ANTHROPOMETRY AND STRENGTH PREDICTORS OF GRINDING PERFORMANCE IN AMERICA'S CUP SAILORS

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This study aimed to determine what anthropometric and strength factors could predict performance in America's Cup grinding. Eleven male America's Cup sailors were measured for 42 anthropometric dimensions, and bench pull strength, and their power output was obtained from repeated eight-second maximal bursts of high load backwards grinding. Strength and body mass had the highest relationships with grinding performance. Stepwise regression analysis indicated that strength was the major determinant in grinding ability, explaining 64% of the known variance in grinding performance. Total arm length and total leg length were the best anthropometric predictors of performance, each explaining 9% of the remaining variance.

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

INTRODUCTION: Grinding set-up on an America's Cup yacht consists of two components: the mechanical grinding pedestal and the sailor who operates the equipment. The exterior of the grinder consists of the grinding pedestal, which projects 87 cm up from the floor, and two large hand cranks which are orientated at 180 from each other, one on either side of the pedestal. Handles are situated at the end of the crank arms making the overall set-up similar to an upper limb bicycle. Grinding drives the winches attached to the sail lines, which are responsible for sail movement - the propulsive force behind the yacht. A large amount of resistance is placed on the grinder system due to the many tonnes of pressure held in the sails. As a result, it can be very difficult to turn the cranks even with the different gears available through the grinder. Given that large amounts of force need to be produced in a short period of time (single tack), and repetitively over the course of a race, the efficiency of the grinding set-up can have a significant effect on the overall performance of a boat.

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. Torque is the ability of an applied force to cause a rotation around an axis, and is defined by the force applied and its distance from the axis of rotation (T = F x d). However, the performance of the human component or grinder operator is best defined by the amount of power that can be produced using a given set-up. Hull (1988) defined power for a cyclic movement, such as the one previously described, as the product of applied force, length of the crank arm and angular velocity of the movement (P = F x L x). Applied force in both of these formulae is mainly dependent on the human component of the set-up and would therefore be affected by factors such as body mass, neuromuscular control (strength/coordination), height, and lever lengths. However, force production by the operator will also be affected by mechanical components like the height of the grinding pedestal and length of the crank arms in relation to the dimensions of the grinder operator. The distance from the point of force application to the axis of rotation (d) and the length of the crank arm (L) are essentially the same variable. This is due to the distance from the axis of rotation (grinder hub) to the point of force application (handles) being determined in the grinder set-up by the length of the mechanical crank arm. Angular velocity is the speed at which the grinder hub rotates, and as such is determined by the interaction between the mechanical grinder and the grinder operator.

Anthropometric characteristics, reflecting body shape, proportionality and composition, can suggest a functional advantage in some sports (Norton & Olds, 1996). In Olympic weightlifting the shorter more mesomorphic body builds dominate the snatch and clean and jerk events.

The biomechanics of grinding may make the distinction between grinder's body types less apparent with anthropometric measures having a possible effect on grinding performance directly, or as a result of influence on technique.
Brachial index is a measurement of forearm length relative to upper arm length (BI = radius length/humerus length*100) and is reported to influence leverage properties of the upper limb (Norton & Olds, 1996), and therefore force applied by the hands. A relatively shorter upper arm should allow the hand to travel in a more linear path and therefore reducing "wasted" lateral forces, a belief which is given support by the research of Hahn (1990) on rowing.
Body mass is expected to have a positive relationship with grinding performance because additional mass can be used to apply more force to the handles. While the effectiveness of any additional mass will vary according to technique, there should still be an inherent benefit for heavier grinder operators, not least because of its association with strength. Variations in maximal strength have been found to explain up to 50% of variation in grinding performance under high loads, and while strength has a significant neural component it generally increases as a function of body mass to the power of two thirds (Ross & Ward, 1984). Upper leg length (greater trochanter to lateral tibial condyle), total leg length (greater trochanter to floor), sitting height, and total arm length (acromion to radial styloid process) are also thought to influence grinding performance as they will affect the distance an individual can stand from the grinding pedestal. Increasing the distance of the centre of mass from the point of force application should result in an increase in torque and improve performance, i.e., that longer limbs should be beneficial to grinding performance.
In summary, an individual's anthropometry or physical characteristics are likely to influence their grinding performance, both through force generation and helping to determine the length of the effective lever arm. This study aimed to determine what anthropometric and strength dimensions could predict grinding performance in America's Cup Sailing.

METHODS: Eleven male America's Cup grinders were measured for 42 anthropometric dimensions using International Society for the Advancement of Kinanthropometry (ISAK) protocols (Norton & Olds, 1996), with measures taken by an ISAK level 2 accredited anthropometrist. Bench pull was measured using 1RM. Grinding performance was determined by average power output from two repeated eight-second maximal bursts of high load backwards grinding performed on an instrumented grinding ergometer. None of the grinders were injured at the time of the testing and they were free of anabolic hormones as indicated by random drug tests performed as part of the America's Cup competition. All grinders gave written informed consent prior to measurement.
Analysis: Means and standard deviations were calculated for all variables (see Table 1). Relationships between individual characteristics and grinding performance were analysed using Pearson correlation coefficients (see Table 2). Influence of individual characteristics, based on theoretical potential effects, on grinding performance was examined using a stepwise linear regression (see Table 3).

RESULTS: The results from all analyses are displayed in Tables 1-3.

Table 1 Descriptive statistics for variables of interest.

	Mean	Std. Deviation	N
GRIND PERF (kJ)	50536	7020	11
ST HEIGHT (cm)	188.0	7.0	11
UPPER LEG (cm)	51.3	2.5	11
TOTAL LEG (cm)	100.9	4.5	11
SIT HEIGHT (cm)	90.8	4.8	11
TOTAL ARM (cm)	64.3	2.4	11
BRACH IND (%)	80.0	2.4	11
BODY MASS (kg)	104.4	8.5	11
BENCH PULL (kg)	116.4	9.8	11

Table 2 Pearson correlations between individual characteristics and grinding performance.

	GRIND PERF	STAND HEIGHT	UPPER LEG	TOTAL LEG	SITTING HEIGHT	TOTAL ARM	BRACH INDEX	BODY MASS
GRIND PERF	1							
ST HEIGHT	.608(*)	1						
UPPER LEG	.217	.682(*)	1					
TOTAL LEG	.529	.933(**)	.850(**)	1				
SIT HEIGHT	.384	.789(**)	.491	.676(*)	1			
TOTAL ARM	.583	.917(**)	.688(*)	.873(**)	.535	1		
BRACH IND	-.062	-.572	-.702(*)	-.616(*)	-.567	-.518	1	
BODY MASS	.682(*)	.765(**)	.559	.757(**)	.685(*)	.598	-.441	1
BENCH PULL	.800(**)	.516	.271	.556	.429	389	.070	.660(*)

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Table 3 Stepwise linear regression examining the influence of individual characteristic variables on heavy load grinding performance.

Model	R	R Square	Adjusted R^2	Std. Error of the Estimate	Change Statistics R^2 Change	F Change	df1	df2	Sig. F Change
1	.800(a)	.640	.600	4441.7	.640	15.980	1	9	.003
2	.853(b)	.727	.659	4099.3	.087	2.566	1	8	.148
3	.903(c)	.816	.736	3604.0	.088	3.350	1	7	.110
4	.931(d)	.866	.777	3314.0	.051	2.278	1	6	.182
5	.938(e)	.880	.759	3446.0	.013	.549	1	5	.492
6	.942(f)	.887	.717	3736.9	.007	.252	1	4	.642
7	.952(g)	.906	.687	3928.3	.019	.620	1	3	.489
8	.954(h)	.911	.553	4692.3	.005	.103	1	2	.779

Order of predictor entry: bench pull, total arm, total leg, body mass, brach ind, sit height, stand height, upper leg

DISCUSSION: Some characteristics may help determine whether an individual will be good at grinding. Strength has been previously shown as a having a significant relationship with high load grinding performance (Pearson, 2003), a result supported by the findings of this study. One-repetition maximum bench pull scores correlated highly with grinding performance ($r = 0.800$; $p<0.01$) and accounted for 64% of the known variance in high load backward grinding performance. Although the finding that strength is the major determinant of high load grinding performance is important, strength is also, to a certain extent, a trainable characteristic. A major purpose of this study was to identify anthropometric characteristics that could help in talent identification of those who may be predisposed to better grinding performance. If the essential structures are already in place, then strength training can help to improve what is already an efficient physical set up for grinding.

Once the influence of strength is taken into account, the anthropometric variables with the greatest effect on grinding performance were total arm length and total leg length which each explained an additional 9% of the variation in grinding performance on top of the 64% explained by strength. This finding is consistent with the theory that longer limbs will enable a greater distance from the individual's centre of mass to the point of force application, increasing the effective lever arm and therefore torque, which in turn corresponds to an improvement in grinding performance. An added benefit of greater limb length in terms of talent identification is the association with strength development. Brechue (2002) examined the role of free fat mass accumulation and skeletal muscle architecture in competitive powerlifting performance by 20 US male elite powerlifters. Fat free mass was strongly correlated to the lift performances ($r = 0.86$-0.95, $p<0.001$), while greater fascicle lengths were associated with greater fat free mass accumulation ($r = 0.59$-0.63, $p < 0.01$) and powerlifting performance ($r = 0.45$-0.56, $p < 0.05$). Brechue (2002) concluded that greatest absolute powerlifting performance was limited by fat free mass accumulation in elite powerlifters. There was also a linear relationship between height and fat free mass until a height of approximately 1.7 m where the relationship appears to level off. As total arm and total leg length are highly correlated with height ($r = 0.917$, $p<0.01$ and $r = 0.933$, $p<0.01$ respectively) and longer segments are associated with greater fascicle length, longer total arm and total leg lengths would appear to have a benefit not only in terms of leverage, but also in terms of fat free mass and strength development.

Body mass was expected to have a positive relationship with high load backward grinding performance due to potential force application benefits of additional body mass. There was a significant relationship between body mass and grinding performance ($r = 0.682$; $p<0.05$) that explained 5% of the variation in grinding performance, after the 64% contribution from the bench pull score. The low level of body mass effect is likely due to the close relationship between bench pull strength and body mass ($r = 0.660$; $p<0.05$), which has been previously document in other athletic populations. The additional 5% of performance explained by body mass independent of the strength association indicates that body mass itself is beneficial to grinding performance in terms of technique, and in particular force application.

Standing height, upper leg length, sitting height, and brachial index were the other anthropometric variables included in these analyses on the basis that they may help predict grinding performance, however, their influence in the model was minimal. For height it seems likely that any influence on grinding performance variation would have been largely dissipated by the presence of total arm length and total leg length in the model, both of which are highly correlated with standing height. The same masking effect may also have occurred with upper leg length and sitting height, although the relationships between these two variables and the main predictor variables were only moderate at best, and therefore the influence of upper leg length and sitting height on grinding performance is still likely to be minimal. Brachial index appears to have little or no influence on backward grinding performance despite its relationship with performance in rowing (Hahn, 1990) - another "pull" based activity. This lack of a relationship is possibly due to the difference in movement mechanics between backward grinding and rowing. In rowing the pull phase finishes when the elbows are almost fully flexed and the base of the thumbs are in contact with the lower ribs, in comparison to the pull phase of backward grinding which is discontinued much further out from the body. As a result a considerably smaller proportion of the pull phase is conducted with the elbows in flexion during backward grinding than in rowing, somewhat negating the potential benefits of a higher brachial index.

CONCLUSION: The major predictor of high-load backward grinding performance appears to be maximal strength as measured by bench pull. In terms of talent identification for grinding performance the individual should be tall and in particular have long arms and legs. This will provide an advantage in terms of leverage, as well as lending itself towards development of fat free mass and therefore increased muscular strength and body mass.

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