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croucher summer courses

Sports biomechanics

Application of instrumented paddles in measuring on-water kinetics

Dr Pui Wah (Veni) KONG 江佩燁

Associate Dean

National Institute of Education

Nanyang Technological University

Singapore

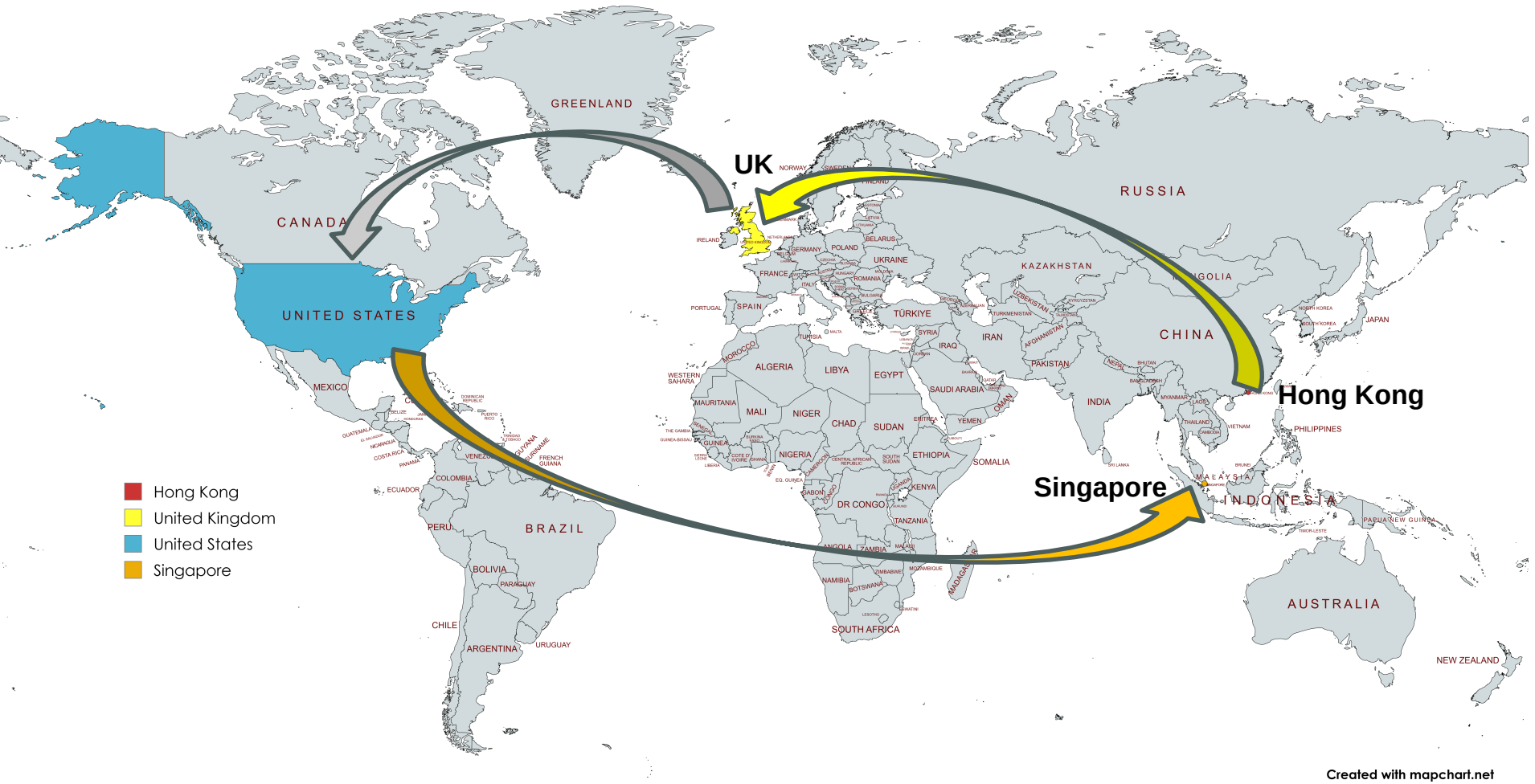
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Croucher Sports Biomechanics Summer Courses, The Chinese University of Hong Kong, 20th to 25th July 2026.

Background


UK
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Background – Education

Student



香港中文大學
The Chinese University of Hong Kong

Loughborough University

BEd → MSc → PhD

University Faculty



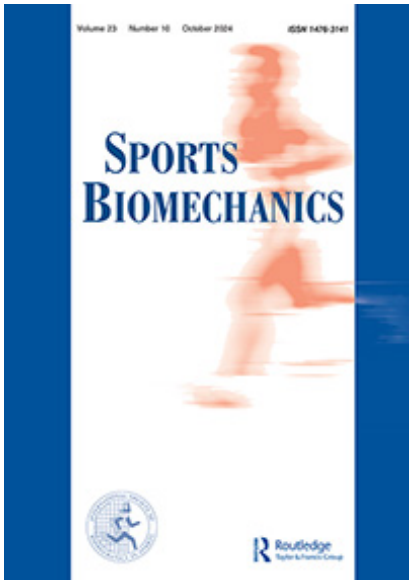
NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

University of Pittsburgh

University of Texas at El Paso

Background – Research Area

Associate Editor



Sports Biomechanics
(2014 – present)



JMMB
(2019 – present)



EJSS (Biomechanics)
(2025 – present)

Background – Research Area

Editorial Board Member

Research in Sports Medicine
(2013 – present)

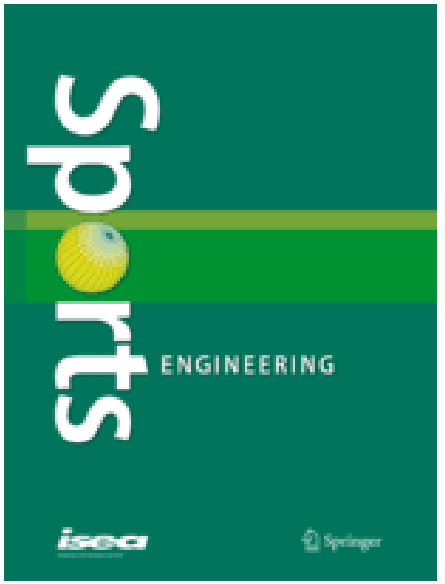




Journal of Exercise Science & Fitness
(2021 – present)

World Scientific Annual Reviews of Biomechanics
(2022 – present)





Sports Engineering
(2023 – present)

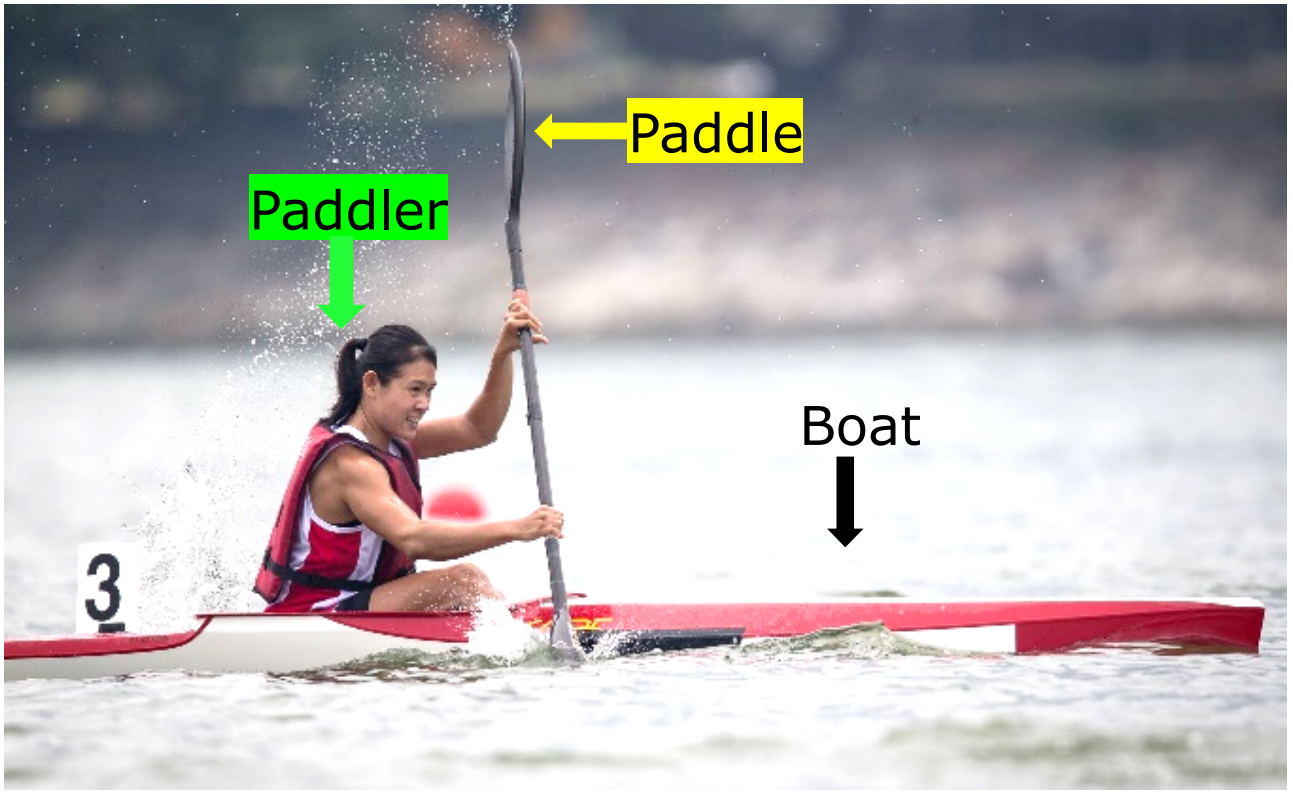


Kayaking

Dr Cheryl Tay
(PhD class of 2018)

Kayaking

皮划艇　　皮艇　　獨木舟　独木舟



Kayak Sprint is an Olympic event. The aim is to complete distances of 200-, 500-, and 1000-m in the shortest possible time.

Kayaking



Who is the expert?

Paddler A





Paddler B



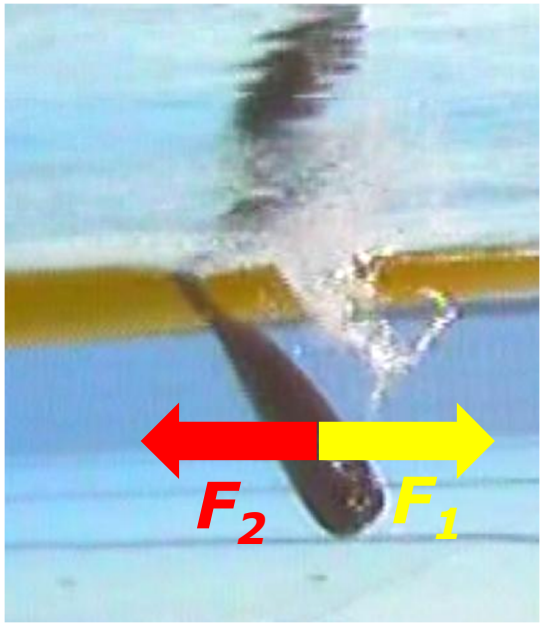


Newton's Third Law

- For every **Action** (force), there is an equal and opposite **Reaction** (force).

牛顿第三定律: 每一个作用力都有一个大小相等、方向相反的反作用力。

Reaction (F_2)
The water pushes the paddle in the opposite direction with the same force.



Action (F_1)
The paddle pushes the water backward.



Direction of Travel

Single & Crew Boat Kayaking

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Singles



K1

Crew Boats



K2



K4

K2 Crew Boat



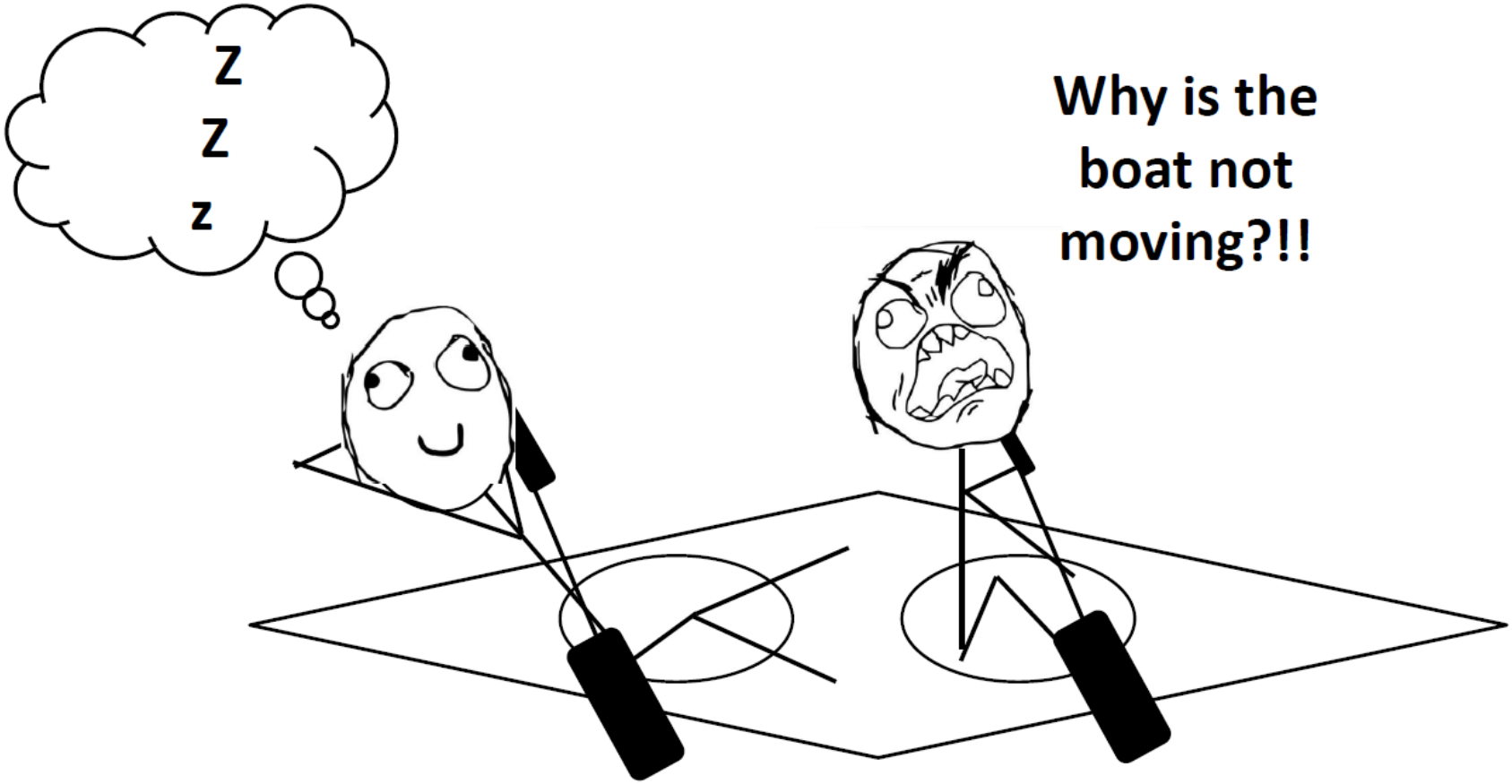
Research Question



- Do the ***front*** and ***back*** paddlers exert the same amount of forces on the paddle?

On-Water Kinetics

- We need to find a way to measure the ***kinetics*** (i.e. forces on the paddle) during on-water paddling.



How to measure paddle force?

Solution 1:

Make our own instrumented paddles

Solution 2:

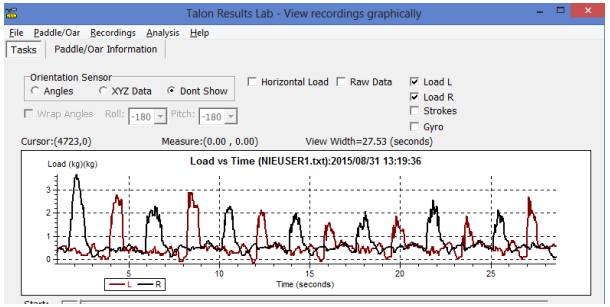
Buy commercial instrumented paddles

How to measure paddle force?

- Options for commercial paddles:

1. Excalibur II Kayak Data Paddle (*Merlingear*)





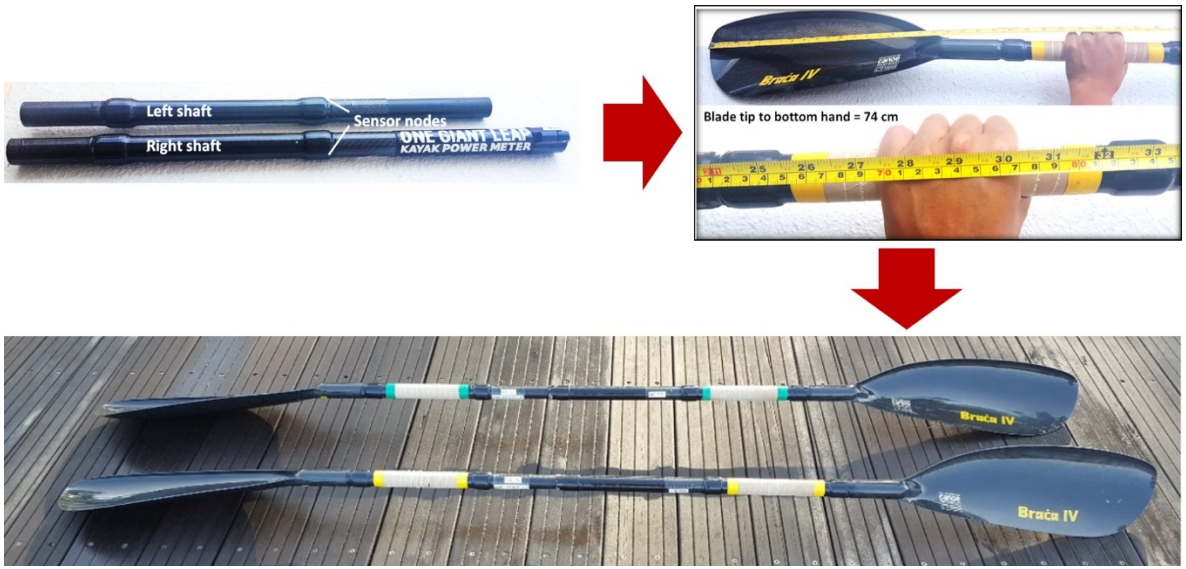
2. Kayak Power Meter (One Giant Leap, New Zealand)



Instrumented Paddle

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Kayak Power Meter (One Giant Leap, New Zealand)



✓ **Measure synchronised data from more than one paddles**

- Validity: within 0.12% to 1.4% of the true value. Reliability ranged from 0.27% to 0.34% for an applied force of 155.9 N.[1]
- Typical measurement resolutions were 1.0 N for the top hand and 2.5 N for the bottom hand, with a range of 780 N to 2100 N.

[1] Macdermid, P.; Fink, P. The Validation of a Paddle Power Meter for Slalom Kayaking. *Sport. Med. Int. Open* **2017**, *01*, E50–E57, doi:10.1055/s-0043-100380.

Study 1: On-water Kinetics

Publication

sensors

MDPI

Article

Application of Instrumented Paddles in Measuring On-Water Kinetics of Front and Back Paddlers in K2 Sprint Kayaking Crews of Various Ability Levels

Pui Wah Kong *, Cheryl Sihui Tay and Jing Wen Pan

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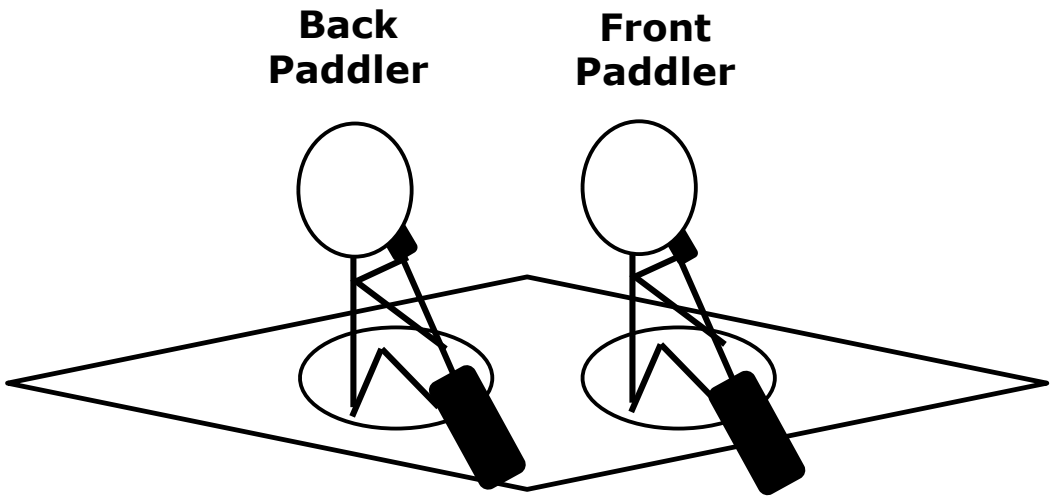
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Study Aims

The present study aimed to:

1) compare the kinetic profiles of the front and back paddlers in a large sample of K2 sprint kayaking athletes, and

2) compare the kinetic outputs between kayakers of varied abilities.



Methods – Participants

- Convenience sample of 74 male sprint kayak athletes (39 K2 crews) comprising a wide range of proficiency levels.

Table 1. Physical characteristics and experience of 74 sprint kayaking athletes

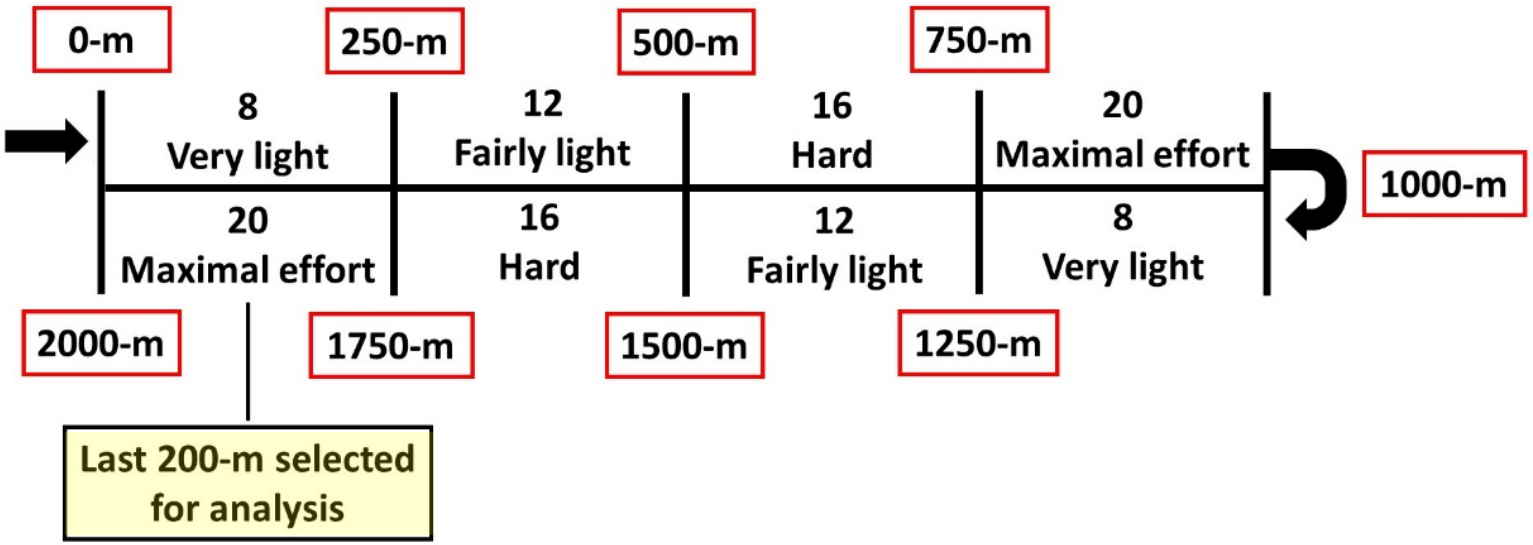
	National (N, n = 9)	Recreational (R, n = 38)	School (S, n = 27)	*p*-value	*post-hoc*	
Age [years]	23.2 [20.1, 26.2]	24.0 [22.9, 25.2]	17.9 [15.7, 20.0]	<0.001*	N>S	R>S
Height [m]	1.74 [1.71, 1.78]	1.73 [1.71, 1.74]	1.70 [1.68, 1.72]	0.033*		
Body mass [kg]	73.4 [71.2, 75.5]	68.3 [65.9, 70.8]	61.8 [59.7, 64.0]	<0.001*	N>S	R>S
Sitting height [m]	0.91 [0.88, 0.93]	0.91 [0.89, 0.92]	0.87 [0.86, 0.88]	0.001*	N>S	R>S
Sitting reach [m]	1.26 [1.22, 1.29]	1.25 [1.23, 1.27]	1.22 [1.20, 1.24]	0.061		
Arm span [m]	1.77 [1.72., 1.82]	1.76 [1.74, 1.78]	1.73 [1.71, 1.76]	0.167		
Experience [years]	10.0 [6.5, 13.5]	5.7 [4.4, 7.0]	2.5 [1.8, 3.2]	<0.001*	N>S	R>S

N = national team, R = recreational club. S = school team. Significant difference ($p < 0.05$) is shown in bold text and indicated by an asterisk.

Methods – Data Collection

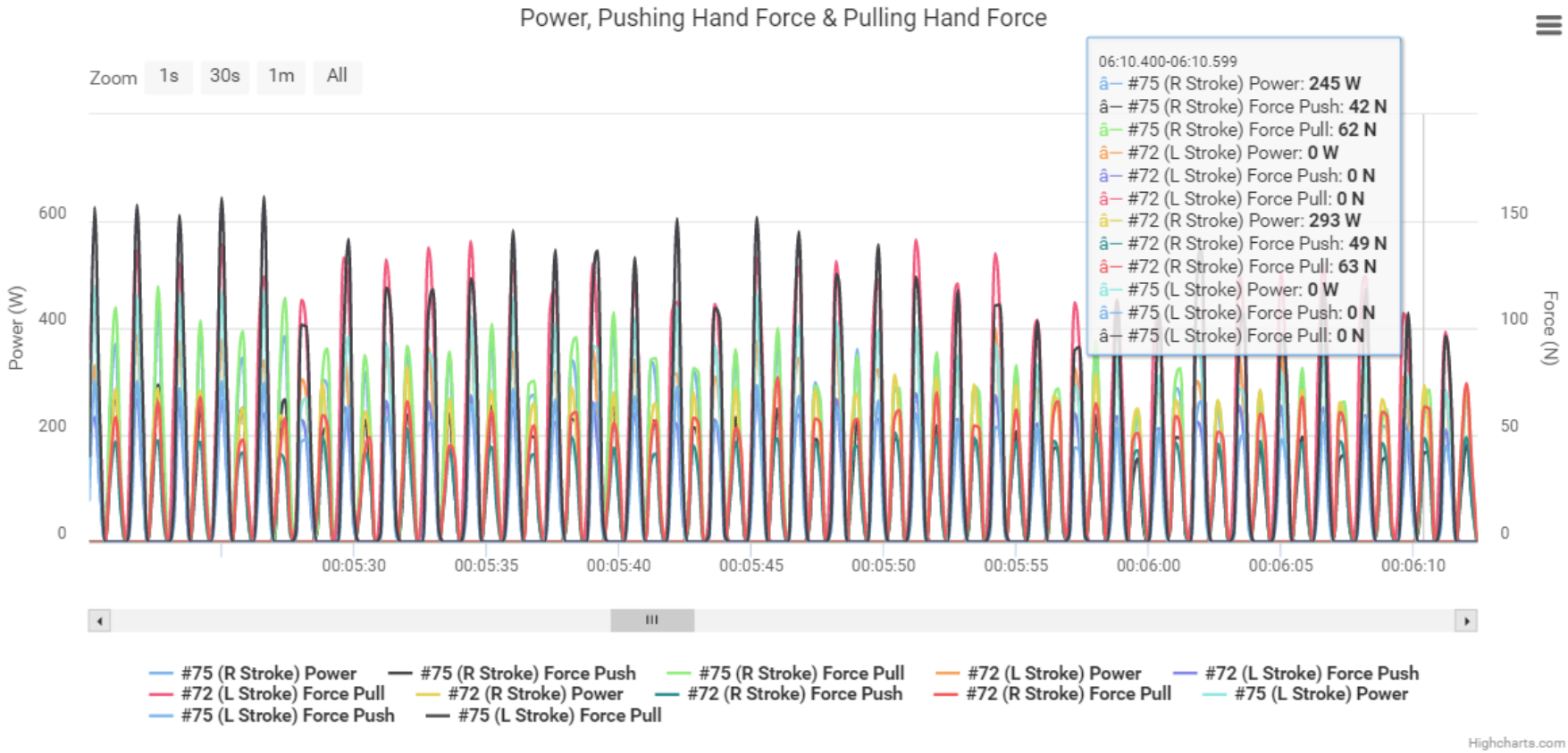
- Step protocol with self-moderated intensities changing every 250-m based on the 6-20 Borg scale.





Methods – Raw Data

- Raw data recorded using the analysis application (http://analysis.onegiantleap.co.nz).



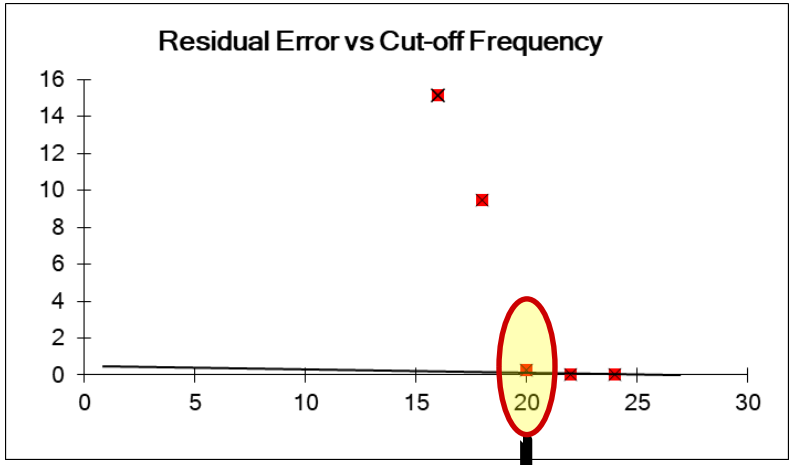
Methods – Data Processing

- What cut-off frequency should we use to filter the raw data?

Gomes, B.B.; Ramos, N.V.; Conceição, F.A.V.; Sanders, R.H.; Vaz, M.A.P.; Vilas-Boas, J.P. Paddling Force Profiles at Different Stroke Rates in Elite Sprint Kayaking. *J. Appl. Biomech*. **2015**, 31, 258–263.

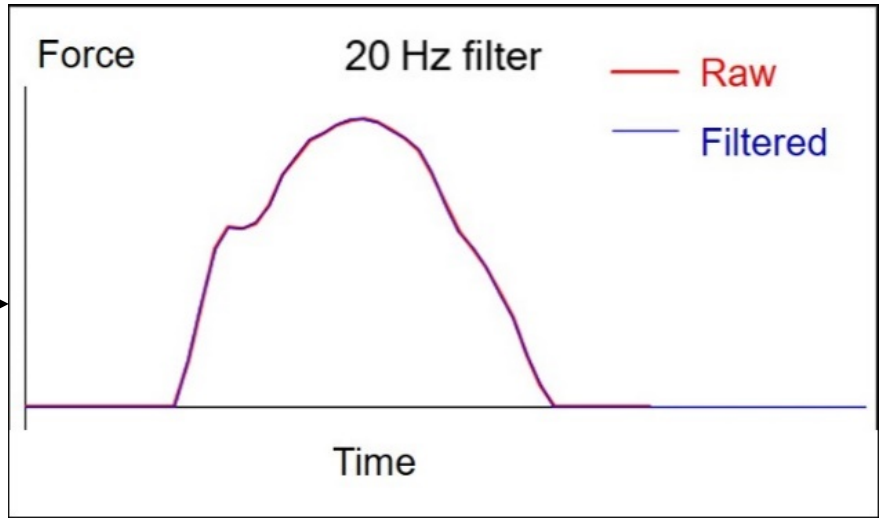
20 Hz (but a different kayak paddle)

- **Residual analysis** comparing 16, 18, 20, 22, and 24 Hz



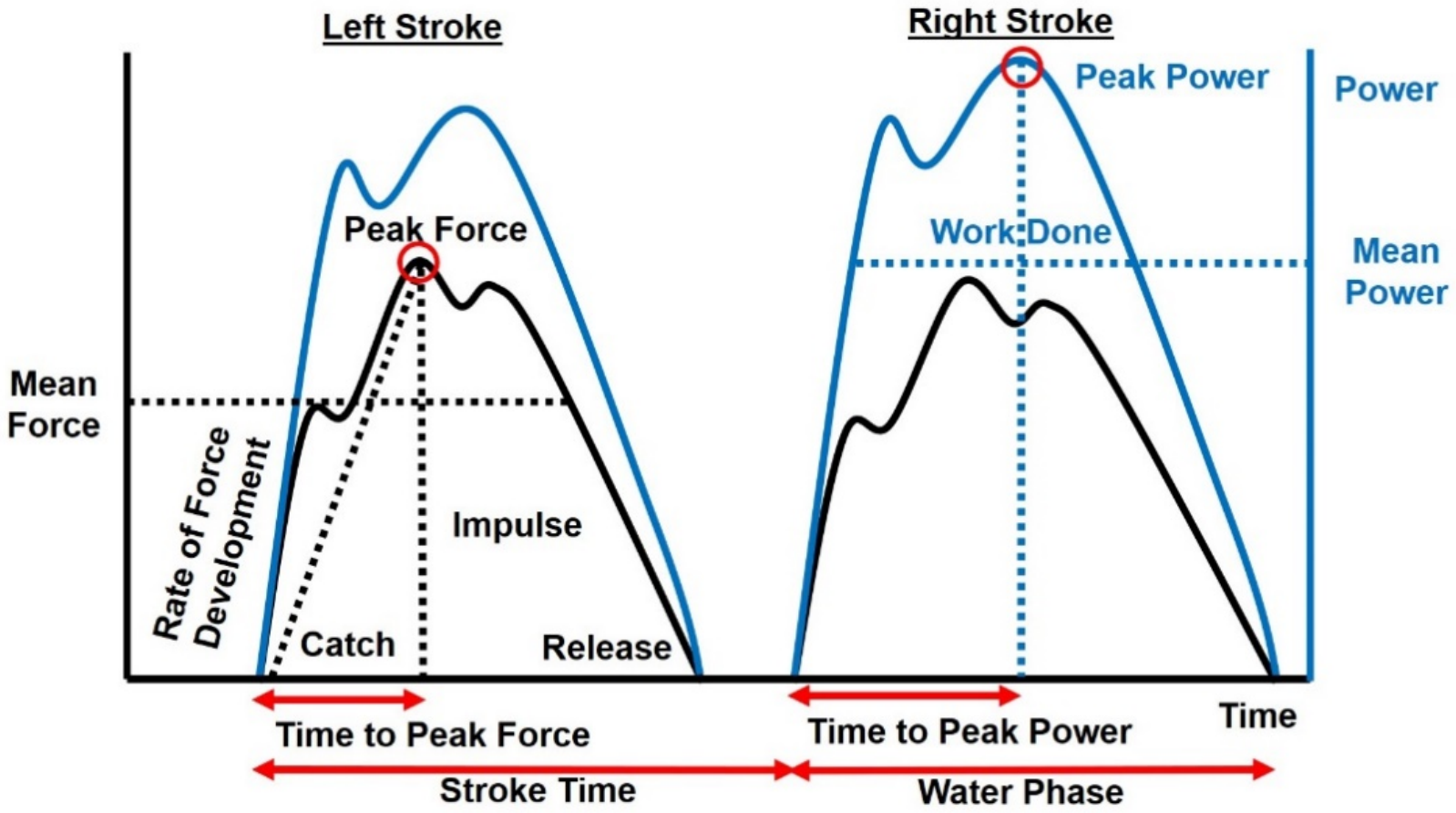
The 20 Hz filter was deemed to be the most suitable.

Visual Inspection



Methods – Data Extraction

- Customised codes were written in RStudio (version 1.0.136, R Core Team 2016) to extract ***force***, power and temporal variables.

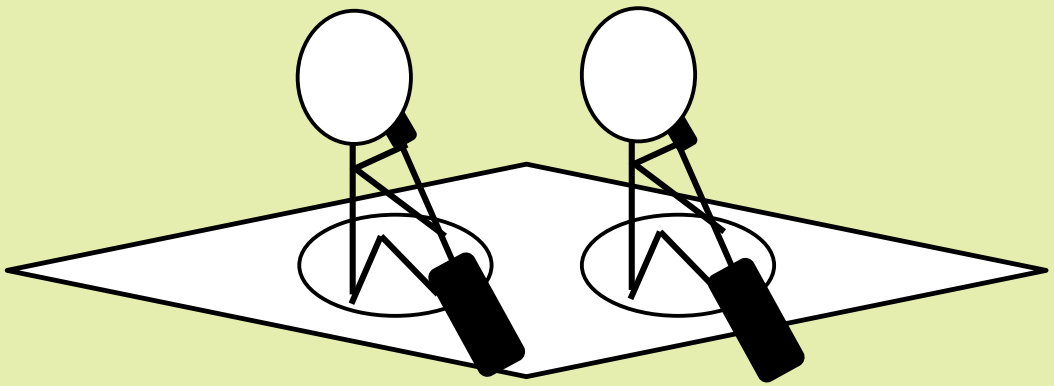


Methods – Statistical Analysis

- A series of 2 × 3 two-way factorial Analysis of Variance (ANOVA) was performed to examine the effects of ***seat*** and ***group*** on the key stroke variables.

Seat

Back Paddler vs Front Paddler



Group

National

vs

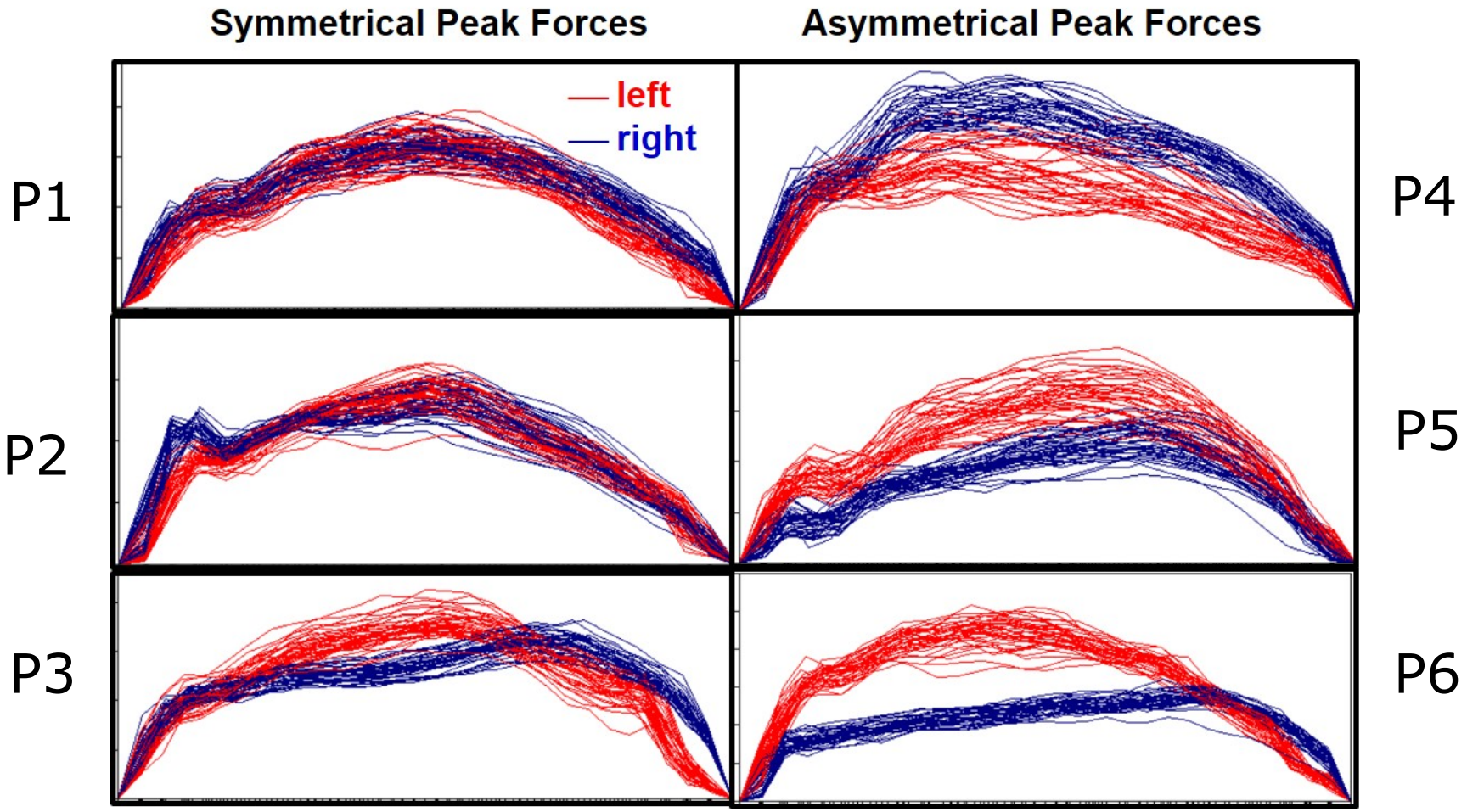
Recreational

vs

School

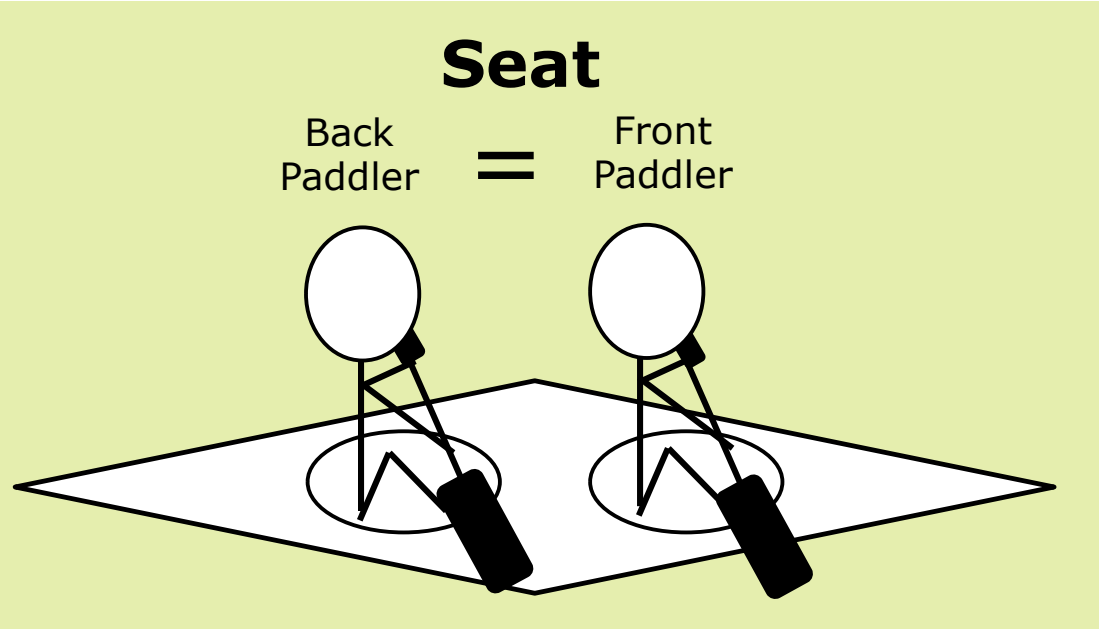
Results – Force Profiles

- Different force-time profiles among the 74 paddlers and between the left and right sides of the same padder.



Results – Seat Position

- There was no significant difference between the front paddlers and back paddlers in all force variables.



Results – Group

- ***National team*** kayakers displayed significant ***higher*** peak force, mean force and rate of force development than the recreational and school athletes (Table 2).
- No *post-hoc* difference between recreational and school groups.

Table 2. Selected force variables of front and back paddlers of K2 crews

		Front Paddler	Back Paddler	Group		*post-hoc*	
				p	η^2_p		
Peak force [N]	N	344.3 [307.6, 381.0]	342.4 [252.9, 432.0]	< 0.001*	0.340	N>R	N>S
	R	239.6 [207.0, 272.1]	241.7 [219.6, 263,9]				
	S	216.9 [188.7, 245.1]	223.3 [182.6, 263.9]				
Mean force [N]	N	205.3 [187.2, 223.4]	200.6 [149.9, 251.4]	< 0.001*	0.329	N>R	N>S
	R	146.5 [130.0, 163.0]	146.6 [134.9, 158.3]				
	S	137.4 [120.0, 154.9]	135.3 [111.1, 159.6]				
RTD [N/s]	N	1929.8 [1460.3, 2399.2]	1699.3 [1197.3, 2201.2]	< 0.001*	0.328	N>R	N>S
	R	1118.2 [938.6, 1297.8]	1233.0 [1016.1, 1449.9]				
	S	972.9 [831.1, 1114.7]	1065.6 [834.8, 1296.4]				

N = national team, R = recreational clubs. S = school teams. RTD = rate of force development. Data are presented as mean [95% CI]. Significant difference ($p < 0.05$) is shown in bold text and indicated by an asterisk.

Discussion

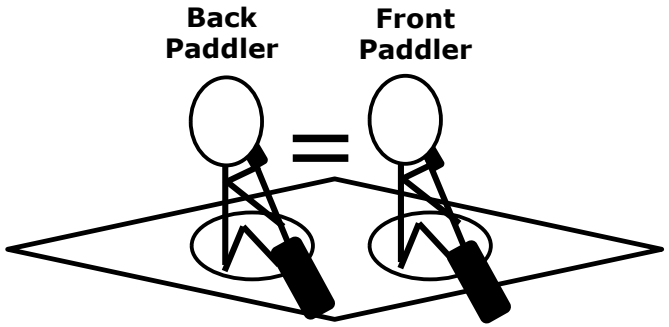
Front vs back seat of a K2 crew boat

- Gomes[1] reported similar force profiles when the same kayaker sat in the front and back seats of a K2 crew boat.
  - Small sample of 11 elite kayakers
  - Did not compare the stroke kinetics of both crew members when they paddle together.

- The present study measured both crew members in a large sample (n = 74) and demonstrated that:

  1) No difference in force characteristics between the front and back paddlers.

  2) Proficient kayakers produced greater forces than less proficient kayakers.



[1]Gomes, B.B. Biomechanical determinants of kayak paddling performance in single-seat and crew boats, Universidade do Porto (Portugal), 2015.

Discussion

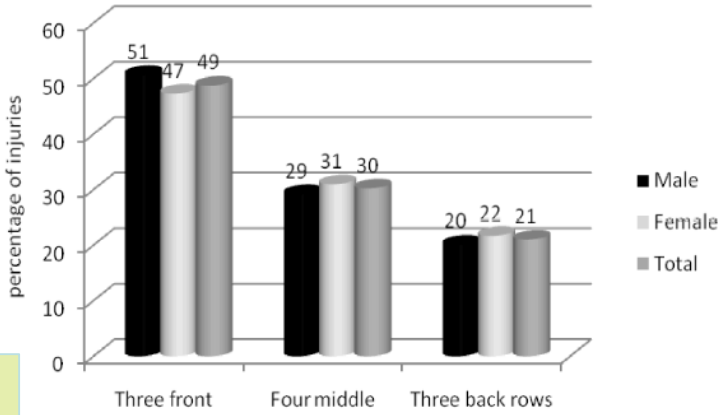
- Injury risk – Dragon Boat



Front positions had more injuries compared with back positions.[1]

- **Front rows**: Paddlers catch stagnant or highly turbulent water → ***higher force?***
- **Back rows**: Paddlers catch backward flowing water → ***lower force?***

No Force Measurements



[1]Zandi, S.; Rajabi, R.; Tavanaei, A.R. Are gender, position in boat and training load associated with the injuries in elite dragon boat paddlers. *World J. Sport Sci.* **2010**, *3*, 113–118.

Conclusion

- Instrumented paddles are useful tools to obtain performance feedback of each crew member in a K2 crew boat during on-water kayaking.

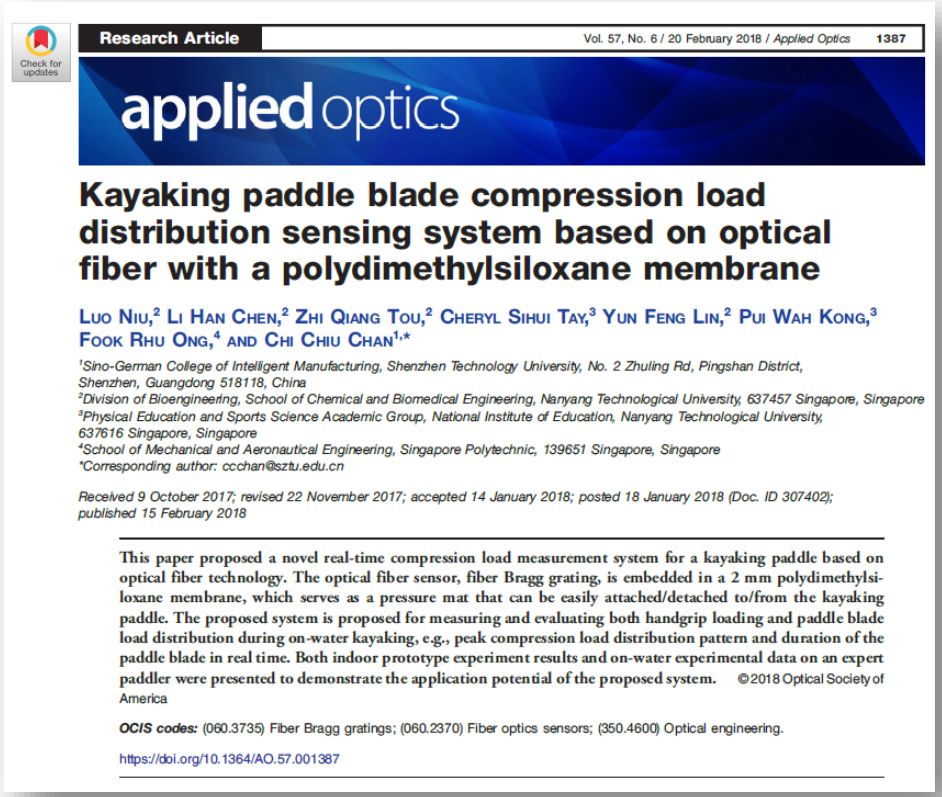
- Using these paddles, we have shown that:
  - Force characteristics of the front and back paddlers were similar during maximal effort sprint kayaking.
  - Proficient kayakers could produce greater kinetic outputs than less proficient kayakers.

- During training, emphasis should be placed on increasing kinetic outputs of both crew members in a K2 boat.

Study 2: Make Our Own Paddles

Publications

- Design an instrumented paddle to measure load distribution on the paddle blade



Research Article Vol. 57, No. 6 / 20 February 2018 / Applied Optics 1387

applied optics

Kayaking paddle blade compression load distribution sensing system based on optical fiber with a polydimethylsiloxane membrane

Luo Niu,[2] Li Han Chen,[2] Zhi Qiang Tou,[2] Cheryl Sihui Tay,[3] Yun Feng Lin,[2] Pui Wah Kong,[3] Fook Rhu Ong,[4] and Chi Chiu Chan[1,*]

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[2]Division of Bioengineering, School of Chemical and Biomedical Engineering, Nanyang Technological University, 637457 Singapore, Singapore
[3]Physical Education and Sports Science Academic Group, National Institute of Education, Nanyang Technological University, 637616 Singapore, Singapore
[4]School of Mechanical and Aeronautical Engineering, Singapore Polytechnic, 139651 Singapore, Singapore
*Corresponding author: ccchan@sztu.edu.cn

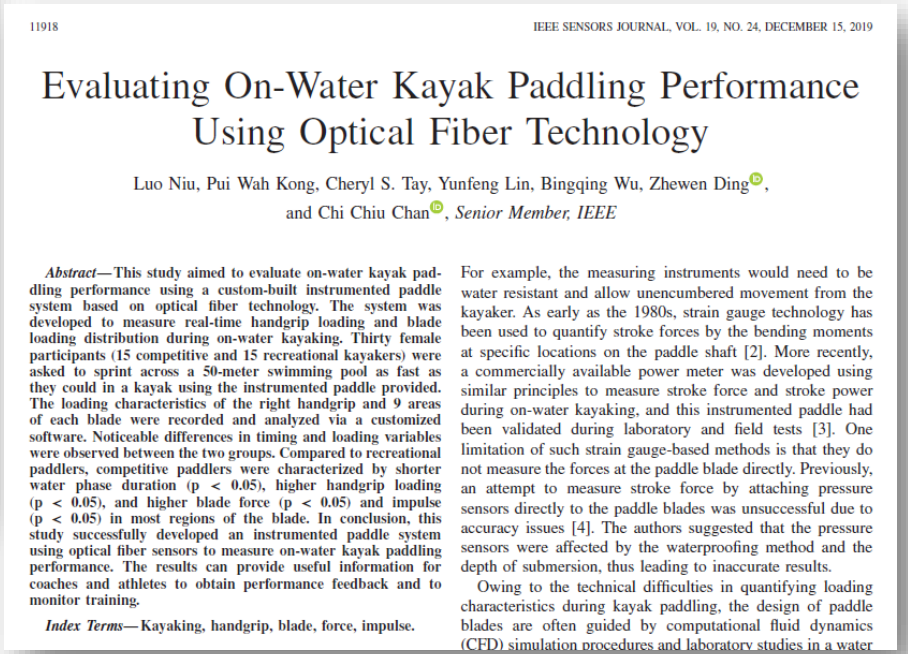
Received 9 October 2017; revised 22 November 2017; accepted 14 January 2018; posted 18 January 2018 (Doc. ID 307402); published 15 February 2018

This paper proposed a novel real-time compression load measurement system for a kayaking paddle based on optical fiber technology. The optical fiber sensor, fiber Bragg grating, is embedded in a 2 mm polydimethylsiloxane membrane, which serves as a pressure mat that can be easily attached/detached to/from the kayaking paddle. The proposed system is proposed for measuring and evaluating both handgrip loading and paddle blade load distribution during on-water kayaking, e.g., peak compression load distribution pattern and duration of the paddle blade in real time. Both indoor prototype experiment results and on-water experimental data on an expert paddler were presented to demonstrate the application potential of the proposed system.

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OCIS codes: (060.3735) Fiber Bragg gratings; (060.2370) Fiber optics sensors; (350.4600) Optical engineering.

https://doi.org/10.1364/AO.57.001387



Evaluating On-Water Kayak Paddling Performance Using Optical Fiber Technology

Luo Niu, Pui Wah Kong, Cheryl S. Tay, Yunfeng Lin, Bingqing Wu, Zhewen Ding, and Chi Chiu Chan, *Senior Member, IEEE*

***Abstract*— This study aimed to evaluate on-water kayak paddling performance using a custom-built instrumented paddle system based on optical fiber technology. The system was developed to measure real-time handgrip loading and blade loading distribution during on-water kayaking. Thirty female participants (15 competitive and 15 recreational kayakers) were asked to sprint across a 50-meter swimming pool as fast as they could in a kayak using the instrumented paddle provided. The loading characteristics of the right handgrip and 9 areas of each blade were recorded and analyzed via a customized software. Noticeable differences in timing and loading variables were observed between the two groups. Compared to recreational paddlers, competitive paddlers were characterized by shorter water phase duration ($p < 0.05$), higher handgrip loading ($p < 0.05$), and higher blade force ($p < 0.05$) and impulse ($p < 0.05$) in most regions of the blade. In conclusion, this study successfully developed an instrumented paddle system using optical fiber sensors to measure on-water kayak paddling performance. The results can provide useful information for coaches and athletes to obtain performance feedback and to monitor training.**

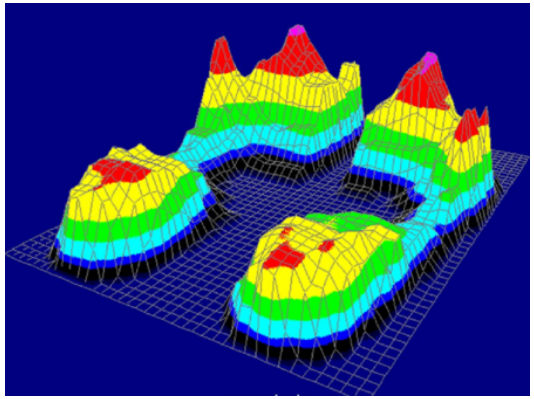
***Index Terms*— Kayaking, handgrip, blade, force, impulse.**

For example, the measuring instruments would need to be water resistant and allow unencumbered movement from the kayaker. As early as the 1980s, strain gauge technology has been used to quantify stroke forces by the bending moments at specific locations on the paddle shaft [2]. More recently, a commercially available power meter was developed using similar principles to measure stroke force and stroke power during on-water kayaking, and this instrumented paddle had been validated during laboratory and field tests [3]. One limitation of such strain gauge-based methods is that they do not measure the forces at the paddle blade directly. Previously, an attempt to measure stroke force by attaching pressure sensors directly to the paddle blades was unsuccessful due to accuracy issues [4]. The authors suggested that the pressure sensors were affected by the waterproofing method and the depth of submersion, thus leading to inaccurate results.

Owing to the technical difficulties in quantifying loading characteristics during kayak paddling, the design of paddle blades are often guided by computational fluid dynamics (CFD) simulation procedures and laboratory studies in a water

Load Distribution

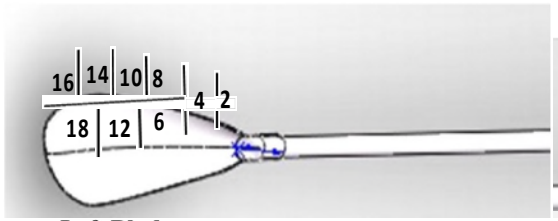
Plantar pressure distribution under the foot



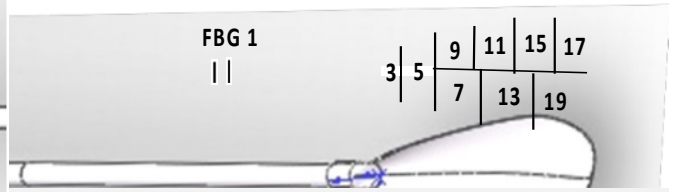
足底压力

(McDonogh et al., 2022)

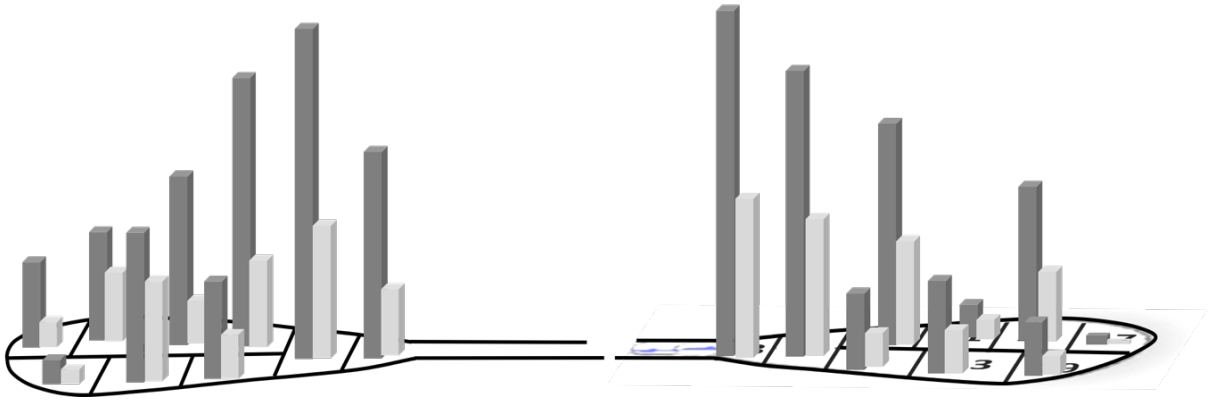
Can we apply this concept to the paddle blade?



Left Blade

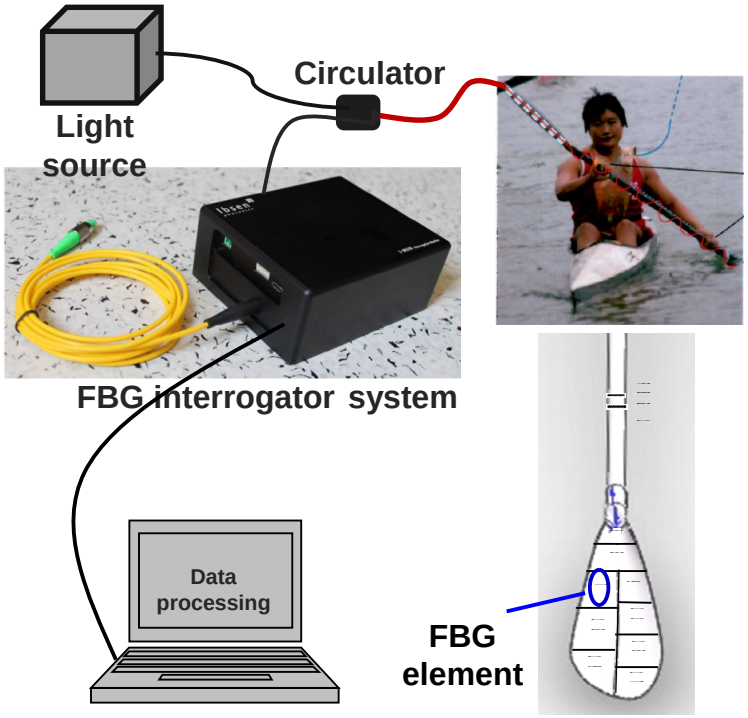


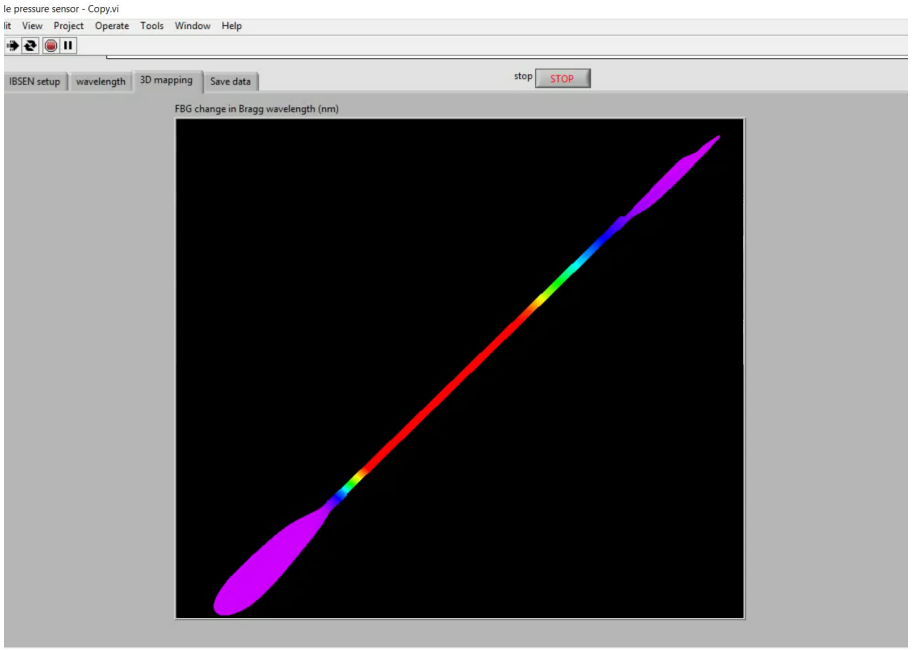
Right Blade



Design

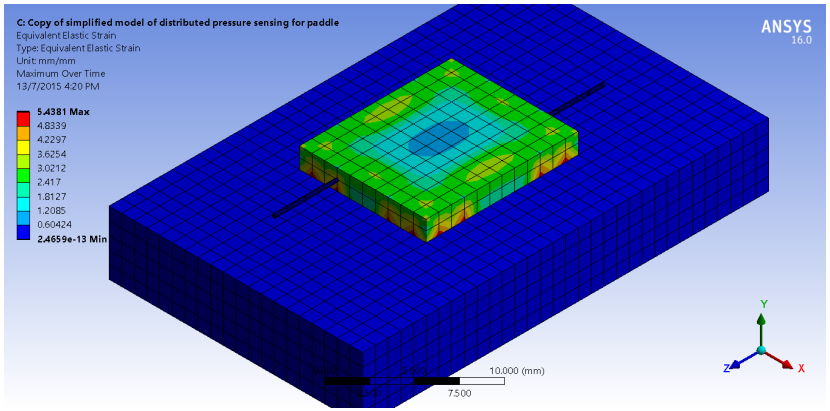
- Optical fibre technology光纤: Fiber Bragg Grating (FBG) sensors



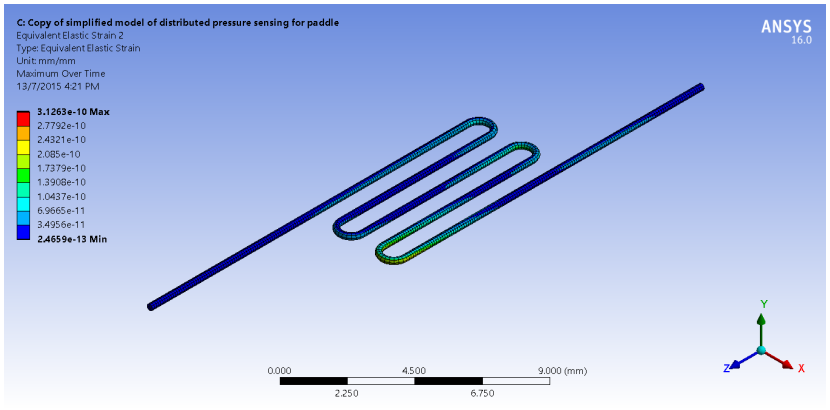


Simulation & Prototyping

➢ ANSYS Workbench Simulation:

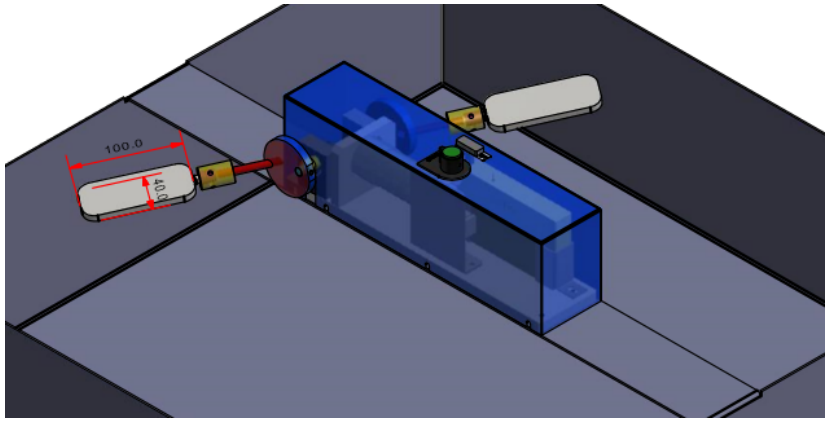


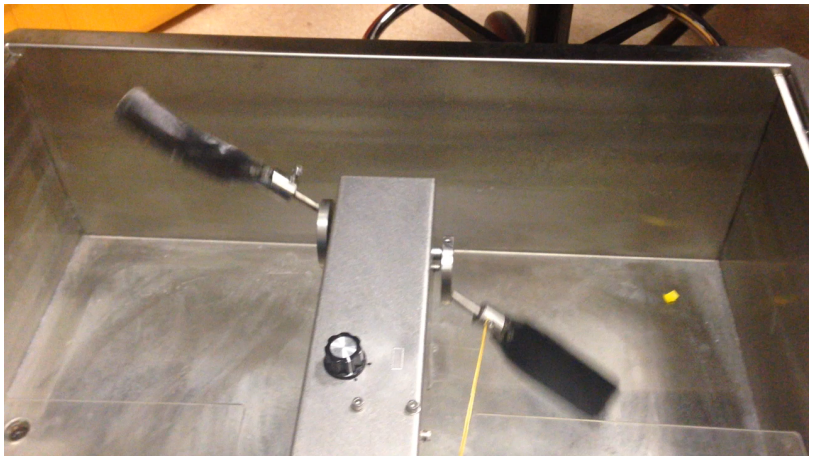
Simulation results of FBG embedded in PDMS



Details of optical fiber sensor

➢ Indoor kayaking prototype:





On-Water Field Tests

Expert Kayaker

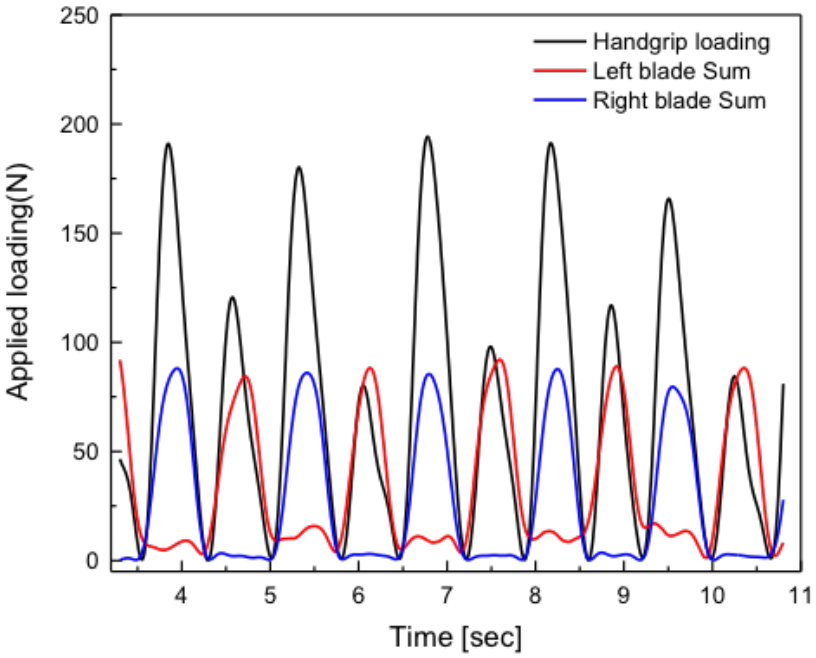


Recreational Kayaker

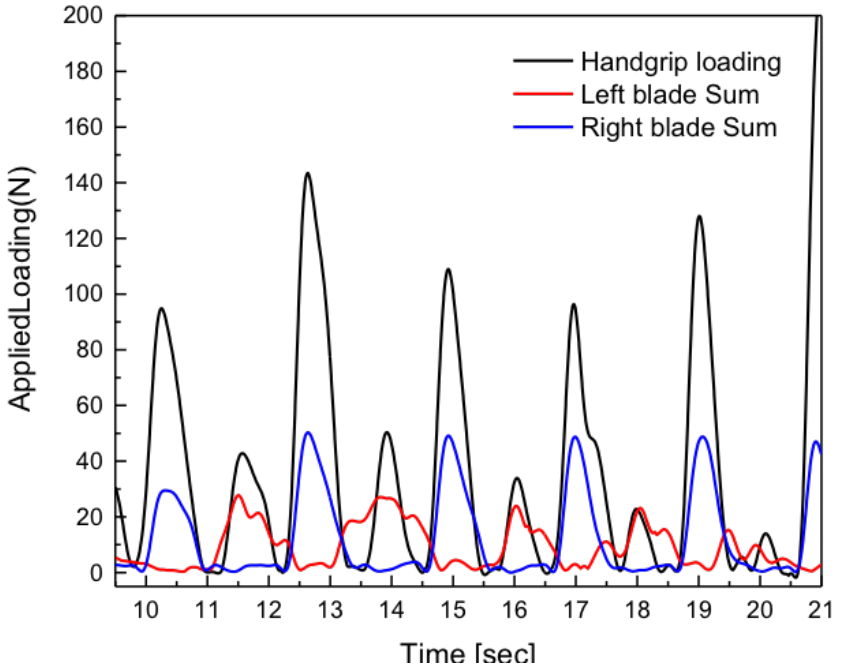


Results

Expert

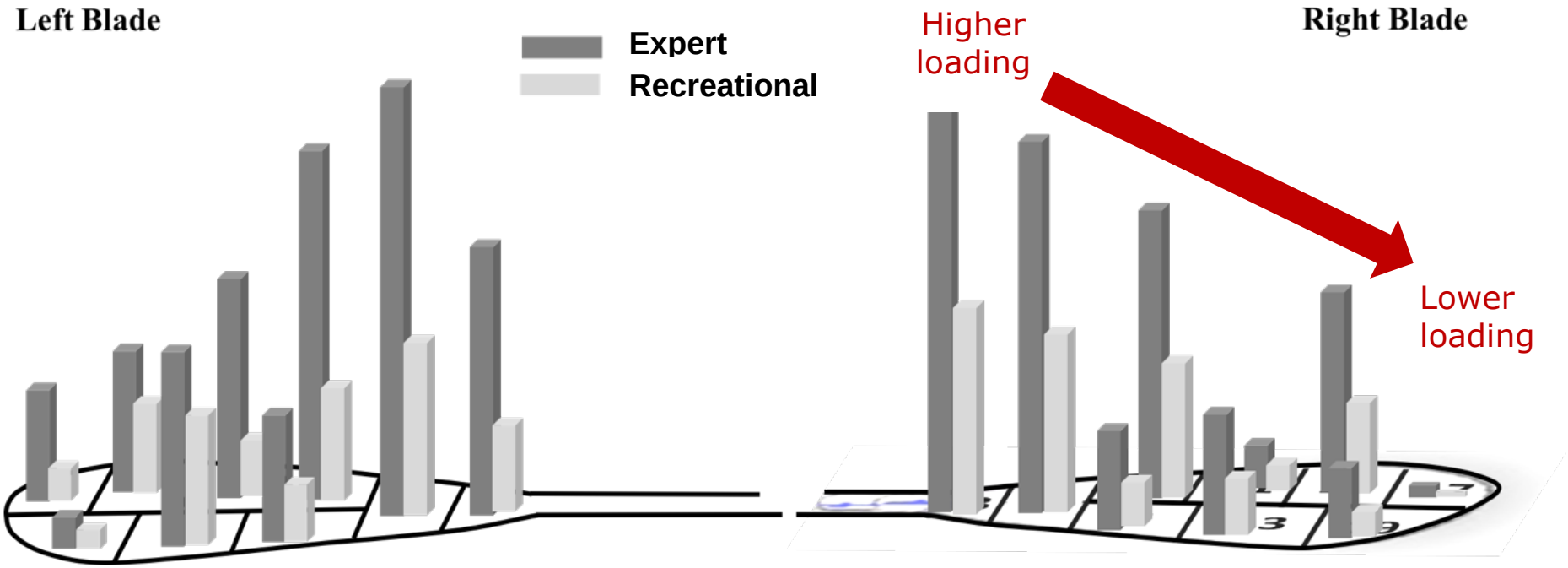


Recreational



Results

- Peak Force in difference blade areas



Conclusion

- Using optical fiber technology, we successfully developed a new kayak paddle that can measure ***load distribution*** on the blade.

- Potential Applications:
  - ✓ Monitor training load and evaluate athletes' performance
  - ✓ Select paddle blades
  - ✓ Guide future design of aquatic sports equipment

Lecture Summary

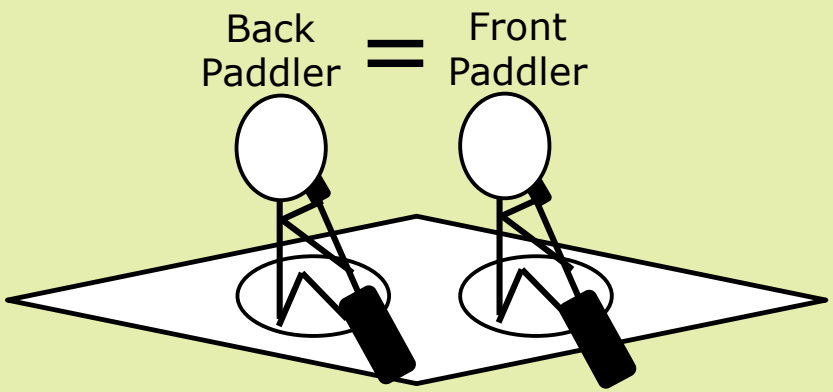
Summary

Application of instrumented paddles in measuring on-water kinetics

Use commercially available paddles



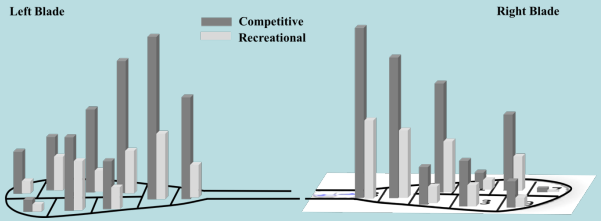
Paddling Force



Make our own paddles



Load distribution *(New!)*



Acknowledgements

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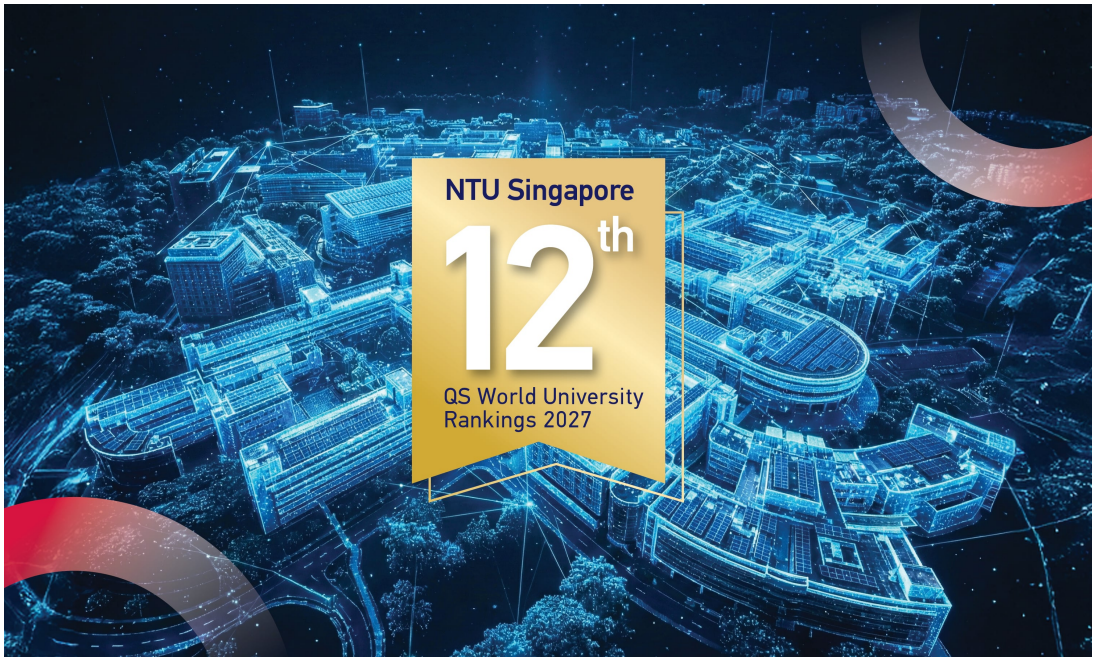
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