©Journal of Sports Science and Medicine (2011) **10,** 52-58
http://www.jssm.org

Research article

Effect of self-selected and induced slow and fast paddling on stroke kinematics during 1000 m outrigger canoeing ergometry

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Abstract
This study aimed to identify the effect of different stroke rates on various kinematic parameters during 1000 m outrigger canoeing. Sixteen, experienced female outrigger canoeists completed three 1000 m outrigger ergometer time trials, one trial each using a self-selected, a Hawaiian (≤ 55 strokes·min^{-1}) and a Tahitian (≥ 65 strokes·min^{-1}) stroke rate. Stroke rate, stroke length, stroke time, proportion of time spent in propulsion and recovery, torso flexion angle and 'twist' were measured and compared with repeated measures ANOVAs. Stroke rate, stroke length and stroke time were significantly different across all interventions ($p < 0.05$) despite no difference in the percentage of time spent in the propulsive and recovery phases of the stroke. Stroke length and stroke time were negatively correlated to stroke rate for all interventions ($r = -0.79$ and -0.99, respectively). Female outrigger canoeists maintain consistent stroke kinematics throughout a 1000 m time trial, most likely as a learned skill to maximize crew paddling synchrony when paddling on-water. While the Hawaiian stroke rate resulted in the greatest trunk flexion movement and 'twist' action, this potential increased back injury risk may be offset by the slow stroke rate and long stroke length and hence slow rate of force development.

Key words: Stroke rate, paddling, torso flexion, female athletes.

Introduction

Six-person craft (OC6) outrigger canoeing involves a stroke rate of between 42 and 70 strokes·min^{-1} (Holmes, 1996; West, 2006) with paddlers alternately completing 10 to 20 strokes on each side of the canoe. The lower end of the stroke rate range is associated with a long reach and exaggerated torso movement and is referred to as the Hawaiian style, while the upper stroke rate range is referred to as the Tahitian style and includes a fast action incorporating a shorter stroke with predominantly arm movement (Holmes, 1996; West, 2006). These Hawaiian and Tahitian styles are the traditionally adopted stroke rates for outrigger canoe racing. However, a recent survey of Australian coaches identified that 81% of responding coaches prescribe a stroke rate of between 55 and 65 strokes·min^{-1} (Sealey, 2009) without scientific basis.

Stanton and colleagues (2001) report a negative correlation ($r = -0.928$) between stroke rate and stroke length during outrigger canoeing performance, as also evidenced when swimming at constant velocity (Fritzdorf et al., 2009; Thompson et al., 2000), with swim velocity the product of stroke rate and stroke length (Fritzdorf et al., 2009; Thompson et al., 2000; Toussaint et al., 2006). It has been well established in swimming and rowing that a high stroke rate is directly related to high velocity (Chollet et al., 1997; Seifert and Chollet, 2005; Soper and Hume, 2004) while a significant positive correlation between stroke length and velocity has been reported for swimming, with faster swimmers using a longer and more consistent stroke length (Chollet et al., 1997). Also in swimming, attempts to maintain velocity during a race are made by increasing stroke rate in response to a fatigue-induced reduction in stroke length (Alberty et al, 2008; Laffite et al, 2004). It is not yet known how stroke rate and stroke length are related to performance in outrigger canoeing.

It has been reported in outrigger canoeing that a fast stroke rate is associated with a shorter stroke and minimal body movement (West, 2006). More specifically, as stroke rate increases from 50 to 80 strokes·min^{-1}, torso flexion angle decreases as stroke length decreases, although at stroke rates exceeding 80 strokes·min^{-1}, torso flexion angle increases despite further reductions in stroke length (Stanton et al., 2001). The outrigger canoeing technique involves a combination of torso flexion-extension and rotation (Stanton, 1999) with torso flexion angles of between 34 and 67° reported (Stanton et al., 2001). As with sweep-oar rowing and kayaking, this combination of prolonged sitting, repeated torso flexion and torso rotation has the potential to contribute to back pain or injury (Howell, 1984; Karlson, 2000; Kizer, 1987; Reid and McNair, 2000; Soper and Hume, 2004, Stanton, 1998). It is not yet known how different stroke rates that are commonly used in outrigger canoeing, affect this torso movement.

The aim of the current study was to identify the effect of common stroke rates on various kinematic variables of female outrigger canoeists during a sport-specific 1000 m ergometer time trial. The results will provide coaches with information regarding how these stroke rates affect performance and technique.

Methods

Subjects

Sixteen female outrigger canoeists (age = 38 ± 10 yr, height = 1.68 ± 0.05 m, mass = 76 ± 16 kg) from three clubs in north Queensland, Australia, volunteered and gave written informed consent to participate in the study approved by the James Cook University Human Ethics Committee. Participants had between one and eight years (3 ± 2 yr) competitive paddling experience and were in

Received: 25 June 2010 / Accepted: 28 October 2010 / Published (online): 01 March 2011

the competition phase of the outrigger canoeing season when testing occurred.

Study design

Prior to testing all participants completed a familiarisation session using the outrigger ergometer which comprised of a Model D Concept II™ rowing ergometer (Breakwater, Australia) with a paddling adaptor (Vermont waterways, Vermont, USA). The familiarisation session involved 10 min submaximal effort paddling on the ergometer followed by a 5 min rest and then a maximum effort 1000 m time trial. During the familiarisation time trial participants used a self-selected stroke rate, technique and frequency of paddle-side changes to mimic on-water 1000 m racing.

Following familiarisation, participants completed three more 1000 m time trials over three consecutive weekends using a different stroke rate intervention each session. During the first time trial participants were asked to use their self-selected stroke rate (SS) while on the 2nd and 3rd occasions participants were asked to perform the time trials using either the slow Hawaiian stroke rate (H) of ≤ 55 strokes·min^{-1} or the fast Tahitian stroke rate (T) of ≥ 65 strokes·min^{-1}, with these two trials allocated in random order. The SS trial was always completed first so that participants' technique was not influenced by the induced stroke rate trials. Each time trial was preceded by a 3 min warm-up consisting of 2 min at moderate intensity, 30 s at near maximal intensity and another 30 s at moderate intensity paddling. Participants were asked to complete each time trial in the fastest time possible and were not informed of any potential effect that different stroke rates might have on performance. Participants were free to alternate paddling sides as per their normal on-water technique, which typically resulted in changing paddling side every 10 to 20 strokes.

Kinematic data collection and analysis

During each time trial, performance time and the kinematic variables of stroke rate, stroke length, proportion of time spent in the propulsive and recovery phases of the stroke, and the angles of the paddling and non-paddling sides of the torso were measured. Performance time was measured with a handheld stopwatch (TM-104, Nyda, China) and stroke rate was recorded every 15 s from the ergometer display unit and averaged over each 250 m split and across the entire 1000 m. All other variables were measured with the Peak Motus™ system (Version 9, Vicon Motion Systems, Centennial, CO, USA). Seven optical cameras were placed around the ergometer at varying heights to cover a data capture volume of 3.5 m (x axis, parallel to ergometer length) x 3 m (y axis, perpendicular to ergometer length) x 1.5 m (z axis, vertical). The cameras captured at a frequency of 50 Hz with the test space calibrated using the standard Peak Motus™ (Vicon Motion Systems, Centennial, CO, USA) calibration frame (1.2 m x-axis, 0.7 m y-axis, 0.08344 m z-axis) and portable wand (0.914 m length) for a 240 s period resulting in 2000 of the total 12,000 captured frames being used for calibration, with a mean 96.0 ±2.8% of individual camera field of view linearised and a mean 72.4% of total testing space covered. Reflective 1 cm diameter spherical markers were placed on the left and right acromions and iliac crests of the participants and on the front side of the bottom of the ergometer paddle shaft prior to testing. Kinematic data were collected with the Peak Motus™ system during left side paddling for 8 s at approximately 100 m (during the 1st 250 m split), 400 m (during the 2nd 250 m split), 600 m (during the 3rd 250 m split) and at 900 m (during the 4th 250 m split) to ensure at least six full strokes at each split were captured.

The stroke length, proportion of time spent in the propulsive and recovery phases of the stroke and torso angle data for each split was reported as the average of six consecutive strokes during each split, with the average of all 24 strokes (six strokes across four splits) used for the overall 1000 m average. Stroke length was measured as the average distance travelled along the x-axis during the propulsive phase by the marker situated at the bottom of the paddle. The proportion of time spent in the propulsive and recovery phases of the stroke were calculated by counting the number of frames taken to complete each stroke and each phase and multiplying that number of frames by 0.02 s, the time taken to complete one frame. The propulsive phase was measured from the first frame of backward movement of the paddle to the most rearward position of the paddle, while the recovery phase was measured from the first frame of the paddling moving forward to the most forward position of the paddle. The time spent in the propulsive and recovery phases were then converted to a percentage of total stroke time. Torso angle was measured from the upward vertical to the iliac crest-acromion segment of the paddling (left) and non-paddling (right) side of the torso. Paddling and non-paddling side torso range of motion were calculated as the difference in torso angle between the start and the end of the propulsive phase, with positive nomenclature representing an extension movement and negative nomenclature indicating increased flexion. The term 'twist' has been used in outrigger canoeing literature (AOCRA, 2000; West, 2006) and subsequently by coaches to describe the rotation about the torso during the propulsive phase of outrigger canoeing. For the purpose of this study, the amount of 'twist' was defined as the absolute difference between the start and end of the propulsive phase, for the difference between the non-paddling side and paddling side torso angles, i.e. [(non-paddling side minus paddling side torso angle at end of propulsive phase) minus (non-paddling side minus paddling side torso angle at start of propulsive phase)].

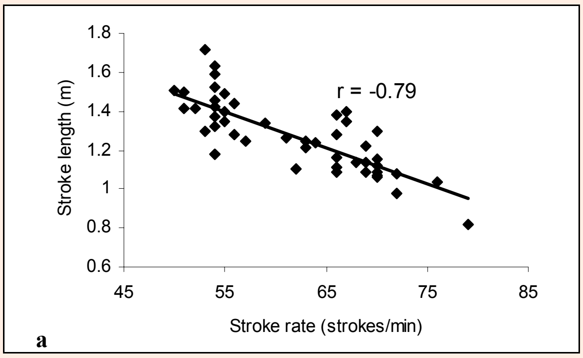
Statistical analysis

Data were analysed with the Statistical Package for Social Sciences (Version 17, SPSS Inc, Chicago, Ill, USA). All data are reported as means ±SD for each 250 m split and for the total 1000 m time trial for each stroke rate intervention. Coefficients of variation (CV) were also assessed (as SD divided by the mean, multiplied by 100), for the overall 1000 m data. Differences in the kinematic variables between stroke rate interventions were assessed with two-way repeated measures (stroke rate x split) and one-way repeated measures (stroke rate) ANOVAs for the split data and 1000 m data, respectively. Where significant differences were reported, *post-hoc* Tukey HSD tests were applied to locate the significant differences. For all statistical analyses alpha was set at 0.05.

Table 1. Mean ±SD (coefficient of variation) stroke data during 1000 m ergometer time trial performance for three stroke rate interventions of female outrigger canoeists (n = 16).

Variable	SS	H	T
Stroke rate (strokes·min^{-1})	61 ± 6 (9.8)	54 ± 1 (1.9) *	70 ± 4 (5.7) *†
Performance time(s)	371 ± 38 (10.2)	358 ± 30 (8.4) *	357 ± 28 (7.8) *
Stroke length (m)	1.27 ± .15 (11.8)	1.43 ± .12 (8.4) *	1.12 ± .13 (11.6) *†
Propulsive phase (% stroke)	56.5 ± 2.3 (4.1)	55.8 ± 2.3 (4.1)	56.2 ± 2.3 (4.1)
Recovery phase (% stroke)	43.5 ± 2.3 (5.3)	44.2 ± 2.3 (5.2)	43.8 ± 2.3 (5.3)

SS = self-selected stroke rate, H = Hawaiian stroke rate, T = Tahitian stroke rate. * = significantly different to SS; † = significantly different to H.



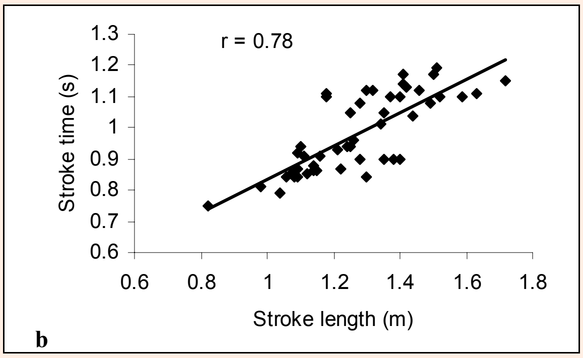


Figure 1. The relationship between stroke rate and stroke length (a), and stroke length and stroke time (b) for female outrigger canoeists during 1000 m time trial ergometry.

Results

Mean 1000 m stroke rate and stroke length were significantly different between the three interventions (Table 1) with stroke rate negatively correlated to stroke length ($p < 0.001$, Figure 1a) and stroke length positively correlated to stroke time ($p < 0.001$, Figure 1b). The 1000 m performance time for the H and T were similar with both significantly faster than the SS (Table 1). Within each intervention, there was no difference in stroke rate or stroke length across the four, 250 m splits indicating that the chosen technique was consistent throughout the time trial (Table 2).

During the 1000 m time trial, there was no difference in the proportion of stroke time spent in the propulsive and recovery phases of the stroke between interventions (Table 1). However, the proportion of stroke time spent in the propulsive phase of the H was significantly greater during the 4th 250 m split than during the 1st 250 m split (Table 2).

There were no significant differences between interventions for the torso angles measured for both the paddling side and non-paddling side of the torso either at the start (Figure 2) or the end (Figure 3) of the propulsive phase. The T average range of motion for the paddling side of the torso and non-paddling side of the torso during the propulsive phase of the stroke (9.0 ± 8.8° and -4.3 ±8.0°) were significantly less than both the SS (14.5

Table 2. Mean (±SD) stroke data during each 250 m split of 1000 m ergometer time trial performance for three stroke rate interventions of female outrigger canoeists (n=16).

Variable	250 m split	SS	H	T
Stroke rate (strokes·min^{-1})	Split 1	62 (7)	54 (2) *	71 (4) *†
	Split 2	61 (6)	54 (1) *	69 (4) *†
	Split 3	61 (6)	54 (2) *	69 (4) *†
	Split 4	61 (6)	54 (2) *	70 (4) *†
Performance time (s)	Split 1	89 (9)	89 (8)	87 (7)
	Split 2	92 (10)	89 (7)	89 (7)
	Split 3	94 (11) ‡	90 (7) *	90 (8) *
	Split 4	96 (11) ‡	90 (7) *	91 (7) *‡
Stroke length (m)	Split 1	1.34 (.16)	1.47 (.15) *	1.14 (.13) *†
	Split 2	1.26 (.16)	1.43 (.12) *	1.13 (.14) *†
	Split 3	1.24 (.15)	1.42 (.12) *	1.12 (.14) *†
	Split 4	1.25 (.15)	1.41 (.13) *	1.10 (.14) *†
Propulsive phase (% stroke)	Split 1	55.8 (2.0)	55.2 (2.3)	56.1 (2.0)
	Split 2	56.8 (2.2)	56.0 (2.5)	56.3 (2.5)
	Split 3	56.5 (2.7)	55.7 (2.4)	56.2 (2.5)
	Split 4	56.7 (2.7)	56.3 (2.7) ‡	56.4 (2.6)
Recovery phase (% stroke)	Split 1	44.2 (2.0)	44.8 (2.3)	43.9 (2.0)
	Split 2	43.2 (2.2)	44.0 (2.5)	43.8 (2.6)
	Split 3	43.5 (2.7)	44.2 (2.2)	43.8 (2.5)
	Split 4	43.3 (2.7)	43.8 (2.7)	43.6 (2.6)

SS = self-selected stroke rate, H = Hawaiian stroke rate, T = Tahitian stroke rate. * = significantly different to SS; † = significantly different to H; ‡ = significantly different to Split 1.

±14.1° and 1.8 ± 10.8°) and H (17.3 ±13.9° and 0.3 ± 8.8°), respectively ($p < 0.05$). There were no significant differences in the amount of propulsive phase 'twist' across interventions, with group average values of 18.3 ± 9.2°, 21.3 ± 9.3° and 17.8 ± 7.5° recorded for the SS, H and T, respectively .

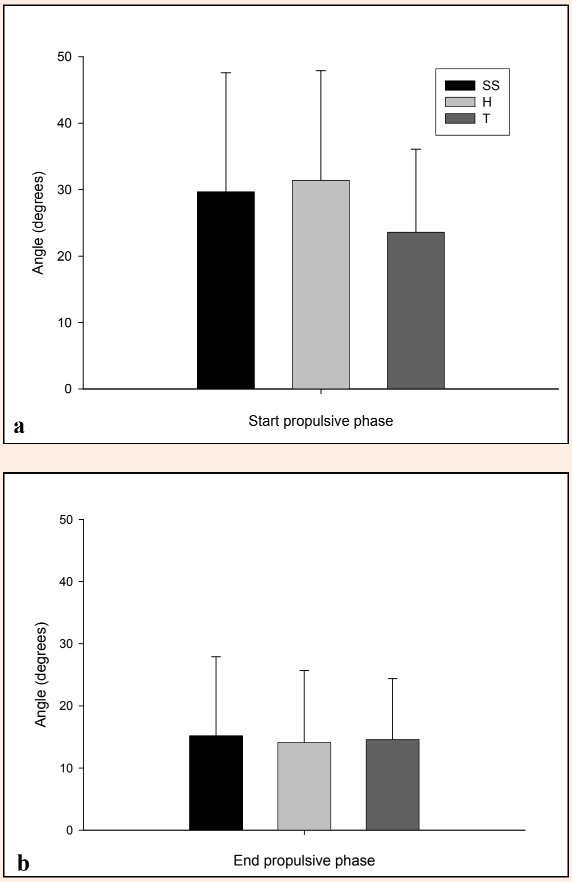


Figure 2. Mean ±SD torso angles at the start (a) and end (b) of the propulsive phase for the paddling side of the torso for three stroke rate interventions of female outrigger canoeists.

Discussion

The current results demonstrate the unique biomechanical aspects of outrigger canoeing whereby altering stroke rate results in changes to stroke length but not the proportion of time spent in the propulsive phase; and that these kinematic modifications were consistent throughout a 1000 m time trial. Further, the T demonstrated significantly less torso flexion-extension range of movement than the H and SS interventions with no other movement pattern differences evidenced.

As reported previously during OC1 paddling (Stanton et al., 2001), rowing (Soper and Hume, 2004) and swimming (Fritzdorf et al., 2009; Thompson et al., 2000), as stroke rate increased, stroke length decreased. It has also been reported that stroke rate and stroke length, while inversely proportional, are both directly proportional to performance velocity in swimming and rowing (Chollet et al., 1997; Fritzdorf et al., 2009; Soper and Hume, 2004). In the current study however, both the slow H with the long stroke length and the fast T with the

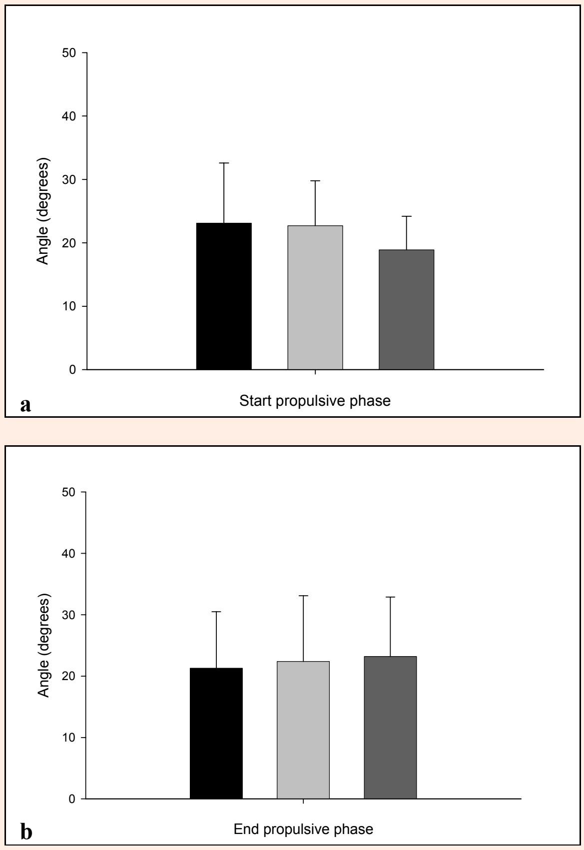


Figure 3. Mean ±SD torso angles at the start (a) and end (b) of the propulsive phase for the non-paddling side of the torso for three stroke rate interventions of female outrigger canoeists.

shorter stroke length resulted in similar 1000 m performance time, indicating that it is not so much the individual stroke rate or stroke length used that determines performance, but the interaction of these two variables and how that interaction affects average power output. What is not clear from the current study, is why the SS elicited a significantly slower performance time given that the SS also demonstrated a significant negative correlation between stroke rate and stroke length ($r = -0.57$, $p = 0.02$). Potential mechanisms are the large range of average stroke rates used during the SS intervention (50 to 72 strokes·min^{-1}) resulting in a large CV (9.8) and the methodological design of performing the SS intervention first. However, the rationale for the participants using their own preferred stroke rate and to assess this time trial first was to ensure that the study captured the kinematics of the stroke rate adopted by Australian outrigger canoeists, without influence from the traditional techniques. Previous 1000 m outrigger canoeing research has indicated that following one practice, performance across three consecutive time trials performed on separate days resulted in similar performance (Sealey et al., 2010) and therefore it is unlikely for the trained population of the current study that a learning effect would have occurred between trials. Future research should investigate the effect of a stroke rate of 61 strokes·min^{-1} (the average SS of the current participants) on performance and technique and to randomise this intervention with the H and T interventions to confirm the results of the current study.

In the current study, average stroke length varied between 1.12 and 1.43 m, which was a similar length to that reported for both dragon boat paddlers and rowers (Elliott et al., 2002; Ho et al., 2009; Steer et al., 2006) but approximately double that reported for OC1 paddling with a stroke rate-dependent range of 44 to 90 cm (Stanton et al., 2001). In the current study, stroke length did not change throughout the time trial, indicating that female outrigger canoeists were able to maintain a consistent stroke length across all interventions. This is in contrast to swimming where it has been reported that as a race progresses, stroke length shortens due to fatigue (Thompson et al., 2000) despite more skilled swimmers being more able to maintain a consistent stroke length (Chollet et al., 1997; Toussaint et al., 2006). However, it must be considered that the swim performance papers report stroke length as the distance of water covered in each stroke, whereas in the current study stroke length represents the distance that the paddle moves. Therefore, the stroke length change in swimming may be due to decreased movement efficiency despite no change in arm movement distance during each stroke. Irrespective of the different calculation of stroke length, it is likely that the adoption of a consistent stroke length throughout the outrigger canoeing time trial is a learned skill, given that anecdotally, coaches encourage stroke consistency in OC6 paddlers to maximise within-crew paddling synchrony.

Regardless of the stroke rate used for the 1000 m time trial, the proportion of time spent in both the propulsion and recovery phases of the stroke was similar for each intervention. Indeed, for each intervention, the percentage time spent in propulsion and recovery varied by only 0.5 to 2.3% across all splits, thus remaining constant throughout each time trial. The consistent 56% of time spent in propulsion in the current study is higher than that reported for canoeing (38 to 51%; Pelham et al., 1992), below that for kayaking (64 to 69%; Sanders and Kendal, 1992), but similar to both rowing (57%; Dawson et al., 1998) and dragon boating (56%; Ho et al, 2009), with no previous reports of outrigger canoeing available. It has been noted in rowing that as stroke rate increased, the proportion of time spent in propulsion increased (Dawson et al., 1998; Martin and Bernfield, 1980) and boat velocity increased (Martin and Bernfield, 1980). Therefore, it remains to be determined whether an induced reduction in recovery time (in order to increase the proportion of time spent in propulsion) will elicit positive changes in outrigger canoeing performance, and whether this performance enhancement will result in improved crew paddling consistency, given that the recovery phase has been reported to be the major source of stroke variability in rowing (Dawson et al., 1998).

Similar to rowing, canoeing, kayaking and dragon boating (Ho et al., 2009; Plagenhoef, 1979; Shephard, 1987), the outrigger canoeing technique typically moved toward torso extension as the propulsive phase progressed. In the current study, the range of individual torso angles at the start and end of the propulsive phase was large. However, the group average torso flexion at the start of the propulsive phase of 24° to 31° for the paddling side and 19° to 23° for the non-paddling side, are greater than those reported for kayaking (10° to 15°, Plagenhoef, 1979; Shephard, 1987), similar to those reported for rowing (22° to 32°, Elliott et al., 2002; McGregor et al., 2005;), and less than those reported for OC1 paddling (34 to 67°, Stanton et al., 2001), canoeing (30° to 47°, Plagenhoef, 1979; Shephard, 1987) and dragon boat racing (41°, Ho et al., 2009). While it was expected that trunk flexion angles would be similar to that reported for OC1 and dragon boating, the methodology used to measure trunk flexion in the Stanton et al. (2001) research was not explained, and the placement of the markers for measurement of the trunk segment angle differed between the current study and Ho and colleague's (2009) dragon boat study. These methodological variations make it impossible to meaningfully compare results.

With respect to the paddling side of the torso, the T started the propulsive phase with the most upright posture, at least 6° more than the H and SS trials, with all trials finishing the propulsive phase within 1° of each other. Consequently, the T resulted in the smallest torso range of motion. This finding is in agreement with Stanton and colleagues (2001) whom reported a negative correlation between stroke rate and trunk flexion (r = -0.844) up to a stroke rate of 80 strokes·min^{-1}.

Previous research reports that on-water sports such as rowing, kayaking and outrigger canoeing may predispose the participant to back pain due to the combination of the seated posture and repeated torso flexion and rotation (Howell, 1984; Karlson, 2000; Kizer, 1987, Reid and McNair, 2000; Soper and Hume, 2004; Stanton, 1998). The current study confirms that irrespective of the stroke rate adopted the outrigger canoeing technique does involve repeated torso flexion and rotation with no difference in torso rotation but a significantly less amount of flexion-extension range of motion occurring at the faster stroke rate. This reduced flexion-extension movement of the faster stroke rate may reduce injury risk, however spinal loading was not assessed and consideration should be made for the potential that despite a smaller range of motion, the faster stroke rate may require a more rapid rate of force production which has been linked to increased injury risk (O'Sullivan et al., 2003).

This potential increased injury risk associated with a rapid rate of force production has particular impetus when considering dragon boat racing, a sport that is similar to outrigger canoeing that has yet to receive much research attention. Dragon boating uses similar equipment, overall similar movement patterns, similar stroke length and similar race distance to outrigger canoeing. Further, the proportion of time spent in the propulsive phase of the stroke for dragon boating is 56% (Ho et al., 2009), the same used in outrigger canoeing. The difference between the sports however is evident with the amount of torso flexion being 41° in dragon boating and the stroke rate being 80-90 strokes·min^{-1} (Ho et al., 2009). Given the higher stroke rate and torso flexion evidenced in dragon boating, dragon boat coaches should be aware of the increased associated risk reported rapid rate of force production (O'Sullivan et al., 2003) as is required when moving through a stroke length of 1.3 m at a rate of 80-90 strokes·min^{-1} (Ho et al., 2009). Potentially, a slowing of the stroke rate, as occurs in the Australian and Hawaiian techniques of outrigger canoeing, in order to lessen the rate of force production at a large torso flexion angle should be considered by dragon boating coaches to minimize potential back injury risk.

While this study provides insight into the effect that the H, T and SS have on the kinematics of outrigger canoeing, future research should investigate whether increasing the proportion of time spent in propulsion results in enhanced performance, as reported for rowing (Martin and Bernfield, 1980) and kayaking (Sanders and Kendal, 1992). Further, a more extensive investigation of torso biomechanics should be considered. A limitation of the current study was that torso movement was determined from markers placed on the acromions and iliac crests. Future research should use spinal markers for a more direct measure of torso movement, as this was unable to be done in the current study due to methodological constraints.

Conclusion

The outrigger canoeing technique appears unique in that the stroke kinematics are adapted to the selected stroke rate and kept consistent throughout a 1000 m time trial. This consistency may be a specialised skill induced by the coaching emphasis placed on crew paddling synchrony. Specifically, outrigger canoeists adopt a shorter stroke length when using a fast stroke rate, and adopt a longer stroke length when using a slow stroke rate, with these variables consistent throughout the time trial. Further, female outrigger canoeists use a greater range of torso movement when adopting a slow stroke rate. Future investigation is warranted to determine if technique alterations in response to different stroke rates is likely to contribute or reduce the risk of developing back injuries in outrigger canoeists and dragon boat paddlers.

Acknowledgements
The authors thank the members of the Magnetic Island, Coral Sea and Townsville Outrigger Canoe Clubs for participation in this study; and Ms Teneale McGuckin, Ms Lana Watson and Mr Damien Spann for their assistance with data collection.

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Key points

- As outrigger canoeing stroke rate increased, stroke length decreased but the proportion of the stroke time spent in the propulsive phase was kept consistent.
- The outrigger canoeing technique involved a similar amount of torso flexion-extension movement to rowing, with an additional twisting motion of the torso evidenced, that may increase the risk of back injury.
- A slower stroke rate, to lessen the rate of force production, may minimize potential back injury in outrigger canoeists and dragon boat paddlers.

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