UPPER BODY KINEMATIC ANALYSIS OF THE PADDLING STROKE IN FEMALE RECREATIONAL STAND-UP PADDLE BOARDERS

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The aim of this study was to quantify differences in self-taught paddling techniques in four female, recreational stand-up paddle boarders. Three-dimensional, kinematic data of the stroke were collected, bilaterally to determine joint angles and range of motion (ROM) of the shoulders, elbows and trunk, segmental velocities, stroke length, stroke rate and the duration of drive and recovery phases in simulated stand-up paddling (SUP). Participants demonstrated significant ($p < 0.05$) bilateral asymmetries in ROM and joint angles. Substantial inter-participant variations were seen in joint angles at start, mid and end drive, joint ROM and stroke length. These findings assist those within the SUP community to understand self-taught SUP paddling technique.

KEYWORDS: paddle sports, water, SUP, technique.

INTRODUCTION: Stand-up paddling (SUP) is a comparatively-new sport that has recently seen a rise in popularity. The basics of flat-water SUP are easy to learn and, consequently, many boarders have developed their technique without formal coaching. The horizontally-adducted position of the leading (top) shoulder throughout the SUP stroke, coupled with repetitive joint flexion and extension at the shoulders, elbows and trunk could contribute to musculoskeletal injuries. Griffin et al. (2015) reported that of 42 competitive SUP boarders, 28.6% had suffered a shoulder injury and 33.3% had injured the lower back. Furness et al. (2017) reported that musculoskeletal injuries to the shoulder, lower back and elbow accounted for 32.9%, 14.3% and 11.8% of reported injuries, respectively, amongst 230 competitive and recreational SUP boarders. However, to date there are no published studies that have examined the kinematic characteristics of the SUP stroke or considered possible biomechanical effects of stroke variation. Therefore, the purpose of this study was to analyse the upper body kinematics of recreational SUP boarders to quantify variations in typical self-taught SUP strokes.

METHODS: After gaining institutional ethics approval for this research, four self-taught, injury-free, female recreational SUP boarders (Mean ± SD: 41.7 ± 3 years, 64.4 ± 2.5 kg, 1.67 ± 0.03 m) were recruited and provided informed consent to participate. All participants had a minimum of six months flat-water SUP experience, paddling recreationally at least twice a week.

An indoor, simulated paddling environment was used. Two high-density foam mats (2 m x 1 m x 0.04 m) were placed in the centre of the filming area. A 3.2 m x 0.79 m (10’6” x 31”) all-rounder SUP board (Fanatic, Molln, Austria) was centred on the foam mats and balanced on top of two high-density foam rollers (0.45m x 0.15m), which allowed clearance for the blade during the stroke and provided lateral instability similar to that experienced when paddling on water.

Eighteen, 12mm retroreflective spherical markers (3M, Minnesota, USA) were placed on each participant bilaterally at the acromions, epicondyles, styloid processes and, anterior and posterior superior iliac spines, and C7, T8, sternal notch and xiphoid process. Marker clusters were attached to upper arms and forearms to minimise soft tissue artefact using the CAST technique (Cappozzo et al., 1995). An adjustable paddle with a blade width of 0.17 m (Fanatic, Molln, Austria) was used for all trials and identified by markers on the handle, top and bottom of the paddle shaft, centre of gravity (COG), and blade base.

Once habituated with the testing environment, participants were instructed to simulate forward paddle strokes using their usual on-water style and stroke rate for 20 trials, alternating paddling sides after each 30 second trial. All data were recorded using eight optoelectric cameras (Qualisys, Gothenburg, Sweden) positioned around the board and sampling at 100 Hz using Qualisys Track Manager (Qualisys, Gothenburg, Sweden) and processed in Visual 3D (C-Motion Inc., Maryland, USA) with upper body joint kinematic variables derived according to ISB conventions (Wu et al., 2005)

Data were smoothed using a quintic spline filter. Ten consecutive strokes on each side were selected for analysis. Each stroke was divided into a drive phase, beginning at the point of peak maximum blade-base velocity in the anterior direction ('start') and ending at the point of peak minimum blade-base velocity in the posterior direction ('end'), and a recovery phase during which time the paddle was returned to the start position. A mid-drive ('mid') position was identified as the point at which the blade base reached its lowest point in the drive phase.

Flexion and extension of the elbow, shoulder and trunk, and trunk rotation were analysed to determine joint angles at start-, mid- and end-drive positions and joint angular ROM. Motion during the recovery phase and movements of the supporting (lower) arm were not analysed in this study. Horizontal displacement of the blade and the duration of drive and recovery phases were used to calculate stroke length, stroke rate and time in each phase. Resultant blade velocity was used to examine similarities in stroke characteristics.

Data were analysed in Microsoft Excel (Microsoft Corporation, Washington, USA). Due to the small sample size and data not meeting checks of normality, Wilcoxon signed-rank non-parametric tests were applied to detect significant (p< 0.05) bilateral asymmetries between the left and right arms within each participant for joint ROM and joint angles at start- mid- and end-drive positions. Descriptive statistics (mean and standard deviation (SD), range and percentage difference) were used in the analysis of all other intra- and inter-participant parameters.

RESULTS AND DISCUSSION: Stroke characteristics for all participants are shown in Table 1. Limonta et al. (2010) and Bjerkefors et al. (2017) associated increased stroke lengths and non-detrimental reductions in stroke rate with greater early forward reach in kayakers, hypothesising that this resulted in faster early-drive paddle motion and greater propulsive forces. Such a pattern was reflected in the stroke characteristics of participants A and C.

Table 1: Stroke rate, length and duration in drive and recovery phases

	Mean stroke rate (strokes/min ± SD)			Mean stroke length (m ± SD)			Mean time in drive/recovery phases (% of stroke ± SD)	
	Left leading arm	Right leading arm	Difference (% ± SD)	Left leading arm	Right leading arm	Difference (% ± SD)	Left leading arm	Right leading arm
Participant A	27 (± 0.8)	23 (± 4)	6 (± 3)	2.1 (± 0.1)	1.9 (± 0.1)	9 (± 7)	50/50 (± 0)	49/51 (± 1)
Participant B	33 (± 0.6)	37 (± 1)	12 (± 4)	1.1 (± 0.1)	1.0 (± 0.1)	7 (± 0.1)	50/50 (± 1)	50/50 (± 1)
Participant C	26 (± 0.7)	27 (± 0.6)	2 (± 3)	2.5 (± 0.1)	2.4 (± 0.1)	1 (± 0.0)	49/50 (± 1)	50/50 (± 1)
Participant D	22 (± 0.7)	24 (± 0.9)	8 (± 2)	1.9 (± 0.1)	1.8 (± 0.1)	9 (± 0.1)	51/49 (± 1)	50/50 (± 1)

Significant (p< 0.05), individualised stroke asymmetries were seen within each participant with different upper body joint kinematic strategies noted. Participants A and B showed symmetry in shoulder and elbow flexion and trunk rotation at start positions but not at mid or end positions. Participant C demonstrated symmetry in shoulder, elbow and trunk flexion mid-drive, but not throughout the drive. As hand dominance was not noted in this study, future research should examine whether this may influence paddling technique. The presence of significant asymmetries was not unexpected and likely reflects the novice status of participants (Limonta et al., 2010). However, asymmetric strokes (assuming similar kinetics) could alter board trim and trajectory, requiring the boarder to adjust their stroke to make corrections. Persistent asymmetries could contribute to stroke inefficiencies, muscular imbalances and joint pathologies in SUP boarders, a hypothesis reflected in the findings of Limonta et al. (2010) who noted the contribution of asymmetric paddling styles to overuse pathologies in kayakers.

In addition to intra-participant asymmetries, differences in upper body joint kinematics were observed between participants (Figure 1). Elbow joint kinematics are seen in Figures 1c and 1d. Participant C demonstrated the greatest elbow extension at start position but the smallest ROM across the drive (mean ROM 38 ± 10º and 19 ± 11º, extension 111 ± 9º and 124 ± 8º, left and right leading arms respectively) suggesting that the elbow was used in stabilising the paddle but not instrumental in generating propulsive force. In contrast, Participant A extended the elbow more than 100° through the drive for both leading arms (ROM 103 ± 10º and 114 ± 10º, extension 43 ± 9º and 35 ± 9º, left and right leading arms respectively) suggesting that propulsive forces, particularly from start to mid drive, were principally generated through elbow extension. Participants B and D displayed similar start to mid drive patterns of elbow extension, although with smaller ROM. Relying on smaller, more distal muscles to generate propulsive forces would logically increase fatigue and injury risk when compared to reliance upon stronger proximal muscles.

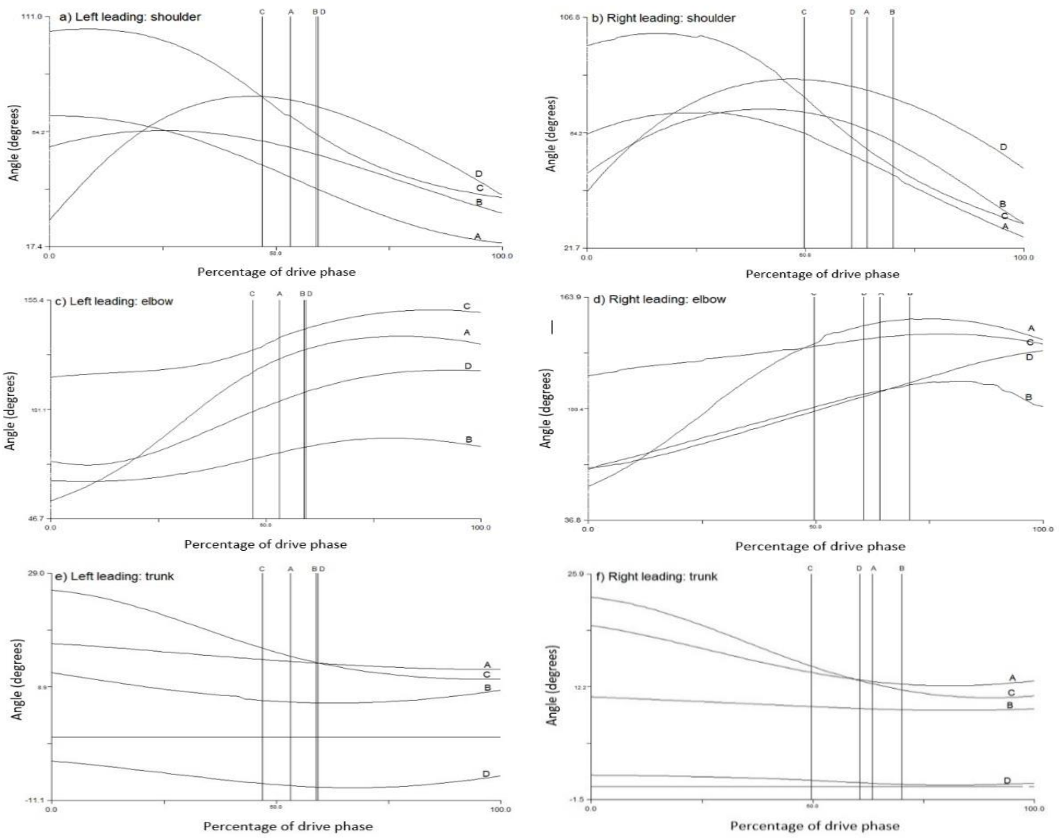

Figure 1. Inter-participant variation in upper body joint kinematics during the drive phase; (a) left leading arm shoulder flexion, (b) right leading arm shoulder flexion, (c) left leading arm elbow flexion, (d) right leading arm elbow flexion, (e) left leading arm trunk flexion, (f) right leading arm trunk flexion. Traces for each participant are labelled A, B, C and D. Vertical lines denote mid-drive positions.

Inter-participant joint kinematics of the shoulders and trunk for left and right leading arms are illustrated in Figures 1a, 1b, 1d and 1f, respectively. Participant C adopted greater shoulder and trunk flexion than other participants at start positions and extended the shoulder and trunk through the drive (ROM 82 ± 9º and 76 ± 6º, 18 ± 3º and 14 ± 3º, left and right leading arms, shoulder and trunk respectively). Limonta et al. (2010) proposed that a paddling action initiated from the trunk generated greater blade velocity and might improve performance in kayaking. Participant C demonstrating the largest trunk ROM and the highest peak paddle velocity (1.8 ± 0m/s and 1.9 ± 0m/s, left and right leading arms respectively). Participant A extended the shoulder and trunk from start through to end positions in a similar manner to participant C although ROM at both joints were smaller (52 ± 6º and 48 ± 12º, 5 ± 2º and 7 ± 2º, left and right leading arms, shoulder and trunk respectively). Subsequent lower peak paddle velocities (1.3 ± 0m/s and 1.1 ± 0m/s, left and right leading arms respectively) indicted that reduced trunk and shoulder ROM and a greater reliance on the smaller musculature of the elbow were less effective in generating propulsive forces at the paddle. Peak paddle velocities were lowest for participants B and D (1.2 ± 0m/s and 1.0 ± 0m/s, left and right leading arms respectively, both participants) and these results probably reflected limited trunk and shoulder flexion at start positions and the need to increase shoulder flexion from start to mid drive reducing the effectiveness the kinetic chain, which was evidenced in these results as less effective proximal to distal force summation and reduced peak paddle velocities.

Although paddle forces are an important determinant of performance, risks are associated with increased shoulder flexion and ROM in paddle sports (Fleming et al., 2012). Well-coordinated scapulohumeral rhythm is essential in facilitating coordinated shoulder movements and maintaining the subacromial space. Furthermore, the risk of shoulder injury is increased for the SUP boarder due to the need to control a long paddle, which acts as a long lever arm increasing torque at the shoulder (Herrington and Horsley, 2014).

This study incorporated a simulated paddling set up and therefore future research should incorporate either on-water testing or the use of a validated SUP-specific ergometer. Whilst the simulated set up enabled participants to reproduce their usual paddling style, differences in lateral instability and lack of resistive forces associated with on-water paddling are likely to have influenced findings.

CONCLUSION: This study quantified kinematic differences in the paddling styles of self-taught, recreational, female SUP boarders in a simulated paddling environment. Increased early trunk and shoulder flexion, coupled with controlled extension through the drive resulted in greater paddle velocity and better proximal to distal sequencing. Conversely, reliance on the smaller structures of the elbow resulted in less effective paddle velocity and could increase the risk of injury. While the basics of SUP may seem easy to learn, these results show that substantial differences in paddling techniques can result from self-coaching and further research is needed to establish technique effects on performance and the risk of overuse injury.

REFERENCES:

Bjerkefors, A., Tarassova, O., Rosen, J., Zakaria, P., & Arndt, A. (2017). Three-dimensional kinematic analysis and power output of elite flat-water kayakers. *Sports Biomechanics*, 20, 1-14. doi:10.1080/14763141.2017.1359330

Cappozzo, A., Catani, F., Della Croce, U., & Leardini, A. (1995). Position and orientation in space of bones during movement: anatomical frame definition and determination. *Clinical Biomechanics*, 10, 171-178.

Fleming, N., Donne, B., & Fletcher, D. (2012). Effect of kayak ergometer elastic tension on upper limb EMG activity and 3D kinematics. Journal of Sports Science and Medicine, 11, 430-437.

Furness, J., Olorunnife, O., Schram, B., Climstein, M., & Hing, W. (2017). Epidemiology of injuries in stand-up paddle boarding. *The Orthopaedic Journal of Sports Medicine,* 5*,* 1-9. doi:10.1177/2325967117710759

Griffin, A., Perriman, D., Neeman, T., & Smith, P. (2015). The prevalence of musculoskeletal injury in Australian paddle sports. *Journal of Science and Medicine in Sport,* 195, 33-56. doi:10.1016/j.jsams.2015.12510

Herrington, L., & Horsley, I. (2014). Effects of latissimus dorsi length on shoulder flexion in canoeists, swimmers, rugby players and controls. *Journal of Sport and Health Science*, 3, 60- 63. doi:10.1016/j.jshs.2013.01.004

Limonta, E., Squadrone, R., Rodano, R., Marzegan, A., Veicsteinas, A., Merati, G., & Sacchi,
M. (2010). Tridimensional kinematic analysis on a kayaking simulator: key factors to successful performance. *Sport Sciences for Health,* 1*,* 27-34. doi:10.1007/s11332-010-00937

Wu, G., Van der Helm, F., Veeger, H., Makhsous, M., Van Roy, P., Anglin, C., et al. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. *Journal of Biomechanics*, *38*, 981-989