FORCE-ANGLE CHARACTERISTICS AND LEVEL OF COMPETITIVE REPRESENTATION IN ON-WATER ROWING

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The graphical presentation of the propulsive force applied by the oar to the pin, plotted against the oar horizontal angle, has been used as a diagnostic tool for rowing skill. How the pattern is related to variables such as level of competitive has not been well identified. Bivariate functional principal components analysis (*bf*PCA) was used on force-angle data to identify the main modes of variation in curves representing twenty seven female rowers of two different competition levels (Australian Domestic and Australian International level), rowing at 32 strokes per minute in a single scull boat. Discriminant function analysis showed strong classification of rowers using force-angle graphs across both sides of the boat, with increased rate of force development identified as an important characteristic for international rowers. Additionally for the bow-side, spending less time in the first half of the drive phase was also identified as an important feature for international rowers. The results of this demonstrate that there are potentially some common characteristics of the force-angle that are important for selection in international level sculling boats.

KEY WORDS: principal components analysis, shape, waveform, on-water.

INTRODUCTION: A range of studies have examined force characteristics measured at the oar handle, pin (oarlock) and the oar blade (Soper & Hume, 2004). These forces are usually represented graphically with force plotted either against time (Smith & Spinks, 1995) or against the horizontal angle of the oar (Spinks, 1996); and rowers have been descriptively identified by their distinctive shape or harmonic structure on such graphs. Despite commonalities and idiosyncratic differences in the continuous force "signatures", empirical research determining the specific importance of different shape characteristics and their relationship with performance is currently limited. There is much conjecture on what exactly constitutes a 'good' or 'bad' force shape, given that theoretical and experimental support for a range of different shapes exists (Kleshnev, 2006; Martin & Bernfield, 1980, Smith & Loschner, 2002). Functional data analysis (FDA) techniques such as bivariate functional principal components analysis (*bf*PCA) have been used effectively in the assessment of gender differences for these signatures in on-water rowing (Warmenhoven et al. 2015). This study aims to use *bf*PCA as a means of exploring potential differences in the propulsive pin force (PPF)-angle profile as a factor of level of competitive representation for a group of highly skilled female single scullers.

METHODS: Subjects: Following institutional ethical approval, data from twenty seven female subjects were analysed. The rowers consisted of highly trained heavyweight and lightweight scullers. Athletes were classified as Australian Domestic (AD) (*n* = 14), Australian International (AI) (*n* = 13) athletes according to their level of competitive representation in sculling boats.
Testing and Data Processing: Athletes were directed to row at four stroke rates in 250m steps (20, 24, 28, 32 Str min^{-1}), separated by one minute of light rowing. Ten strokes from the 32 Str min^{-1} data only were analyzed. The drive and recovery phases were identified using the horizontal angle of the oar (Smith & Loschner, 2002), and only the drive phase was analysed for this study. A linear length normalization strategy using an interpolating cubic spline was applied, normalizing each curve to 100% of the drive phase. An amplitude normalization (AN) technique was also applied, ensuring that variability described in the curves was only reflective of shape

characteristics independent of amplitude. For AN, force was converted to a percentage relative to each curve's maximum value. Similarly, horizontal oar angle was normalized to a percentage relative to the length of each drive phase. Both normalization formulas are below:

$$Force_{Norm(i)} = \left(\frac{Force_{(i)}}{Force_{(Maximum)}}\right) \times 100(\%) \qquad Angle_{Norm(i)} = \left(\frac{Angle_{(i)}}{Angle_{(Maximum)} - Angle_{(Minimum)}}\right) \times 100(\%)$$

The horizontal oar angle normalization strategy is expressed as a relative percentage of the drive phase length, but still preserves important information on where the oar is relative to the boat. An average curve created from each participant's ten strokes was used for further analysis.

***bf*PCA and Discriminant Analysis**: For *bf*PCA, B-spline basis functions were used for force-time and angle-time curves. A composite function was derived from the inner product of the bivariate functions. This composite function was then used to extract a set of bivariate functional principal components (*bf*PCs) and corresponding *bf*PC scores (Ramsay, 2006). A separate *bf*PCA was conducted for each side of the boat (bow-side and stroke-side). *bf*PC scores were input into separate stepwise discriminant function analyses (SDFA) for classification according to competition level. Univariate ANOVAs were also used in conjunction with SDFA to assess the significance of differences between *bf*PC scores for the competition levels.

Table 1: Descriptive statistics (*bf*PC scores means and standard deviations) univariate ANOVA results and linear discriminant function coefficients for discrete performance outcomes for comparison of *bf*PC scores across competition levels for both sides of the boat.

	International *bf*PC Mean (SD)	Domestic *bf*PC Mean (SD)	Discriminant Coefficients	*F* Value	Sig.
Bow *bf*PC1	8.48 (51.57)	-7.87 (31.82)	0.23	1.00	0.33
Bow *bf*PC2	11.18 (46.08)	-10.38 (45.16)	0.70	1.51	0.23
Bow *bf*PC3	7.88 (22.05)	-7.32 (26.03)	1.14	2.66	0.12
Bow *bf*PC4	6.61 (22.8)	-6.14 (18.74)	0.22	2.53	0.12
Bow *bf*PC5	12.17 (19.08)	-11.3 (21.32)	0.69	9.04	0.01
% Classified	76.9% (n = 10)	92.9% (n = 13)			
Stroke *bf*PC1	9.75 (42.88)	-9.06 (40.47)	0.28	1.38	0.25
Stroke *bf*PC2	10.24 (40.24)	-9.50 (31.58)	-0.48	2.03	0.17
Stroke *bf*PC3	1.68 (24.89)	-1.56 (23.81)	0.38	0.12	0.73
Stroke *bf*PC4	10.45 (21.20)	-9.70 (21.50)	1.14	6.00	0.02
Stroke *bf*PC5	3.85 (27.43)	-3.58 (23.75)	0.20	0.57	0.46
% Classified	69.2% (n = 10)	71.4% (n = 9)			

RESULTS: The first five *bf*PCs for bow-side and stroke-side force-angle curves accounted for 95.2% and 95.9% of all variance for bow side and stroke side curves respectively with each *bf*PC's individual contribution to this variation illustrated in Figure 1.

***bf*PCA and SDFA:** Univariate ANOVAs comparing *bf*PC scores between competition levels on the bow side of the boat revealed that scores for the fifth *bf*PC were significantly different ($p = 0.006$) between competition levels, with international rowers featuring more prominently as positive scorers. Discriminant analysis of bow side *bf*PC scores also showed that the third *bf*PC discriminated most strongly according to its canonical discriminant function coefficient (Table 1). The bow side *bf*PC score discriminant function model was able correctly classify 85.2% of all bow side force curves, with 76.9% of international athletes and 92.9% of national athletes being correctly classified using *bf*PCs for bow side force application.

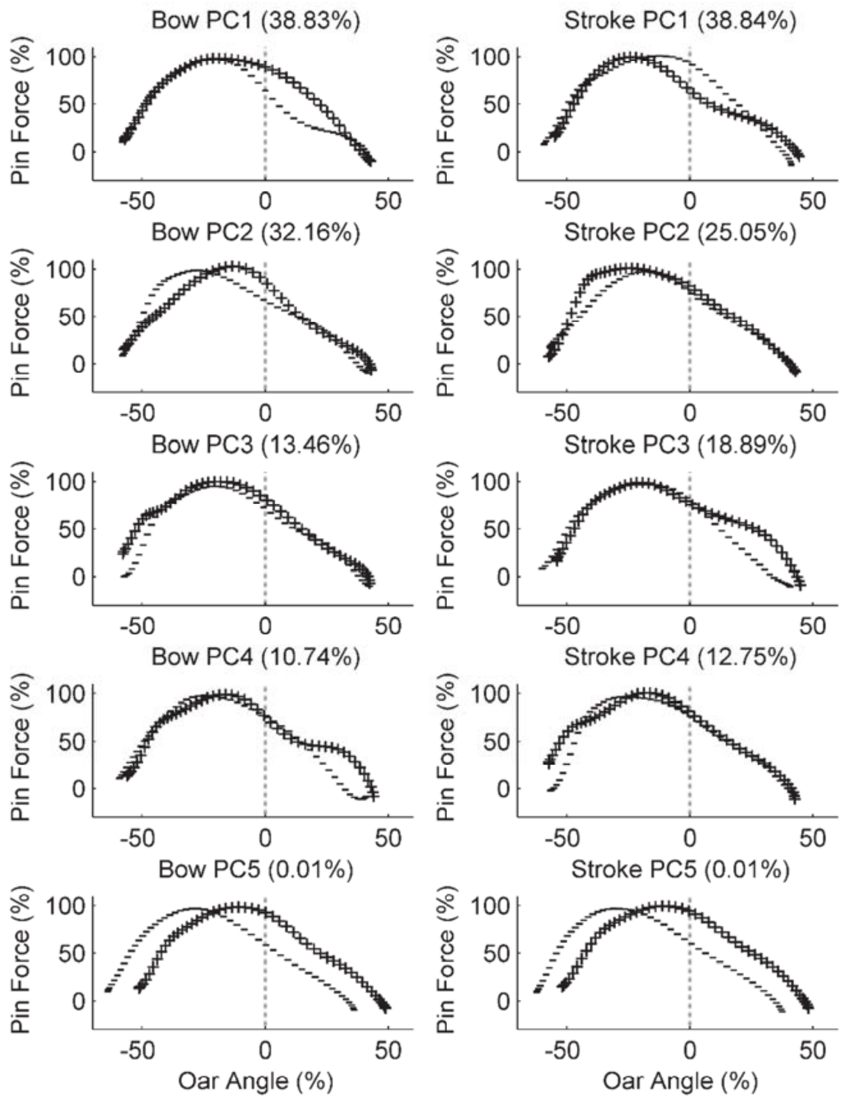

Figure 1: *bf*PC plots for each of the first five *bf*PCs for bow and stroke-side PPF-angle profiles. In plot positive scorers are more indicative of the '+' line and negative scorers the '–' line. *bf*PCs have been weighted as +/– 2 SD of the bfPC scores away from the mean function.

Univariate ANOVAs comparing *bf*PC scores between competition levels on the stroke side of the boat revealed that scores for the fourth *bf*PC were significantly different (p = 0.012) between competition levels, with international rowers featuring more prominently as positive scorers. Discriminant analysis of stroke side *bf*PC scores also showed that the fourth *bf*PC discriminated most strongly according to its canonical discriminant function coefficient (Table 1). The stroke side *bf*PC score discriminant function model was able correctly classify 70.4% of all stroke side force-angle curves, with 69.2% of international athletes and 71.4% of national athletes being correctly classified using *bf*PCs.

DISCUSSION: Irrespective of the side of the boat, discriminant function analyses of *bf*PC scores revealed rate of force development at the start of the drive phase as most important when examining differences between rowers as a factor of competition level, with the bow side discriminating more effectively than the stroke side of the boat. For the bow-side, spending less time in the first half of the drive phase was also identified as important, and alludes to a potential asymmetrical offset being present between the stroke side and bow side for rowers at a higher level of competition. This could be due in part to the different way that oars must move during the drive phase, as a consequence of how the boat is rigged for each athlete with the bow hand overlapping and sitting above the stroke side hand during the drive phase for this group of rowers (Smith & Loschner, 2002; Soper & Hume, 2004). The fact that this offset is only present on the bow side is also of interest given the ability to predict competition level using discriminant function analysis was different according to the side of the boat analysed. It is therefore important to establish whether consistent structural biomechanical offsets exist due to the boat rigging, influencing the need for rigid coordination structures, or whether a particular side of the boat, such as the bow side in the present study, often acts as a driver of motor pattern execution, with the other side acting more flexibly to account for steering of the boat and balance during skill execution. If the latter was true this would assist in explaining the larger amount of variability in the *bf*PC scores noted for the international level rowers for stroke side *bf*PC scores in the present study. Irrespective of the content of these findings, *bf*PCA has proven to be a powerful tool for assessing information in rowing biomechanics, particularly the novel adaptation for assessing the covariance structures that exist between the movements of the oar relative to the production of force. This allows for spatial application of force to be assessed empirically and any differences in these characteristics to be quantified between athletes.

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