TEST-RETEST RELIABILITY OF SELECTED ERGOMETER GRINDING PERFORMANCE MEASURES

Simon Pearson[1], Patria A. Hume[1], John B. Cronin[1], David Slyfield[2]

[1]Institute of Sport and Recreation Research New Zealand, AUT, NZ
[2]Emirates Team New Zealand, Auckland, NZ

Reliability of grinding performance on a custom-built ergometer was assessed using 18 highly trained America's Cup sailors. Sixteen grinding conditions varied by load, deck heel (tilt), and grinding direction (forward or backward) were examined. Performance measures were peak power (W) and external work over five seconds (kJ). Statistics were difference in mean (M_{diff}), standard error of measurement (SEM) and intra-class correlation coefficients (ICC). External work (SEM = 1.6-6.9%; ICC = 0.91-0.99) was more reliable than peak power (SEM = 1.3-9.6%; ICC = 0.84-0.99). Performance was more consistent when varied by load than by heel condition, and was most reliable in lighter load conditions. Within heel conditions, downhill-uphill tilt was more reliable than right-left tilt. Grinding direction did not appear to affect performance reliability.

KEYWORDS: grinding, reliability, performance, America's Cup, sailing.

INTRODUCTION: Grinding performance in America's Cup racing is an important determinant of overall boat speed. Grinding winches are responsible for the movement of the sails and therefore provide the power behind tacking and gybing (where the yacht crosses the wind to change direction). In addition the winches are used for trimming the sails which changes the angle the yacht is headed and the efficiency of wind usage.
To monitor the effects of various technique changes, training schemes or other performance enhancing interventions on grinding performance an instrumented grinding ergometer was built. When assessing the reliability of a testing procedure it is important that the assessment is as specific as possible to race conditions as there may be a number of factors that may alter the level and consistency of performance. With this in mind the ergometer (Dynapack, Wellington, New Zealand) was constructed using standard on-board grinding hardware to ensure familiarity for the sailors. Grinding performance can be influenced by a number of conditions such as grinding direction (forward or backward depending on what gear the winches are in), system resistance, and deck heel (tilt). System resistance (load on the grinding winches) increases with wind strength and sail position relative to wind direction, while heel is the sideways lean of the yachts' deck when sailing up-wind, which can increase with wind strength up to 25-30°. Deck heel was included in this study, as an area of research interest is the influence of deck-layout on grinding performance, in particular, what differences in performance there may be between grinding pedestals orientated fore-aft (resulting in left-right/medio-lateral tilt when grinding under heel conditions), and pedestals orientated across the boat (uphill-downhill/anterior-posterior tilt).
Quantifying trial to trial performance variation in grinding for each of these conditions is essential for monitoring performance. For a test to be valuable it must be specific enough to measure the variable of interest but also reliable enough to detect the relatively small differences in performances that are beneficial to elite athletes (Schabort *et al.*, 1999). A reliable test is one with small changes in the mean, a low standard error of measurement (SEM), and a high test-retest correlation between repeated trials (Hopkins *et al.*, 2001). The purpose of this study was therefore to quantify the variability in grinding performance under different load, direction, and heel conditions.

METHODS:
Data Collection: Ergometer testing was divided into two rounds on separate days (Load, Heel) for the effects on reliability of peak power (W) and external work over five seconds (kJ) for both forward and backward grinding. Male America's Cup sailors who performed grinding routinely participated in this study; 18 completed load testing and 9 completed heel testing

(due to availability). The grinding ergometer was set up with standard pedestal (870 mm vertical) and crank arm (250 mm) dimensions for a main sheet grinding pedestal on an America's Cup class yacht. Gearing for the ergometer was linked through a multiple-speed dynamometer set up to output a number of grinding performance measures. Ergometer hydraulic load was applied using a dynamic closed loop controller. For each round, the sailors completed a self-selected warm-up on the grinding ergometer, then a maximal trial of all conditions once within a single session, with the session repeated 5 hours later. All grinding trials were maximal effort, eight-seconds in length, and separated by a 3-5 minute rest period, with verbal “go” and “stop” signals the only in-trial feedback.

Round 1 - Load testing: Both forward and backward grinding were tested using three torque loading conditions; 39 Nm (Light), 48 Nm (Moderate), and 68 Nm (Heavy). All 18 sailors completed the light and moderate loads but due to the physical requirements for grinding effectively at the heavy load only the six sailors regarded as primary grinders completed the heavy load condition. Load conditions were randomised, with trials alternating between forward and backward grinding to reduce the possible influence of fatigue by alternating the prime-mover muscle groups. The session was completed in 40 minutes.

Round 2 - Heel testing: Forward and backward grinding performance of nine sailors was tested for five heel conditions: Flat (0°), downhill (grinding from above the pedestal with 25° deck heel), uphill (from below at 25°), right (with right side of the body on the high-side of the pedestal at 25°), left (left side high at 25°). All conditions were against the same 45 Nm load. The 25° angle was selected as an upper range heel angle experienced in racing conditions, and angles were verified for the ergometer platform using a SmartTool™ digital spirit level (M-D Building Products, Oklahoma, USA). Heel condition order was randomised, with trials alternating between forward and backward. The session was completed in 60 minutes.

Data Analysis: Descriptive statistics for all variables are represented as mean and standard deviations. Data for external work (kJ) and peak power (W) were log transformed to provide measures of reliability as standard error of measurement (SEM). Intra-class correlation coefficients (ICC) were calculated. Presence of significant systematic discrepancy between reliability measures of different conditions was determined using a two-tailed unpaired *t*-test.

RESULTS: There were small changes in the group means for peak power and external work performed under all directional and loading conditions (see Table 1). Average SEM across all conditions was similar for external work and peak power (3.1 and 3.3% respectively) but less variation was observed for external work (1.6-3.9%) than peak power (1.3-5.4%). SEM tended to increase with load for both forward and backward grinding.

Between-test differences in mean peak power and mean external work were larger for heel direction testing (0 to 4.3%) than for load testing (0.1 to 2.1%). SEM was lower for external work than peak power in seven of the ten conditions, and on average (external work = 5.5%, peak power = 6.1%). External work SEM (4.6-6.9%) was less variable than peak power SEM (3.5-9.6%). SEM was significantly greater in right-left heel conditions than uphill-downhill heel conditions for both peak power ($p = 0.028$) and external work ($p = 0.030$) (Table 3). Test-retest intra-class correlation coefficients were all 0.92 or greater.

Table1. Reliability of grinding performance during different load conditions.

Grinding condition	*Test 1* Mean ± SD	*Test 2* Mean ± SD	M_{diff}	SEM	ICC
Peak Power (W)					
Back – Light 39 Nm	650 ± 51	673 ± 58	-0.1%	1.3%	0.98
Back – Moderate 48 Nm	609 ± 135	604 ± 132	-0.7%	3.1%	0.98
Back – Heavy 68 Nm	796 ± 134	797 ± 112	0.4%	4.2%	0.93
Forward – Light 39 Nm	722 ± 59	729 ± 55	1.1%	1.6%	0.96
Forward – Moderate 48 Nm	697 ± 140	683 ± 136	-2.1%	4.2%	0.96
Forward – Heavy 68 Nm	913 ± 128	929 ± 100	2.1%	5.4%	0.84
External Work (kJ)					
Back – Light 39 Nm	90.3 ± 6.2	94.2 ± 8.9	-0.5%	1.6%	0.96
Back – Moderate 48 Nm	79.5 ± 16.6	79.5 ± 16.9	-0.2%	3.9%	0.97
Back – Heavy 68 Nm	108.3 ± 16.1	109.5 ± 16.1	1.2%	3.7%	0.95
Forward – Light 39 Nm	100.9 ± 8.4	101.5 ± 8.5	0.7%	2.6%	0.91
Forward – Moderate 48 Nm	88.3 ± 17.2	89.9 ± 17.9	1.1%	3.5%	0.97
Forward – Heavy 68 Nm	124.2 ± 16.5	125.8 ± 13.7	1.5%	3.7%	0.92

Note: n=18 sailors except n=6 for heavy load conditions.

Table 2. Reliability of grinding performance during different heel conditions at a load of 45 Nm (n=9 sailors).

Grinding condition	*Test 1* Mean ± SD	*Test 2* Mean ± SD	M_{diff}%	SEM%	ICC
Peak Power (W)					
0° – Back	635 ± 231	620 ± 239	3.3	6.1	0.97
25° – Back, Downhill	559 ± 181	533 ± 157	-4.1	5.9	0.96
25° – Back, Uphill	612 ± 237	625 ± 234	2.6	5.0	0.98
25° – Back, Right	587 ± 196	593 ± 197	1.0	9.6	0.92
25° – Back, Left	617 ± 227	604 ± 202	-1.0	6.8	0.96
0° – Forward	717 ± 292	719 ± 282	0.6	6.1	0.98
25° – Forward, Downhill	656 ± 230	681 ± 264	2.6	4.3	0.99
25° – Forward, Uphill	702 ± 290	734 ± 312	3.9	3.5	0.99
25° – Forward, Right	662 ± 245	677 ± 229	1.6	7.5	0.96
25° – Forward, Left	680 ± 251	684 ± 267	0.0	6.0	0.98
External Work (kJ)					
0° – Back	81.4 ± 32.7	80.1 ± 30.6	-0.9	4.6	0.99
25° – Back, Downhill	68.7 ± 23.5	68.6 ± 22.7	0.2	5.0	0.98
25° – Back, Uphill	78.3 ± 29.9	80.7 ± 32.2	2.4	4.7	0.99
25° – Back, Right	74.0 ± 23.8	76.5 ± 27.5	2.3	5.8	0.97
25° – Back, Left	81.0 ± 30.3	77.7 ± 26.2	-3.0	6.8	0.97
0° – Forward	90.8 ± 37.5	90.6 ± 35.1	0.6	4.8	0.99
25° – Forward, Downhill	84.6 ± 28.5	89.9 ± 35.2	4.3	4.8	0.98
25° – Forward, Uphill	90.6 ± 34.6	93.7 ± 40.9	1.2	5.9	0.98
25° – Forward, Right	86.6 ± 31.5	89.5 ± 36.3	1.8	6.9	0.97
25° – Forward, Left	84.7 ± 30.5	86.2 ± 33.9	1.0	5.7	0.98

DISCUSSION: Variation in grinding performance was small across all load conditions, with the least variation observed with light load backward grinding and the most variation with heavy load forward grinding. Performance became increasingly more variable in both forward and backward grinding as load increased. A similar pattern was seen in the ICC's with the relative consistency of performance between individuals decreasing as load increased. An additional factor which affected the apparent variability at heavier load grinding was the fewer subjects completing the trials at the heavy load compared to the moderate and light loads. As heavy load trials only included the most accomplished grinders the standard deviation for the heavy load conditions was lower than for the moderate load conditions, however, the low statistical power associated with low subject numbers led to a higher SEM. Nevertheless, based on current results a change in external work of over 4% or a change in peak power of over 5.5% can be interpreted with a fair degree of certainty under any loading condition.

Testing at different heel angles was considerably more variable than at different loads on a flat (0°) heel. Although the difference in the mean was never more than 5% for any heel condition, SEM varied from 3.5% (forward grinding from below at 25°) to 9.6% (backward grinding, right-hand side high at 25°) for peak power and between 4.6% (backward grinding at 0°) and 6.9% (forward grinding, right-hand side high at 25°) for external work. Performance changes can therefore only be interpreted with any confidence if they are over 7% for external work or 10% for peak power. While in some circumstances a standard error of measurement under 10% may be considered small (Bennell *et al.*, 1999), it is important to interpret levels of error in their relevant context, and in the case of America's Cup grinding performance a level of closer to 5% is more appropriate. Higher variability in the heel testing compared to the load testing is likely to be a result of a reduction in base of support stability when shifting from a flat to a tilted surface. However, reliability could be improved with development of the testing protocol. The heel testing sessions involved 10 maximal grinds at a moderately heavy load making it a more intensive session due to the volume of work performed. By altering the number of grinds performed and/or recovery time the influence of fatigue and performance variability may be reduced. This contention is supported by the greater variability in both the forward and backward flat conditions within the heel testing when compared to a similar condition in the load testing (forward and back, moderate load) where grinders performed only four to six grinds. The influence of either physiological or mental fatigue from the longer session may have affected reliability.

While there is little difference in reliability between external work (kJ) and peak power (W) when grinding load and direction are varied, peak power is substantially less reliable when deck heel is involved. While there was little difference between the ICC values overall, only five of the total 16 conditions tested had a lower level of absolute variability (SEM) in peak power than external work. While a high correlation indicates good repeatability in terms of relative rankings, the ability to accurately quantify absolute changes in performance is generally more important when examining the effect of any kind of intervention.

CONCLUSIONS: External work appears more reliable than peak power as a means of quantifying grinding performance, although peak power may still be useful in flat heel conditions. Using current protocols the SEM for external work was up to 4% in different load conditions and up to 7% for heel conditions. A change of 5-10% in grinding performance would be considered substantial and therefore it would be beneficial to improve the precision of measurement, especially in terms of heel condition testing, in order to be confident of detecting changes of a smaller magnitude. External work is more appropriate for assessment of grinding performance than peak power as it is important to the performance of the boat for power output to be maintained over a period of time.

REFERENCES:

Bennell, K., Crossley, K., Wrigley, T., and Nitschke, J. (1999). Test-retest reliability of selected ground reaction force parameters and their symmetry during running. *Journal of Applied Biomechanics,* **15**, 330-336.

Hopkins, W., Schabort, E. J., and Hawley, J. A. (2001). Reliability of power in physical performance tests. *Sports Medicine,* **31**, 211-234.

Hull, M. L., & Gonzalez, H. (1988). Bivariate optimization of pedalling rate and crank arm length in cycling. *Journal of Biomechanics, 21*(10), 839-849.

Schabort, E. J., Hawley, J. A., Hopkins, W. G., and Blum, H. (1999). High reliability of performance of well-trained rowers on a rowing ergometer. *Journal of Sport Sciences,* **17**, 627-632.