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The contribution of selected anthropometric and physiological variables to 10K performance of wheelchair racers: A preliminary study

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Abstract—The purpose of this study was to determine the relationship between selected anthropometric and physiological variables and 10K time. Eleven male wheelchair athletes with spinal cord injuries in training for national competition performed continuous progressive exercise tests on a wheelchair ergometer to determine maximal metabolic and cardiorespiratory values. Anthropometric data were also collected. The laboratory data were analyzed for correlation with the best 10K time of each subject during the test period. The subjects averaged 27 min 30 sec for their 10K races, 2.49 $L \cdot min^{-1}$ for VO_{2max} and 35 percent for maximal gross mechanical efficiency during submaximal exercise. Speed at peak oxygen consumption ($r = -0.66$), gross mechanical efficiency ($r = -0.56$), and body density ($r = -0.57$) was found to be significantly ($p < 0.10$) correlated with 10K time. The results show very little correlation between VO_{2max} and 10K time ($r = 0.02$). Further study is indicated for the relationship between gross mechanical efficiency, speed at maximal oxygen consumption, body density, and 10K time; these variables may be useful in evaluating training programs for improving race performance.

Key words: *gear ratio, gross mechanical efficiency, performance, sports science, wheelchair racing.*

INTRODUCTION

Wheelchair racers and their coaches are continuously searching for new methods of evaluating and improving performance. Hedrick, Morse, and Figoni (1) found that many wheelchair racers know little about effective training techniques. Nearly all wheelchair racers need guidance and can benefit from investigations that provide information about the physiological and biomechanical characteristics of other racers. The training of wheelchair racers has yet to become as well understood as that of "able-bodied" athletes. Some important questions confronting participants in wheelchair racing are: How mechanically efficient and metabolically economic are wheelchair racers? What is the optimal push-ring size (gear ratio)? How is race performance related to the anatomical and physiological attributes of the successful racer?

Results from several studies of runners have indicated that maximal aerobic power is an important determinant of running performance (2). However, maximal aerobic power is not always a significant predictor of 10K* time among runners who are relatively homogeneous (3). Among highly trained and experienced runners of comparable ability and similar maximal oxygen consumption, running economy and velocity at maximal oxygen consumption account for large and significant amounts of variation in 10K performance (4). Initial efforts in developing a database for the aforementioned reports investigated relationships between a

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* "K" is the terminology used by runners and racers to indicate the length of a race in kilometers (e.g., 10K time, 10K performance).

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number of physiological variables and distance-running performance (5). This study represents an initial effort in developing a database on trained wheelchair-athletic performers analogous to the information specific to trained runners. In addition to metabolic values, wheelchair racers and their coaches are interested in the anthropometric characteristics of other wheelchair racers and how they relate to the mechanical interaction with the wheelchair and performance (6).

The purpose of this investigation was to determine if there were any statistically significant correlations between selected anthropometric, metabolic, and cardiorespiratory measures and 10K time for well-trained paraplegic wheelchair racers.

METHODS

Subjects

Eleven trained male paraplegic wheelchair racers (30.9 $\pm$5.8 years of age) with spinal cord injuries gave informed consent to participate in this investigation. Paralysis in one subject was due to spina bifida; all others had spinal cord injuries caused by trauma. Each athlete completed a medical history questionnaire and was given a preliminary 12-lead ECG before participating in this study. The study procedures were approved by the Committee for the Protection of Human Subjects of California State University. At the time of the investigation, the subjects were in training for either the National Wheelchair Athletic Association (NWAA) Track and Field Championships or the NWAA 10K Championships. All tests were completed within 2 months of these competitions. Within one month of laboratory testing, all study participants gave their best performances on the Athletic Congress certified loop course. By employing this arrangement, each athlete was afforded the flexibility in his competitive schedule to optimize his race performance. By using the best performances of each athlete within one month after testing, factors such as weather, illness, and equipment problems were minimized, while still being meaningful for correlational analysis. This design circumvented problems such as an athlete becoming ill for one race, since he could race in another the following week. The same would be true if the weather was bad, an equipment problem arose, or the competitive field was better in another race. The quality and quantity of competitors can also affect performance in any race. In order for laboratory testing to be of benefit for coaching, training, and performance prediction, the results of actual races must be employed in any analysis in order to include the variability present during competitions. Metabolic, cardiorespiratory, and anthropometric measures may be invaluable for plotting the course of the training of an individual athlete, but it is equally important to examine the relationship between these factors and actual race performance.

Experimental protocol

Forced Vital Capacity (FVC), Forced Expired Volume (FEV), Slow Vital Capacity (SVC), and Maximal Voluntary Ventilation (MVV) were determined from pulmonary function tests after completion of a preliminary resting 12-lead ECG. Anthropometric measurements were made with a steel tape, with the subject on an examination table in the supine position (7). Using a strain gauge hand dynamometer, maximal static handgrip strength was established for both right and left hands. The best of three trials for each hand was recorded as maximal static handgrip strength. Handgrip strength was used because the equipment required to test one-repetition maximal bench press (which may be more highly correlated with gear ratio or performance) was not available.

The racing wheelchair ergometry exercise test was based upon incremental speed with a constant resistance set to be nearly equivalent to riding conditions on a flat, smooth road. Prior to exercise testing, experiments were completed comparing coast-down curves for a flat, smooth road and for the test dynamometer using subjects of various weights with the corresponding roller inertia. The inertia of the dynamometer was set to 1.45 $kg \cdot m^2$ (equivalent to a 70 kg subject and chair) (8). The dynamometer and the validation thereof has been described by Cooper (6,9). The subjects started exercise at 2.23 $m \cdot s^{-1}$ (5 mph) and increased their speed by 0.446 $m \cdot s^{-1}$ (1 mph) every 2 minutes until they were unable to initiate further increases in speed at this rate.

Prior to the exercise test, each athlete was weighed while wearing his race clothing (except for his shirt). He was then asked to put his shirt back on and mount his racing wheelchair. The subject and his wheelchair were then loaded onto the dynamometer. Measurement of metabolic and cardio-

respiratory parameters were begun 2 minutes prior to the start of exercise and continued for 5 minutes after the subject stopped exercise. Blood pressure was measured immediately prior to and after completion of exercise. Each athlete was weighed again after he had removed his wet shirt and dried off.

The body density of each athlete was assessed via standard underwater weighing procedures (10) and out-of-water residual lung volumes determined by helium dilution (11). Because the Brozek equations for body composition were established using cadaver models developed for individuals without spinal cord injuries, there is some question as to the validity of these equations when applied to subjects with spinal cord injuries. The effect of such variables as age at onset of injury, complete versus incomplete paralysis, and level of injury on body composition have not been determined. Therefore, body density was used in the data analysis since its foundation is based upon physical laws.

Metabolic and cardiorespiratory data collection

Metabolic data were collected on-line via an IBM-XT microcomputer interfaced with the appropriate hardware. Inspired ventilation was measured by software integration of the flow signal from a Fleisch #3 pneumotachometer, which was calibrated with a known volume of air delivered with a 3-L syringe. Mixed expired gases were sampled from a 3-liter mixing chamber at 100 Hz and measured for oxygen (Applied Electrochemistry S3-A) and carbon dioxide (Beckman LB2) concentrations which were averaged over 30 sec. Oxygen consumption and carbon dioxide production were calculated via standard open-circuit procedures. The analyzers were calibrated prior to and following each experiment with known gas concentrations. Cardiac frequencies (Fc—heart rate) were determined in 30-sec segments using a Computer Instruments Corporation Heart Rate Monitor. Three criteria were used to determine when VO_{2max} was reached: a respiratory quotient (RQ) greater than 1.0; a peak heart rate near the expected maximum for paraplegic wheelchair racers (9,12); and a plateau in the oxygen uptake with increasing speed. Mean 30-sec data were displayed on the computer screen during the test which made it possible for the investigators to determine when their criteria for VO_{2max} were met. Based on these criteria, all subjects reached their maximum.

Gross mechanical efficiency (GME) during submaximal exercise was calculated from the mean internal power (the metabolic power [P_m]) which was a result of the mean change in internal energy (dE_m/dt) and the external mechanical power output (P_o). The metabolic power (P_m) was assumed to be equal to the power equivalent of the measured oxygen consumption.

$$GME = [\text{Mechanical Power/Metabolic Power}] \times 100$$

$$GME = [P_o/P_m] \times 100$$

The maximal gross mechanical efficiencies were determined for submaximal workloads.

Statistical analysis

Correlation matrices were calculated for anthropometric parameters, pulmonary, metabolic, cardiorespiratory functions, and 10K times. The variables were expressed in absolute terms to avoid possible bias due to ratio scores in the correlations (13). In a preliminary study, Type II error may be more serious than Type I error. A significance level of $p = 0.10$ was chosen to help avoid type II error (not detecting potentially significant correlations) since this study was preliminary.

RESULTS

The mean anthropometric, mechanical, and 10K performance data for the subjects appear in **Table 1**. The group means for the metabolic, cardio-

Table 1.
Anthropometric and mechanical parameters of the wheelchair racers.

Parameters	Units	Mean		SD
Height	cm	174.8	±	10.1
Trunk Length	cm	55.3	±	3.4
Upper Arm Length	cm	29.4	±	2.2
Forearm Length	cm	26.8	±	2.2
Hand Length	cm	9.2	±	0.9
Body Mass	kg	65.9	±	6.1
Body Density	kg/m^3	1.053	±	0.012
Handgrip	kg	47.0	±	4.9
Gear Ratio		0.531	±	0.022

Level of injury (N) T3 = 2, T4 = 1, T5 = 3, T6 = 1, T9 = 1, T10 = 1, T12 = 1, L1 = 1
Gear Ratio = pushring diameter/wheel diameter
SD = standard deviation

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respiratory, and mechanical data are presented in **Table 2**. Heart rate data obtained on six of the subjects while racing in 10Ks and immediately following the finish of 10K races were similar to those obtained during exercise tests and during recovery from the tests. This was interpreted to indicate a similar level of effort for both environments.

Table 2.
Physiological parameters of the wheelchair racers at maximal exercise (mean ± SD).

Physiological Parameters	Mean		SD
VO_{2max} (L/min)	2.49	±	0.23
VO_{2max} (mL/kg min)	38.05	±	4.31
V_{Emax} (L/min)	109.09	±	23.72
O_{2pulse} (mL/beat)	13.43	±	1.03
RQ	1.20	±	0.09
F_R (breaths/min)	56.80	±	12.10
F_c (beats/min)	186.20	±	10.70
GME_{max} (%)	35.00	±	5.30

F_c = cardiac frequencies
F_R = frequency of respiration
GME = gross mechanical efficiency
SD = standard deviation
RQ = respiratory quotient
Maximal GME was determined during submaximal exercise.

10K performance

The correlation matrix for the metabolic, cardiorespiratory, anthropometric, and 10K time is presented in **Table 3**. Speed at VO_2 peak ($r = -0.66$) gross mechanical efficiency ($r = -0.56$), and body density ($r = -0.57$) were significantly ($p < 0.10$) correlated with 10K time. The largest positive nonsignificant correlations with 10K time were for weight and cardiac frequency. There was very little correlation between VO_{2max} and 10K time. The 10K times ranged from 24 min 3 sec to 32 min 40 sec with a mean of 27 min 30 sec and a standard deviation of 2 min 50 sec.

DISCUSSION

The relationship between metabolic, cardiorespiratory, and anthropometric parameters, and 10K time for wheelchair racers has not been previously studied. Housh, Thorland, Pohnson, Hughes and Cisar (3) investigated the relationship between

Table 3.
Correlation matrix for the metabolic, cardiorespiratory, and anthropometric values with respect to 10K time for well-trained wheelchair racers (N = 11).

	V_{Emax}	VO_{2max}	F_{Rmax}	F_{Cmax}	RQ	Height	Weight	BD	Grip	Gear	GME	MVV	vVO_2	10K-T
V_{Emax}	1.00													
VO_{2max}	0.81@	1.00												
F_{Rmax}	0.34	0.07	1.00											
F_{Cmax}	0.56#	0.57#	0.35	1.00										
RQ	0.90	0.16	0.73+	0.48	1.00									
Height	−0.55	−0.18	−0.30	−0.73+	−0.50	1.00								
Weight	−0.23	0.28	−0.53	−0.24	−0.30	0.37	1.00							
BD	−0.15	−0.40	0.34	−0.59#	−0.16	0.59#	−0.27	1.00						
Grip	−0.61*	−0.03	−0.43	−0.49	−0.77@	0.53	0.35	0.33	1.00					
Gear	−0.21	−0.15	−0.36	−0.44	−0.29	0.13	0.26	−0.15	−0.02	1.00				
GME	−0.16	−0.05	−0.09	−0.49	−0.23	0.28	0.44	0.36	0.14	0.30	1.00			
MVV	0.13	−0.02	−0.14	−0.23	0.13	0.11	0.34	−0.28	−0.06	0.58#	−0.05	1.00		
vVO_2	0.54	0.34	0.54	0.42	0.67	−0.35	−0.32	0.25	−0.81@	−0.10	0.09	0.01	1.00	
10K-T	0.01	0.02	−0.28	0.40	0.10	−0.29	0.24	−0.57#	0.07	−0.44	−0.56#	0.01	−0.66*	1.00

Significant with ($p < 0.10$)
* Significant with ($p < 0.05$)
BD = body density
F_R = respiratory frequency
F_C = cardiac frequency
Gear = gear ratio
+ Significant with ($p < 0.02$)
@ Significant with ($p < 0.01$)
GME = gross mechanical efficiency
MVV = maximal voluntary ventilation
vVO_2 = speed at peak oxygen consumption
10K-T = 10K Time

3,220-m (2-mile) time trials and metabolic, cardiorespiratory, and anthropometric values for 30 runners. They found fat weight and running economy to be significantly correlated with race time. Generally for runners, VO_{2max} (L/kg•min) and running economy are considered to be the best metabolic predictors of long distance running time (2). Conley and Krahenbuhl (4) reported that for runners that are homogeneous in VO_{2max}, running economy and speed at peak oxygen consumption tend to be more correlated with 10K time. For cyclists, VO_{2max} (L/min) is considered the best metabolic predictor of race time (14). This is probably because the weight of a cyclist is supported by the bicycle. We found speed at peak oxygen consumption (vVO_2) and gross mechanical efficiency (which is a measure of economy) to be significantly correlated ($p<0.10$) with 10K time (**Table 3**). Because our subjects were relatively homogeneous in VO_{2max}, our results are in agreement with those of Conley and Krahenbuhl (4).

Our study has identified the first laboratory variables correlated with actual race performance among well-trained wheelchair racers relatively homogeneous in VO_2. Our results indicate that some of the variability in race performance may be accounted for by the variations in speed, efficiency, and body density during incremental speed wheelchair ergometry. The racers who had the highest body density were efficient, had high speed at maximal oxygen consumption, and tended to have the lower 10K times. There were no significant correlations between body density, gross mechanical efficiency, and speed at maximal oxygen consumption.

The results suggest that exercise stress tests using incremental speed protocols may be helpful in evaluating training programs and for improving race performance of well-trained wheelchair racers, provided the athletes are tested in their own wheelchairs. Possibly our sample included some subjects with very high metabolic values and less-than-optimal gear ratios, as well as subjects with lower metabolic values but efficient gear ratios. Metabolic parameters by themselves may not be sufficient for predicting performance. This is because metabolic parameters of trained individuals are similar and the differences are even further reduced for elite athletes; therefore, they may not be adequate for predicting performance. However, variability in performance may be accounted for by examining performance-related variables (like speed) at maximal oxygen consumption and gross mechanical efficiency. This suggests that metabolic parameters in conjunction with performance-related variables (i.e., speed, power, economy), may account for differences in performance.

The results of this investigation indicate that further study of speed at maximal oxygen consumption, gross mechanical efficiency, and body density is required. In addition, aspects of wheeling economy need to be investigated. Future studies could focus on determining biomechanical and wheelchair construction variables as related to economical and uneconomical forms of wheelchair propulsion.

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