Correlation between Efficiency in Cycling and Maximal Power of Human Extensor Muscles

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ABSTRACT

The maxlmal power of knee extensor muscles was measured by fly-wheels of various equivalent masses, and the work efficiency in cycling at submaximal work rates was determined on nine healthy adult men. Among the various combinations of power and efficiency, only one significant correlation (r=0. 853, p<0. 01) was found between power at the lightest equivalent mass of 18. 3 kg and efficiency in cycling at the highest pedal frequency, 100 rpm.

Key Words: work efficiency, fly-wheel, muscle power

INTRODUCTION

Thorstensson et al. (1976) demonstrated significant correlations between peak torque produced at the highest speed of muscle shortening and the relative area of fast twitch (FT) fibers in the contracting muscle. Davies et al. (1970) and Awan and Goldspink (1970) reported that the slow twitch (ST) muscles have evolved for efficiency in maintaining isometric tension whereas FT mammalian musclian muscles have evolved for efficiency in doing external work. Furthermore, Suzuki (in press), comparing subjects who had different ratios of ST/FT fibers in the lateral portion of m. puadriceps femoris, found that efficiency in cycling at 100 rpm was significantly lower in the ST group than in the FT group.

Taking the above-mentioned findings into consideration, it might be expected that the person who can exert the highest power by a bout of maximal knee extension would show the highest efficiency in cycling at higher pedal frequencies. Therefore, the present study was designed to determine whether there is a correlation between efficiency in cycling and maximal power in a single contraction of knee extensor muscles.

METHODS

Nine healthy graduate students of our laboratory were used as subjects. All were males with an average age of 25. 5 years (range: 23. 6 to 30. 1 years of age). The mean height was 168. 5 cm (range: 162. 7 to 170. 8 cm) and the mean weight was 64. 4 kg (range: 57. 0 to 74. 7 kg).

The maximal power of knee extensor mucles was determined by a fly-wheel, which was fundamentally the same as the one used by Hill (1922). Equivalent masses of the fly-wheel were 18. 3, 31. 6, 76. 6, 285. 5 and 713. 7 kg. The subjects were seated in an adjustable chair fastened with a seatbelt and the string from the fly-wheel was firmly attached to the right or left ankle. After preliminary practice the subjects performed two maximal knee extensions on each side from 90 to 0 degrees (0 degrees=fully extended knee). The maximal value on each side was used in the results.

The speed of rotation of the fly-wheel was measured by an electrical device. An electric tension detector was tied between the string and the fly-wheel, and the time during which the force was exerted on the fly-wheel was measured. Then power was calculated from the rotary speed, the moment of inertia of the fly-wheel and the time.

The efficiency in cycling ("Monark" Sweden) was measured during steady-state exercise at two different pedalling speeds, 40 and 100 rpm. At five different work loads (29.43. 58.86, 88.29, 101.37, 147.15 watt), subjects performed for five to seven minutes at each pedalling speed. Five minutes of rest was allowed between the exercise at different work rates. Exercise at each pedalling speed was performed on separate days during one week.

When the subjects had reached a steady-state, as judged from the heart rate monitored continuously by the ECG, expired air was collected twice for one minute in Douglas bags. The volume of gas was measured by a dry gasometer, and gas analyses were performed by the Scholander micro-gas analyzer. When the difference in oxygen uptake ($\dot{V}O_2$) between the two samples was more than 5%, the test was repeated. When the difference was less than 5%, the higher value was used in the results. The respiratory exchange ratio (R) was used to estimate caloric output.

Ordinary statistical methods were used to calculate means and standard deviation (SD). Significance of linear correlation coefficients was tested according to Snedecor and Cochran (1967).

RESULTS

The power per body weight exerted by the leg extensors is presented in Table 1. The highest power recorded was obtained at the relatively light equivalent masses of 31.6 or 67.6 kg. The individual difference in power was largest (from 4.30 to 8.76 watt/kg. b.w.) at the lightest equivalent mass of 18.7 kg.

Means and SD of $\dot{V}O_2$ and R as related to work rate are shown in Table 2. $\dot{V}O_2$ increased almost linearly with work rate at each pedalling speed. $\dot{V}O_2$ at a pedalling speed of 100 rpm was significantly higher than $\dot{V}O_2$ at 40 rpm despite the same work rate. R increased step by step with work rate.

Table 1 Individual values of maximal power per body weight in watt/kg of knee extensor muscles in relation to equivalent mass

Subj.		Equivalent mass (kg)				
		18.3	31.6	67.6	285.5	713.7
SU	R	3.55	3.76	4.21	3.53	2.55
	L	3.68	2.96	3.52	2.77	2.21
TY	R	3.40	4.32	3.55	3.44	2.34
	L	3.69	3.61	3.79	3.22	2.80
KI	R	4.07	3.51	3.29	2.48	1.81
	L	3.93	3.70	2.69	2.04	1.69
SS	R	3.92	3.14	2.98		1.86
	L	4.50	3.87	3.81		2.53
RM	R	4.21	4.14	4.28	3.20	2.34
	L	4.55	4.76	4.34	3.74	2.53
TM	R	2.31	2.70	2.91	2.62	1.58
	L	1.99	2.42	2.50	2.53	1.66
YF	R	2.33	2.80	3.22	3.01	2.43
	L	2.48	2.80	2.96	2.13	2.05
MS	R	3.12	3.48	3.71		2.32
	L	2.90	3.02	3.56		2.00
YH	R	2.63	2.38	2.65	2.72	2.46
	L	2.41	3.07	2.70	2.49	2.37

R: Right leg L: Left leg

A high linear correlation between caloric output and work rate at each pedalling speed was obtained (Table 3). The regression equation between caloric output (Y) and work rate (X) was calculated on each subject at each pedalling speed (Table 3). The value b in the equation ($Y=aX+b$) could be assumed to be the caloric output for static work when sitting upright and kinetic energy in the movements of the legs. Additionally, the work efficiency was defined as $1/a \times 100$ and calculated for all subjects at each pedalling speed (Table 3). The work efficiency at the pedalling speed of 100 rpm was higher than at the lower speed of 40 rpm except for one subject.

No significant correlation between work efficiency and power of the knee extensors was found except that between efficiency in cycling at 100 rpm and power at the lightest equivalent mass of 18.3 kg ($r=0.853$, $p<0.01$). (Figure 1.)

Table 2 Means and standard deviations of $\dot{V}O_2$ and respiratory exchange ratios (R) with respect to work rate and pedal frequency

			work rate (watt)				
			29.43	58.86	88.29	117.72	147.15
40 rpm	$\dot{V}O_2$	m	0.657	1.025	1.340	1.717	2.087
	(l/min)	SD	0.061	0.074	0.088	0.083	0.089
	R	m	0.77	0.82	0.84	0.87	0.91
		SD	0.06	0.05	0.04	0.06	0.05
100 rpm	$\dot{V}O_2$	m	1.243	1.517	1.805	2.152	2.492
	(l/min)	SD	0.161	0.198	0.211	0.219	0.251
	R	m	0.89	0.90	0.92	0.93	0.95
		SD	0.05	0.05	0.05	0.04	0.05

Table 3 Correlation coefficients and regression equations between $\dot{V}O_2$ (Y) and work rate (X), and equivalent work efficiency (E)

Subj.		correlation coefficient	regression equation	E(%)
SU	40 rpm	r=0.995*	Y=4.01X+1.47	24.9
	100 rpm	r=0.991*	Y=3.51X+3.83	28.5
TY	40 rpm	r=0.991*	Y=4.43X+1.56	23.0
	100 rpm	r=0.992*	Y=3.78X+4.07	26.5
KI	40 rpm	r=0.999*	Y=4.12X+1.74	24.4
	100 rpm	r=0.994*	Y=3.39X+5.00	29.5
RM	40 rpm	r=0.998*	Y=4.53X+0.79	21.7
	100 rpm	r=0.997*	Y=3.30X+3.50	30.3
SS	40 rpm	r=0.998*	Y=3.76X+1.47	25.4
	100 rpm	r=0.998*	Y=3.60X+3.78	27.8
YF	40 rpm	r=0.999*	Y=4.66X+1.24	22.0
	100 rpm	r=0.993*	Y=4.21X+5.22	23.8
MS	40 rpm	r=0.995*	Y=3.91X+1.78	25.8
	100 rpm	r=0.994*	Y=3.79X+4.70	26.4
TM	40 rpm	r=0.998*	Y=4.11X+1.93	26.0
	100 rpm	r=0.999*	Y=3.91X+5.51	25.6
YH	40 rpm	r=0.999*	Y=4.23X+1.56	23.4
	100 rpm	r=0.996*	Y=3.95X+5.05	25.3

* Significance at .001 level.

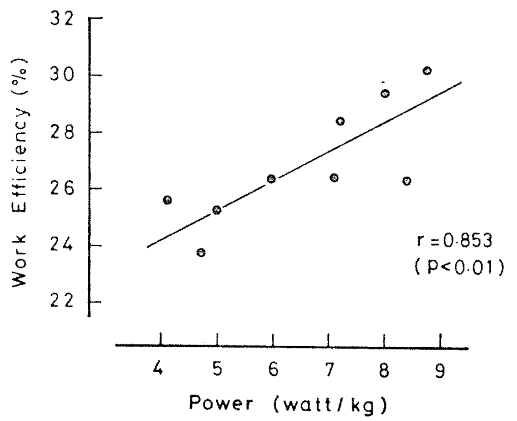

Figure 1 Relationship between the increment in work efficiency in cycling at 100 rpm and power per body weight at the lightest equivalent mass of 18.3 kg.

DISCUSSION

Data on R (Table 2) indicate that the metabolic rates of the present subjects were generally below their anaerobic threshold (Gaesser and Brooks 1975, Wasserman et al. 1973). Because a linear relationship between caloric output and work rate was obtained in each subject, a constant efficiency within the aerobic range of work rates could be determined as the "work efficiency" described by Whipp and Wasserman (1969). The mean value of the *Y* intercept of regression of caloric output on work rate in this study coincided well at 100 rpm with Gaesser's value (4.52 Kcal/min) and was slightly less at 40 rpm (2.03 Kcal/min). Therefore, the same results, i.e., that gross and net efficiencies decrease with work intensity while "work efficiency" remains remains relatively constant, were obtained in the present study as in those previously reported by Gaesser and Brooks (1975).

The results obtained in the present study, i.e., that the highest power could be exerted at relatively light equivalent masses, were similar to the results found by Lupton (1923) who used a fly-wheel with equivalent masses of 11.67 to 681 kg.

Thorstensson et al. (1976) demonstrated a significant correlation between peak torque of human knee extensor muscles at high angular velocity and the percentage of FT fibers in m.vastus lateralis, and concluded that this correlation indicates the importance of muscle quality in terms of fiber types for dynamic muscle strength in certain situations. Differences in muscle fiber composition of skeletal muscles have been reported by several researchers utilizing the needle biopsy technique (Costill et al. 1976, Edström and Ekblom 1972, Gollnick et al. 1972, Thorstensson et al. 1976). Since the greatest variation in power was found at the lightest equivalent mass (the highest contraction velocity), it might be suggested that muscle fiber composition in knee extensor muscles of the present subjects differed rather widely from each other.

The major finging of this study was the significant correlation between "work efficiency" in cycling at high pedal frequency and the power of a single contraction of the knee extensor muscles at high velocity. Moreover, the gain in "work efficiency" from 40 to 100 rpm shows a postive relation to the power of the knee extensors (Figure 2). These findings might indicate that the subject who has a larger percentage of FT fibers in leg muscles can bicycle at a high speed more efficiently than the subject with a smaller percentage of FT fibers. This indication is supported by the report that efficiency, when expressed as the work done per μmole of ATP, was found to be more than twice as high in fast muscles as in slow muscles (Awan and Goldspink 1970). The authors' explanation is that the longer cross-bridge engagement time of the soleus muscle, which causes it to shorten more slowly, also makes the muscle less efficient for performing work, due to the fact that

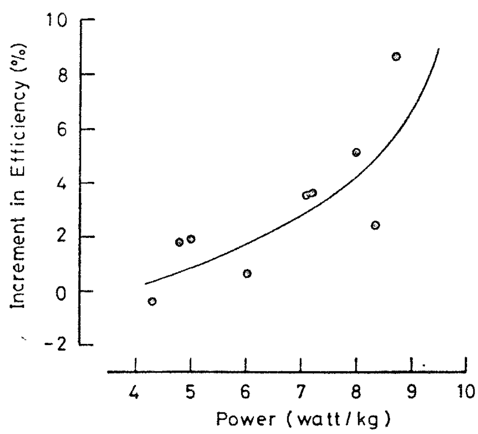

Figure 2 Relationship between the increment in work efficiency from 40 to 100 rpm and power per body weight at the lightest equvalent mass of 18.3 kg.

the myosin cross-bridges that are pulling are working against those that are holding.

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