AMERICA'S CUP GRINDERS' POWER OUTPUT CAN BE IMPROVED WITH A BIOMECHANICAL TECHNIQUE INTERVENTION

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Grinding provides the power behind tacking and gybing, where the yacht crosses the wind to change direction. This study evaluated the effect of a technique intervention on grinding performance. Ten America's Cup grinders were assessed, via videoed joint kinematics and grinder ergometer power output, before and after a technique intervention based on biomechanical principles. Anthropometric measures were obtained from each grinder using ISAK protocols. Maximal strength was assessed using 1 RM bench pull. The intervention produced a 4.7% increase in mean power output ($p = 0.012$). Regression analysis indicated predictors for grinding performance were COM_x position and maximal strength.

KEY WORDS: America's Cup, sailing, grinding technique, performance, anthropometry, kinematics

INTRODUCTION: Grinding in America's Cup sailing provides the power for tacking and gybing, where the yacht crosses the wind to change direction, and is also used for trimming the sails. Grinding is integral to the performance of the yacht, in particular in tacking duels (Armitage, 1997).

The grinding set-up consists of two components: the mechanical grinding pedestal and the sailor who operates the equipment. The effectiveness of the mechanical grinding set-up is determined by the amount of torque produced at the grinder hub, where the drive created at the handles is then transferred to produce movement of the sail lines. Performance of the grinder operator is best defined by the amount of power that can be produced using a given set-up. Hull and Gonzalez (1988) defined power for a cyclic movement as the product of applied force, length of the crank arm and angular velocity of the movement ($P = F \times L \times \omega$).

There are currently no guidelines for grinding technique, which therefore, increases the possibility of improving force output through a technique intervention. Backwards grinding was chosen as the test condition in this study due to greater variation in technique compared to grinding forwards (Pearson, 2003). This suggests that the backward grinding movement is generally less refined and operators may derive more benefit from a technique intervention. High load performance was chosen as it has the greatest effect on how the boat performs and also produces greater variation in technique than low load. The technique intervention was based on two guiding principles:

Body mass is a major contributor to the force produced against the handles. By placing the body into a more extended position and increasing the distance between the axis of rotation (grinder hub) and the body's centre of mass (COM) the effective lever arm would be increased, thereby improving the torque produced.

Lowering the body position will allow a flatter and, therefore, more efficient line of pull (not having to work against gravity) and will also increase the potential contribution of body mass to the main pull phase.

METHODS: Ten male America's Cup grinders from the Team New Zealand syndicate for the 2003 America's Cup participated in this study. Subjects were measured for height (cm), body mass (kg), 1 RM bench pull strength (kg) both pre- and post-intervention. The six-day training period consisted of three one-hour technique adaptation sessions. In the testing sessions each subject was required to perform four trials of backward grinding under a high load (250 W). Each trial was maximal and sustained over a period of eight seconds, with a 5 min rest between each trial. After baseline testing, each subject was given individual instructions as to how their grinding technique might be improved focussing on trunk position relative to the grinding pedestal. Subjects were also provided general instruction as well as real-time verbal and visual feedback. Over the intervention period subjects were given correctional instruction relating to the position of their shoulders, hips, and trunk lean according to the performance model. Following the intervention subjects were re-tested for changes in performance, with comparative kinematic video analysis (25 Hz, sagittal plane) of the test and re-test sessions being used to determine whether recommended changes were implemented. Power output data were sampled at 40Hz with peak power (W) and work over a 5 s period (J) following peak power comprising the variables of interest.

Analysis: Relationships between continuous variables were analysed using the coefficient of variance (CV) procedure in SAS. Relationships between a continuous dependent variable and a discrete or classification variable were analysed using analysis of variance (using the Proc-mixed procedure in SAS). The Student paired t-test (two-way) was utilised to test for significance between each dependent variable in the pre and post-intervention test results for kinematic variables, grinding performance, strength scores, and body weight. The significance level was set at $p < 0.05$ for all tests.

RESULTS: Changes in the primary kinematic variables (COM and shoulder position) are displayed in Table 1. Average force vectors (relative to the grinder hub) were calculated as descriptors of mean COM and shoulder joint position. COM and shoulder position both increased in horizontal distance, while a decrease in vertical distance from the grinder hub was recorded across the group. This corresponded to an increase in vector magnitude and a decrease in vector angle for COM and shoulder.

Table 1 Pre-intervention to post-intervention changes in COM and shoulder joint vectors (from grinder hub) and ranges of motion.

	Variable	Pre	Post	Change	Change (%)	p-value
COM	Position$_x$ (m)	0.38	0.42	0.04	9.0%	0.004
	Position$_y$ (m)	0.04	0.00	-0.04	N/A*	0.013
	Vector magnitude (m)	0.47	0.50	0.04	8.4%	0.018
	Vector angle (°)	4.0	-2.2	-6.2	N/A*	0.027
Shoulder	Position$_x$ (cm)	0.34	0.41	0.08	23.0%	0.001
	Position$_y$ (cm)	0.34	0.30	-0.04	13.0%	0.010
	Vector magnitude (cm)	0.67	0.68	0.01	0.8%	0.432
	Vector angle (°)	45.7	35.6	-10.1	-22.1%	0.002

*Note: The calculation of a percentage change is inappropriate when the actual change crosses the value of 0.

Effects of technique changes on performance: Analysis of power output during grinding performance revealed a significant ($p = 0.012$) mean improvement of 4.7% with a range of -4.0% to 15.0% post intervention. Of the 4.7% average improvement in grinding performance displayed across the group, 2.0% ($p = 0.166$) was explained by changes in the horizontal displacement of COM (COM$_x$) from the grinding pedestal. The relationship effect was a 0.54% ($p = 0.066$) improvement in performance per 1.0 cm increase in COM$_x$ distance from the hub. The hub to shoulder vector angle (pull angle), explained only 0.39% ($p = 0.088$) of the group performance improvement, with a relationship of 0.03% ($p = 0.840$) increase in performance per 1.0 degree decrease in pull angle.

Effect of individual characteristics: The interaction of individual characteristics with technique and performance is displayed in Table 2. Relationship of a characteristic with performance is shown per unit of measurement. The effect of a characteristic on how a kinematic/technique variable influences performance is shown per 1.0 SD of the individual characteristic (height = 7.2 cm; body mass = 8.9 kg; 1RM bench pull = 10.6 kg).

Table 2 Effect of individual characteristics on technique and performance.

	Height (cm)	Body mass (kg)	1 RM Bench Pull (kg)
Relationship with performance (per unit)	0.29% (p = 0.225)	0.33% (p = 0.068)	0.23% (p = 0.144)
Effect on COM_x influence (per SD)	0.12% (p = 0.249)	0.13% (p = 0.207)	0.26% (p = 0.008)
Effect on Pull Angle influence (per SD)	0.06% (p = 0.465)	0.07% (p = 0.336)	0.15% (p = 0.043)

DISCUSSION: One of the most prominent findings from this study was the amount of individual variation in response to the technique intervention. The performance response was generally positive, but there was a large range of performance change amongst the individuals and the mechanisms for these changes did not always appear to be consistent. This suggests that the six days of intervention training may not have been sufficient for some individuals to correctly learn a new technique.

Effects of grinding technique changes on grinding performance: A significant change in power output over the 5 s period (4.7%, p = 0.012) was observed, confirming that the technique intervention was effective in improving grinding performance. A 5% performance improvement in elite-level physical competition is generally considered to be a substantial increase. In practical terms a 5% increase in grinding power output would allow sails to be positioned in a shorter time, maximising wind usage and allow the boat to gain an advantage by reducing the detrimental loss in boat speed associated with tacking or gybing. While the average performance change was a 4.7% increase, there were individual variations in post-intervention performance. As with most sporting activities there will be a certain amount of natural performance variation from day to day, with the results from pilot testing showing variation for this protocol to be 2%-3%. Eight of the ten subjects showed changes of greater than 3%, while some improved by over 10%.

COM_x position was expected to influence grinding performance. The distance between the COM and the grinder hub represents the length of the effective lever arm for the application of body weight at the handles. Increasing this distance should improve the ability of body weight to affect the rotation of the handles and, therefore, improve power output/performance. Changes in COM_x position accounted for approximately 40% of the improvement in performance (2.7% of the mean 4.7% change). The relationship between the two measures showed a 0.54% improvement in performance for every 1.0 cm increase in COM_x distance from the hub.

Angle of pull was also expected to have an effect on grinding performance, such that decreasing this angle might potentially increase the proportion of total body weight contributing to the movement. In addition, any adverse effects of gravity would be decreased as the main pull phase became more horizontal. However, adding shoulder vector angle into the model only reduced the unexplained effect of the intervention by 8%.

Interaction of individual characteristics with technique and performance: Body weight figured prominently in the design of the technique intervention, with both the increase in COM-to-pedestal distance and decrease in pull angle intended, to improve the contribution of body weight to the main pull phase. An examination of this relationship showed a performance increase of 0.33% (p = 0.068) for every 1.0 kg of body weight above the group mean. Body weight also demonstrated a positive relationship with the effect of technique changes, as represented by COM_x position and pull angle. Therefore, a grinder operator of average body weight (104 kg) could expect approximate 2.2% improvement in performance from 4.0 cm change in COM_x position. Similarly, a grinder operator who was 1 SD heavier than the average (113 kg) might expect a 2.7% improvement. While these effects are not particularly large or statistically significant, the results indicate that increased body weight has a positive influence on the effect of the technique intervention.

Operator height was also expected to demonstrate a positive relationship with performance. Thus, a tall individual with relatively longer limbs ought to attain a greater COM distance, a longer effective lever arm, and better performance than an individual of lesser stature. This theory was supported by the analysis, whereby a 0.29% ($p = 0.225$) increase in performance per 1.0 cm increase in height was found.

Maximal strength had been shown in pilot tests to have a strong relationship with high load grinding performance. Post-intervention analyses showed a linear relationship between predicted bench pull 1 RM and grinding performance with a 0.23% ($p = 0.144$) performance increase per 1.0 kg of 1 RM strength (2.4% change per SD). While this result was not as conclusive as that in the pilot study ($p < 0.001$), it does support the close relationship between these variables. A 1 SD (10.6 kg) increase in 1RM bench pull score resulted in performance improvements of 0.26% ($p = 0.008$) for every 1.0 cm increase in COM_x. A likely reason for the influence of strength on COM_x effectiveness is the change in positioning of the muscles at the shoulder. Moving the COM_x position back will result in an increased shoulder angle, putting the muscles used in the main pulling into a more optimum position for creating force. Strength curves for shoulder extension in males have been shown to peak at 90-100° (Campney & Wehr, 1965). Since the increase in shoulder angle seen in this study brought the shoulder angle closer to 90° it should be expected for this adjustment to improve the muscular force production. Therefore, stronger individuals will benefit more from an increase in COM_x distance from the hub. Moving the COM_x position further back will also put the muscles across the back of the shoulder joint (those primarily responsible for the main pulling movement) into a greater state of stretch.

CONCLUSION: The technique advocated in this study was effective in improving performance on a land-based grinding ergometer. We recommended that sailors should employ these techniques during on-water grinding and that analysis of grinding technique on-water is conducted.

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