paddling at a stroke rate of 54 strokes·min^{-1} (1.43 m; Sealey et al, 2011). Results of this study show that there was a small decrease in stroke length even with slight increments in stroke rate.

With an increase in stroke rate there was a significant increase in drive time to total stroke time ratio across all stroke rates (p<0.05) (Table 1). Thus at lower stroke rates, paddlers spent more time in the recovery phase than in the drive phase. This may be due to the relatively low stroke rates chosen for this study which meant that a longer stroke length (and therefore drive time) could not be achieved at the stroke rate.

Table 1: Stroke length and drive time to total stroke time ratio (mean ±SD).

Variable	Stroke rate (strokes·min^{-1})		
	40	50	60
Stroke length (m)	1.49 ±0.02*	1.48 ±0.01*	1.40 ±0.03
Drive time to total stroke time ratio (%)	54.28 ±3.93†	56.12 ±3.37†	57.35 ±3.50†

*Significantly different from 60 strokes·min^{-1} (p<0.05).
†Significantly different from both other stroke rates (p<0.05).

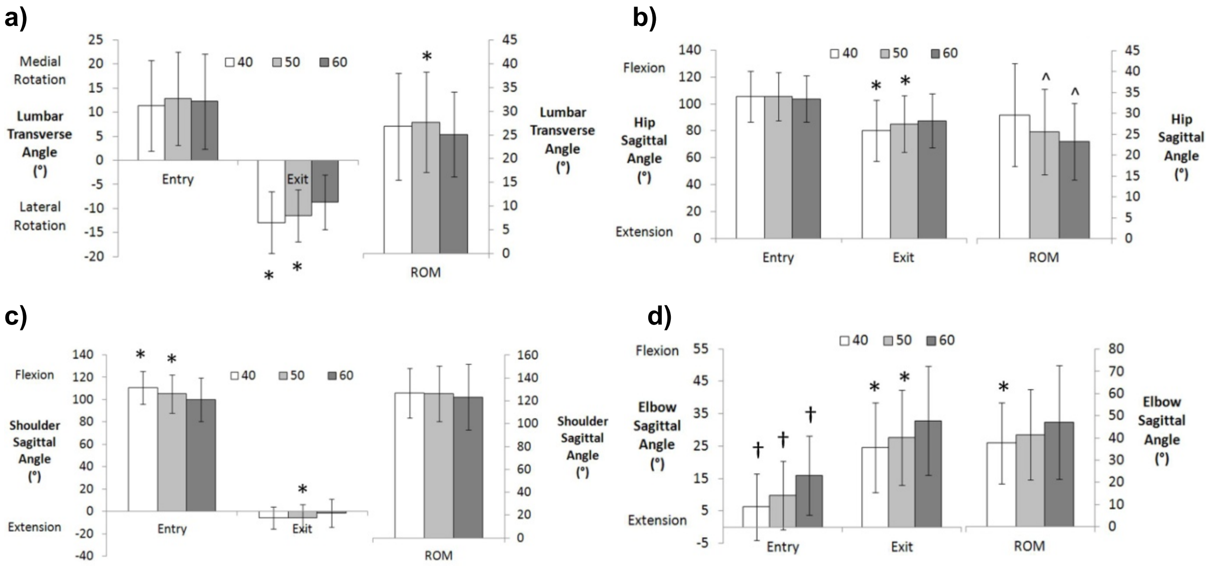

Figure 1: Mean ±SD for joint entry angle, exit angle and joint range of motion (ROM) for a) lumbar joint; b) hip joint; c) shoulder joint and d) elbow joint. *Significantly different from 60 strokes·min^{-1} (p<0.05). ^Significantly different from 40 strokes·min^{-1} (p<0.05). †Significantly different from both other stroke rates (p<0.05).

Results of joint entry angles (Figure 1) showed that there was no change in trunk medial rotation or hip flexion at paddle entry with increasing stroke rate. However, there was a significant decrease in shoulder flexion angle at paddle entry at a stroke rate of 60 strokes·min^{-1} compared to lower stroke rates and an increase in elbow flexion angle at paddle entry across all stroke rates (p<0.05). These findings indicate that at higher stroke rates, paddlers were able to maintain similar trunk rotation and hip flexion angles at paddle entry, but were not able to maintain similar shoulder flexion and elbow extension angles. Maximal stroke length is achieved by entering the blade as far forward as possible at paddle entry through increasing trunk axial rotation and shoulder flexion (Baker & Kelly, 1999; Sanders & Kendal, 1992). The combination of kinematic changes that occurs at high strokes are likely to shorten the entry position of the blade and therefore minimise stroke length.

There were a greater number of significant differences in joint angles at paddle exit compared with paddle entry with changes in stroke rate (Figure 1). With an increase in stroke rate, there was significantly less trunk lateral rotation and hip extension at paddle exit at a stroke rate of 60 strokes·min^{-1} compared to lower stroke rates (p<0.05). However, for the elbow joint, there was significantly greater elbow flexion at a stroke rate of 60 strokes·min^{-1} compared to lower stroke rates (p<0.05).

Comparison of joint range of motion across the different stroke rates (Figure 1) showed that there was no significant change in trunk and shoulder range of motion with stroke rate, but

significantly less hip range of motion and greater elbow range of motion at higher stroke rates compared to lower stroke rates ($p<0.05$). This indicates that at higher stroke rates, more elbow flexion and less hip extension is used to bring the paddle back during the drive phase. As the use of the elbow joint is less powerful and more locally fatiguing than use of the larger muscle groups of the hip and trunk (Pelham & Holt, 1992), this should be avoided.
The limitations of paddling in a laboratory meant that an ergometer was used to provide paddle resistance rather than water. While paddlers were instructed to imitate their on-water paddling technique during the trial, it is now known if there may be differences in technique resulting from paddling with the resistance of an ergometer. Future studies are recommended to describe the three-dimensional kinematics of on-water draon boat paddling in order to validate our findings.

CONCLUSION: Although adopting a higher stroke rate will allow more strokes to be produced over a given time, the effect of stroke rate on paddling kinematics has not been investigated in dragon boat paddling. Findings of this study revealed that an increase in stroke rate resulted in a significant decrease in stroke length. As average boat velocity is the product of both stroke rate and stroke length (Sanders & Kendal, 1992), coaches should consider the trade-off between stroke rate and stroke length when determining the optimum stroke rate for a crew. Furthermore, coaches should be mindful of the changes in joint angles and movements with an increase in stroke rate that may affect power production during the stroke. Future studies should investigate the changes in paddling kinematics across a greater range of stroke rates and determine whether paddlers of different experience levels show similar kinematic changes with increases in stroke rate, particularly considering that elite and sub-elite dragon boat paddlers have been shown to exhibit differences in paddling efficiency and trunk flexion angle at paddle entry (Ho et al, 2009).

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