

BIOMECHANICAL AND KINANTHROPOMETRIC FACTORS AS PREDICTORS OF MEAN C1 CRAFT VELOCITY OF AGE GROUP PADDLERS

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In biomechanics of sport research, the development of a multiple linear regression (MLR) model depends on two factors: 1) The movement to be studied must have a well-defined performance criterion; and 2) The attainment of the performance criterion must be known at least subjectively, to depend upon correct execution of some or many mechanical and kinanthropometric stroke technique factors (Marino et al., 1978). The analysis of information provided by several paddling coaches and sport scientists revealed that a number of mechanical and kinanthropometric stroke technique factors were considered important in the attainment of high mean craft velocity during C-1 paddling, Canadian Canoe Association, (1976), Sport Research Ltd., (1978), Plagenhoef (1979), Kearney et al. (1979), Belcastro (1979), Barss et al. (1980), Alexander et al. (1980), Holt et al. (1980), Campagna et al. (1980), Mann et al. (1980).

This study involved the use of cinema-computer technology and MLR analysis to determine the extent to which mechanical and kinanthropometric factors can account for differences in mean C1 craft velocity of age group paddlers. In addition, two methods of estimating the prediction accuracy of the regression equation were computed.

METHODS

Selection of Subjects

The fourteen subjects (S's) in this study were selected from twenty-six right-handed 13-17 years old age group C-1 paddlers. They represented neither the very best or very worst in performance rankings and were a fairly representative sample of the population of age group paddlers in Nova Scotia. The sample size was limited because of fiscal and logistical restraints.

Data Collection

The data collection occurred in three stages. The first test session was concerned with kinanthropometric data collection of the fourteen S's. During the second test session, the kinanthropometric data was remeasured for reliability purposes. Immediately thereafter the fourteen S's were then exposed for the first time to the testing environment associated with the filming

(Figure 1). Each S was able to take a minimum of five time trials through the film zone for acclimatization, and to measure and define the craft performance parameter for each S. The third test session was concerned with filming the fourteen S's until they satisfied the prespecified limits of the craft performance parameter established during the second test session.

Filming Procedures

The trials were filmed from three perspectives simultaneously. The lateral perspective was filmed by a Locam 16mm high speed camera (model 51.DC) equipped with a 10mm lens. It was located on the pool deck directly above the location of the underwater lateral perspective camera (Figure 1). The cinematographic analysis of the film from this camera provided displacement and velocity in the vertical and horizontal plane of the right side of the craft above the waterline, the paddle shaft during the entire stroke cycle, and the S.

A Bolex model H16 16mm spring wound motion picture camera equipped with a 25mm lens was used to take the underwater lateral perspective film. The location of the camera was directly under the lateral perspective camera, inside the pool's Natatorium (Figure 1). The cinematographic analysis of the film from this camera provided displacement in the vertical and horizontal directions of the paddle blade.

A second Bolex camera equipped with a 35-60mm zoom lens was used for the frontal perspective filming. The camera was located on the pool deck directly in line with the forward direction of travel of the craft and paddler (Figure 1). The data obtained from this camera provided displacement and angle of travel in the vertical and horizontal direction of the frontal perspective of the craft above the waterline, the paddle shaft, and the S.

The film speed was set at 100 frames per sec. for the Locam and 60 frames per sec. for the two Bolex cameras. The filming speeds were validated in the Bolex cameras, by filming an electric clock divided in hundred of seconds, and in the Locam camera with the internal timing light generator.

The projected picture linear scale factor was obtained by measuring the 12" distance between two taped lines on the hull of the craft visible from both the lateral and underwater perspective cameras, and a painted 6" linear scale bar on a 3' pole attached at right angles to the bowdeck of the craft, visible from the frontal perspective camera.

Cinematographic Analysis Procedures

Simultaneous filmed trials from the three perspective cameras were analyzed by hand. A total of forty mechanical variables were measured including 3 timed factors, 28 angular and 9 displacement measurements. A selected number of these factors served as independent variables in the regression equation.

Kinanthropometric Procedures

The body segment and size factors were measured with the use of an anthropometer and a kilogram weight scale. Trunk length, leg length, arm length, shoulder breadth, hip breadth, body weight, age, absolute power output, and relative power output were the kinanthropometric variables used in

this study. A selected number of these factors served as independent variables in the regression equation.

Shoulder and arm power were measured by the use of an adapted Roxon electric ergometer. The use of an ergometer to measure arm and shoulder power was adopted because the testing technique and the power factor being measured is preferred for evaluating the training status of paddlers because of the upper body activity of the sport, Belcastro (1979), Campagna et al. (1980), Pyke et al. (1972), Virijens (1975).

Craft Performance Parameters Procedures

The performance criterion for this study was mean craft velocity during one complete stroke cycle as measured from the lateral perspective film. The investigators had to ensure that the paddling stroke technique demonstrated by each S fairly represented their consistent near maximum effort to propel the craft during the testing. The amount of consistent effort was measured by calculating craft velocity over an established distance during a number of trials. The measuring and defining of the craft performance parameter for each S took place during two test sessions. During the first of these sessions each subject was allowed a minimum of five trials through a measured course forty feet in length (Figure 1). Digital hand-held stop watches were located at the start, mid-portion, and finish at the prescribed course. It should be noted that the film zone for the lateral perspective camera constituted the middle twenty feet of the prescribed course. Thus the craft average velocity was measured over two zones:

Zone A - the start to the mid-portion of the film zone

Zone B - the mid-portion of the film zone to the finish

The investigators were then able to compute and compare the two craft velocity measurements, to see if they met the pre-specified performance standards.

Performance Standards

There were two performance standards established prior to the testing to ensure the following objectives were achieved.

1) At least three time trials for each S had to be with ten percent of each of their average craft velocity over forty feet. The average craft velocity derived from the three trials plus or minus ten percent, was the criterion to be achieved during the filming session.

2) The variance in average craft velocity between Zones A and B had to be within ten percent to ensure that the S had not decelerated the craft while being filmed. This was due to the assumed hazard of colliding with the pool bulkhead, which was in close proximity to the filming zone. This apprehension turned out to be unwarranted as the catch net perfectly decelerated the craft in each and every trial.

The craft performance parameter that was finally defined for each S was the mean craft velocity that met with the requirements of the above stated performance standards.

Statistical Analysis

The use of MLR analysis allowed the investigators to study the multiple linear relationship between a set of predictor factors and the performance criterion (mean craft velocity during one stroke cycle) while taking into account the interrelationships among the predictor factors (Mechanical, Kinanthropometric).

The primary goal of the statistical analysis was to produce a set of linearly compliant predictor factors which correlated as highly as possible with the performance criterion, without being significantly correlated with each other. This linear combination could then be used to "predict" values of the performance criterion, as well as determine the importance of each predictor factor's influence on the performance criterion within the statistical limits of the type of analysis used (Nie, 1975).

Since the maximum number of variables which the programs will admit to the equation is the number of subjects minus one ($n-1$), it was decided that only the most important $n-1$ of the total of 49 mechanical and kinanthropometric variables should be submitted to the analysis. The selection of the most important variables was accomplished by first submitting all of the variables to the program. Part of the printed output of the program is a correlation matrix in which all of the intercorrelations among the variables are listed. This matrix was used to identify the $n-1$ variables which were most closely correlated with the dependent variable. Any significant intercorrelations among these variables were examined and those which were highly related were noted. The members of each set of highly related variables were then ranked according to their correlations with the dependent variable from highest to lowest. From each group of highly related variables only one was submitted to the regression analysis. The variable chosen from each group was either the one which was most easily measured or, if all were equally easy to measure, the one which was most highly correlated with the dependent variable. The variables which were thus eliminated were replaced by the variable next most highly correlated with the dependent variable provided it was not highly related to a variable already included.

RESULTS

The intercorrelation matrix including the dependent variables selected for the MLR analysis and the criterion score are contained in Table 1. Below the table are the listed predictor factors.

TABLE 1

SELECTED MECHANICAL/KINANTHROPOMETRIC FACTORS AND
THE PERFORMANCE CRITERION
PEARSON PRODUCT MOMENT CORRELATION MATRIX

PAA	-						
PKB	-.38	-					
LHTC	.60	.01	-				
TMA	.17	-.20	.15	-			
TLA	-.24	.35	-.07	-.53	-		
UHTB	-.46	.12	-.32	-.68	.40	-	
PTB	.42	-.17	.23	.46	-.55	-.39	-
CRITA	-.85	.63	-.66	-.43	.41	.50	-.41
	PAA	PKB	LHTC	TMA	TLA	UHTB	PTB

Listed Predictor Factors

- PAA: Paddle angle at Position one
- PKB: Height of paddler
- LHTC: Lower hand displacement between Position 3-4
- TMA: Trunk angle at Position 1
- TLA: Thrust leg angle at Position 1
- UHTB: Upper hand displacement between Position 2-3
- PTB: Paddle tip distance from bow of craft at Position 2
- CRITA: Mean craft velocity during one stroke cycle

The mechanical/kinanthropometric multiple linear regression equation, which significantly accounted for the most explained variance in the performance criterion contained the following combined predictor factors.

- Paddle angle at entry (Pos. 1) - PAA
- Trunk angle at entry (Pos. 1) - TMA
- Lower hand displacement during the Steering/Exit Phase - LHTC
- Body Height - PKB

These kinanthropometric/mechanical factors combined to have a Multiple R of .989, and thus explaining 98 per cent of the variance, significant at a p level of .001, and a coefficient of variability of 3.5% with the performance criterion (Table 2).

TABLE 2

REGRESSION ANALYSIS OF THE SELECTED KINANTHROPOMETRIC/MECHANICAL FACTORS							
Factor	Significance Entry/Removal	Multiple R	R Square X 100%	R Square Change x 100%	Simple r	Overall F	Significance
PAA	.001/.002	.855	73.25	73.25	-.85	24.64	.001
PKB	.04/.001	.917	84.15	10.90	.63	21.24	.001
LHTC	.01/.003	.968	93.88	9.72	-.66	35.80	.001
TMA	.01/.01	.989	97.95	4.07	-.43	71.95	.001

Predictor Regression Equation developed with the above Kinanthropometric/Mechanical Factors:
 Predicted Performance Criterion = $-.221$ (PAA) + $.064$ (PKB) - 1.095 (LHTC) - $.047$ (TMA) + 17.84 p $.001$ (C.V. \pm 3.5%)

Weber et al. (1970) and Kerlinger et al. (1973) suggested the following formula could be used to estimate the amount of Multiple R and/or R^2 shrinkage, if the equation was to be used on the other population samples.

$$R^2(E) = 1 - (1 - R^2) \frac{(N - 1)}{(N - K - 1)}$$

$R^2(E)$ - estimated squared multiple correlation in the population

R^2 - obtained squared multiple correlation

N - size of the sample

K - number of predictor factors

When this formula was applied to the kinanthropometric/mechanical equation, the following was the result.

$$R^2(E) = .96 - 1 - (1 - .98) \frac{(11 - 1)}{(11 - 4 - 1)}$$

Based on the results just described, the degree of shrinkage of the Multiple R^2 is 2 percent or an estimated Multiple R of .963 and an obtained Multiple R of .989. The results of this cross-validation technique suggest that the initial kinanthropometric/mechanical regression equation can be used on other similar population samples with a near equal amount of explained variance between the predictor factors and the performance criterion.

Another method of estimating the prediction accuracy of the regression equation is to perform a cross-validation as suggested by Kerlinger et al. (1973). This was done by using three subjects of the original selected test group whose predictor factor measurements were not utilized in the initial regression analyses. The final kinanthropometric/mechanical regression equation was applied to the predictor factors of the three subjects used in the cross-validation, thus yielding a predicted performance criterion. A Pearson r is then calculated between the observed criterion scores and the prediction criterion. The derived Pearson r is analogous to a multiple correlation in which the equation used is the one obtained from the initial test sample.

The difference between the Multiple R of the initial sample and the Multiple R of the cross-validated sample is an estimate of the amount of shrinkage in the Multiple R.

The results of this method are described below:

Test Subject	Y (observed)	Y^1 (predicted)
1	9.99	8.97
2	12.10	11.36
3	11.10	12.19

Formula Used: $Y^1 = -.22 (PAA) + .0647 (PKB) - 1.095 (LHTC) - .0472 (TMA) + 17.84$

The obtained cross-validated Multiple R with the three randomly selected subjects was .73. The initial Multiple R was .989. Apparently there is indicated a greater degree of Multiple R shrinkage as compared to the prediction formula described earlier. The shrinkage in Multiple R is likely due to the small homogeneous number of subjects used in the cross-validation which will bias the Multiple R downwards (Weber et al., 1973). However, the amount of explained variance for the cross-validated Multiple R is significant at .01 with a prediction accuracy of $\pm 7.4\%$.

Figure 1 illustrates the average PAA at 55° , demonstrated by age group paddlers who attained above average performance criterion. Figure 2 illustrates the average PAA at 63° demonstrated by age group paddlers who attained below average performance criterion.

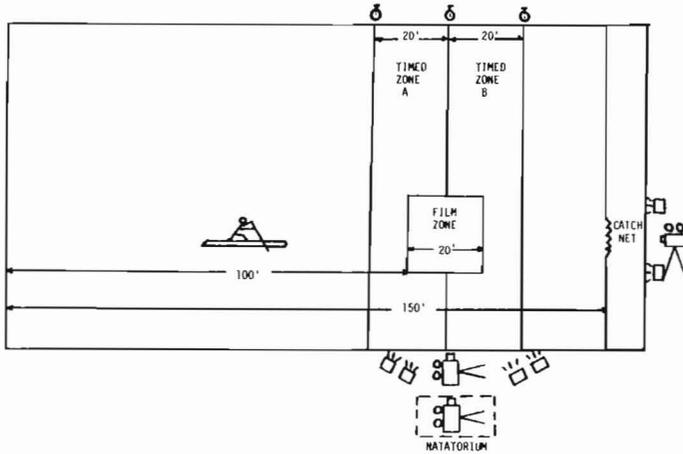


Figure 1

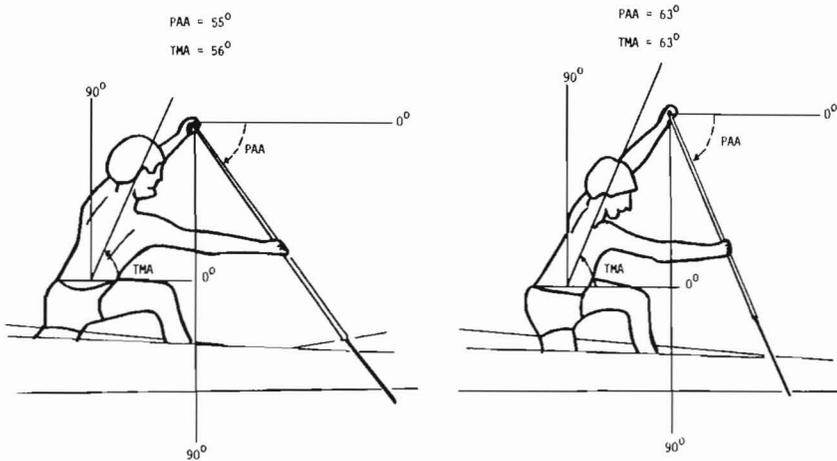


Figure 2

The age group paddlers who demonstrated a more vertical PAA allowed excessive splashing to occur. This water splashing around the paddled blade is indicative of excessive blade surface resistance against the opposing flow of water moving opposite to the direction of the craft. This decreases the effectiveness of the stroke propulsion. This finding was also observed by Plagenhoef (1979) and Kearney et al., (1979), who also noted that PAA could be affected by the blade's distance from the craft's hull and the angle of entry perpendicular to the line of motion of the craft.

The PAA factor was highly correlated (.66) with paddle forward reach at entry (variable PTA, which due to this causal relationship, was not used in the regression). PTA was highly correlated with the performance criterion (-.77). This statistical relationship suggests the following technique implication. Acute paddle angle at entry lengthens the distance between the pivot point of the craft located at the pull knee and the paddle (Figure 2). This increased the distance the paddler must pull the craft to the stationary paddle, thereby increasing the duration of stroke propulsion.

The PAA initiates the catch phase of the stroke. During this particular phase, the paddler must maintain a stable body position in the craft, or unwanted craft movement will decrease overall craft velocity. Body stability is rather difficult to maintain considering the precarious position a paddler assumes in achieving the desired PAA (Kearney et al. 1979). In fact, the age group paddlers who demonstrated less acute PAA showed positional instability during the shifting of their body centre of gravity towards the paddle, while they continued past their point of entry. This applied weight transfer to the paddle was not vertically resisted by the water, since there was less cross-sectional blade area presented.

Figure 2 illustrates the average TMA at 56°, demonstrated by age group paddlers who attained above average performance criterion. Figure 2 illustrates the average TMA at 63° demonstrated by age group paddlers who attained below average performance criterion.

It has been suggested by Kearney et al. (1979) and Plagenhoef, (1979), the degree of trunk flexion is dependent on trunk length and comfort. Both of these factors influence the amount of trunk flexion and rotation in an attempt to achieve the appropriate PAA and PTA.

The age group paddlers who performed the PAA and TMA factors adequately demonstrated the following movements. They continued to flex their trunk from the point of paddle exit until entry. In addition, they also rotated the trunk which placed the pull shoulder below and ahead of the push shoulder at entry.

The LHTC factor as demonstrated by the test subjects indicated a (-.66) high correlation with the performance criterion (Fig. 3). The displacement of the lower hand, during this phase of the stroke is required to initiate paddle-water dissociation and to continue with the necessary actions required for the steering/exit phase (Kearney et al., 1979; Plagenhoef, 1979; Barss et al., 1980; Alexander et al., 1980). The C-1 paddler must therefore strive to employ a steering/exit phase that is directionally effective while producing minimum deceleration (Plagenhoef, 1979). In particular, the distance travelled by the pull during this phase in the stroke has an implication in the degree of forward drag by the paddle, which caused deceleration in the craft (Mann et al., 1980; Barss et al., 1980). Therefore, the paddler must

minimize the time spent in the steering/exit phase, which correlates with distance travelled by the lower hand. Figure 3 illustrates the average LHTC of 1.76 feet by paddlers with above average performance criterion. Figure 4 illustrates the average LHTC of 2.49 feet by paddlers with below average performance criterion.

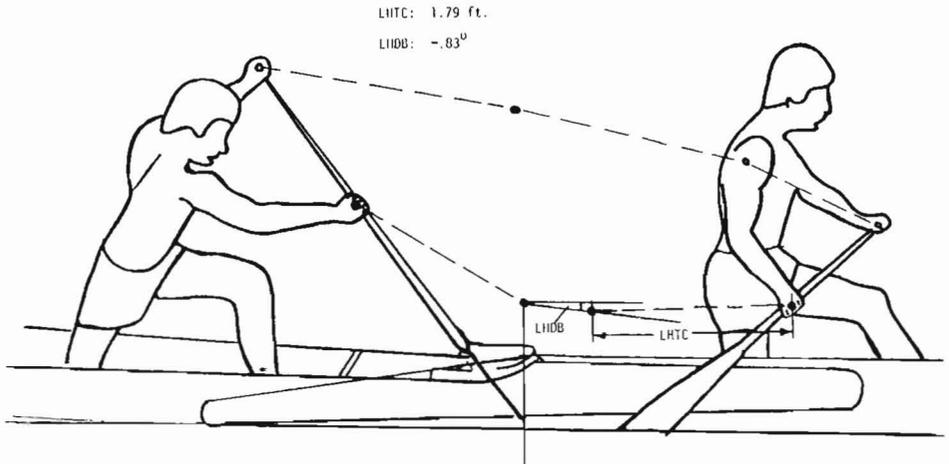


Figure 3

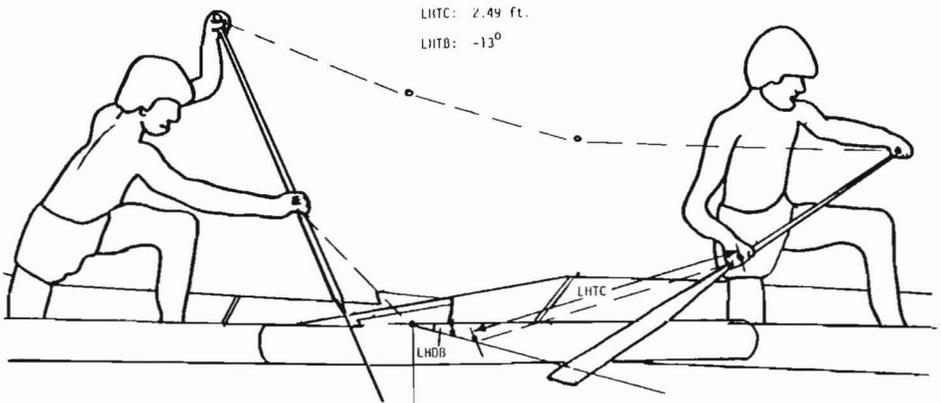


Figure 4

The last and only kinanthropometric factor was Body Height. The PKB factor was inputted into the equation as a secondary factor because of the high intercorrelation amongst the other kinanthropometric factors and the mechanical factors already inputted into the regression analysis. Body height had a low correlation with the selected mechanical factors, but is highly correlated (.63) with the performance criterion. This statistical result suggested that maturation and growth have an implication in how the test is performed. This relationship reflects a mechanical advantage of size for this particular population group due to their heterogeneous range in age. The results also suggested that regardless of age, taller and heavier, earlier maturing boys are experiencing the added benefits of maturation as noted by Astrand et al. (1970).

CONCLUSIONS

The MLR model using selected mechanical and kinanthropometric factors was able to explain 97.95% of the variance in mean craft velocity. Although many factors not selected for the equation were highly related to the criterion the four factors used formed a very useful equation.

It is interesting to note that three of the four factors focus on entrance of the blade (catch position) and lower hand travel following the propulsion phase of the stroke. These variables can readily be observed by coaches and athletes and should be considered as critical to performance optimization in C1 competitive events.

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