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The Effect of External Loading upon Power Output in Stair Climbing

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Summary. Previous studies have examined man's ability to produce external power output during maximal repetitive work cycles of short duration. It appears, however, that there were methodological limitations which would inherently mask man's true capacities. Consequently, we examined the effect of variable external loads upon external power output as measured by running upstairs. Fourteen male subjects (16–31 years of age) who regularly participated in competitive sports performed maximal stair step tests under five experimental loading conditions (no external load, 10.1, 19.2, 24.2, and 29.2 kg). Significant increases ($P < 0.05$) in external power output were found. External power output increased from a mean of 15.9 $W \cdot kg^{-1} \pm 1.0$ (unloaded condition) to 18.5 $W \cdot kg^{-1} \pm 1.5$ (external load of 29.2 kg). This is the first modern investigation demonstrating that external loads effect external power output as measured by this technique.

Key words: External power output-optimal load – Stair step test – Maximizing (anaerobic) power

Past investigators have examined the effects of various factors, such as pedalling frequency (Hamley and Thomas 1967; McKay and Banister 1976), postural position (Astrand and Saltin 1961; Hamley and Thomas 1967; Diaz et al. 1978), seat height (Hamley and Thomas 1967; Schennum and deVries 1976), and elliptical chain wheels (Henderson et al. 1977) on the determination of maximal oxygen uptake during cycle ergometry tests. Other investigators (Taylor et al. 1955; Kasch et al. 1976) have compared the difference between horizontal and incline treadmill protocols for the determination of maximal oxygen uptake.

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Few studies, however, have examined factors capable of influencing the measurement of external power output ($\dot{W}$) as determined from maximal work cycle tests of short duration such as running up stairs. This latter technique as defined by Margaria et al. (1966) seems to have become a standard and popular test for the measurement of $\dot{W}$ in man (Di Prampero et al. 1970; Davies 1971; Margaria et al. 1971; Miliken and Spence 1973; Thorstensson et al. 1975; Fox et al. 1977; Houston and Thomson 1977; Komi et al. 1977; Komi and Karlsson 1978; Vihko et al. 1978). Originally, Margaria et al. (1966) pointed out that step height influenced $\dot{W}$ as measured by this technique. However, there might be other factors, such as stride frequency, leg length, stair angle, or loading which might effect this measurement.

The question, therefore, arises: Does the present method enable man to produce maximal $\dot{W}$? It was the purpose of this study to investigate the effects of variable loading upon subjects who were running upstairs. It was postulated that incremental loading would result in significant increases in $\dot{W}$.

Methods

Fourteen male subjects volunteered to participate in this study. Informed consent was obtained from each subject. All of the subjects were in excellent physical condition and regularly participated in competitive sports. Their ages and weights are given in Table 1. $\dot{W}$ was measured in a manner similar to that of Margaria et al. (1966). Subjects were instructed to run up an instrumented staircase as fast as possible. Each stride covered a vertical rise of 0.345 m. The incline of the staircase was 30° (58% grade). After a constant average velocity had been reached, the time it took to cover a vertical rise of 1.38 m was measured, and then the product of average vertical velocity times the total weight of the subject was used to obtain the average $\dot{W}$. The subjects were instructed to take a 2 m run prior to reaching the first step of the staircase so that the terminal rise velocity could be reached more quickly once climbing began. Each step was instrumented with a "Controlflex" Tapeswitch (Model 131-A). A minimum force of 11.2 N was necessary to cause closure of the switch. When the subject's foot contacted the switch, the switch closed and a spike was recorded on a Hewlett Packard Oscillographic recorder (Model 7402A). A chart speed of 125 mm $\cdot$ s^{-1} was used during recording, giving an accurate time base of 0.001 s. By analyzing the chart, it was quite apparent when the maximal average vertical rise velocity had been reached. The subjects were allowed no warm-up and were permitted 1 min between trials.

The subjects ran up the staircase with and without external loading. They were loaded by wearing a specially constructed vest which could be weighted in a variable manner. The vest could be strapped tightly to the subject with appropriate padding to prevent motion of the weights or injury to the subject. The weights were equally distributed between the chest and back. Following a procedure similar to that used by Blix (1901), all the subjects were loaded with the same absolute weight increments. The five experimental loading conditions were: (1) body weight, no external load; (2) body weight plus 10.1 kg; (3) body weight plus 19.2 kg; (4) body weight plus 24.2 kg; and (5) body weight plus 29.2 kg. The increments were chosen using available weights to approximately match those used by Blix (1901). Three trials were performed at each load. A randomized block design was used to determine the order of loading.

In all statistical analyses, the 0.05 level of significance was used.

Results

The subjects' highest $\dot{W}$ values for each experimental condition are reported in Table 1. The means and standard deviations are also included.

When compared to the mean subject body weight (71.86 kg), the five experimental conditions represented mean relative increases in weight of 0, 14, 27, 33, and 40%, respectively. Corresponding to the four experimental conditions in which the subjects were loaded externally, mean $\dot{W}$ increased 6, 12, 14, and 16%. Figure 1 illustrates the relationship between per cent body weight increment and per cent increase in $\dot{W}$.

Without external loading, the subjects were able to produce from 13.9 to 17.5 $W \cdot kg^{-1}$ with a mean $\dot{W}$ of 15.9 $W \cdot kg^{-1}$. These values closely correspond

Table 1. Highest $\dot{W}$ value found at each experimental condition

Subject	Age	Body weight					
		(kg)	(no load)	(+ 10.1 kg)	(+ 19.2 kg)	(+ 24.2 kg)	(+ 29.2 kg)
1	31	68.27	15.9	14.9	16.7	16.0	15.9
2	26	72.50	16.5	17.3	18.4	18.6	19.0
3	17	63.64	17.5	17.9	19.1	19.3	19.3
4	25	78.64	16.6	17.5	18.8	18.7	19.1
5	18	67.36	16.3	17.8	18.0	18.7	18.8
6	18	74.64	16.3	17.8	17.8	19.8	19.6
7	16	65.73	16.5	17.9	18.2	18.8	19.5
8	18	66.91	15.4	17.1	17.3	17.9	18.4
9	23	70.64	13.9	14.7	15.5	15.8	16.2
10	23	74.91	15.6	16.7	17.8	17.9	18.0
11	28	65.64	17.4	19.0	19.9	21.0	21.4
12	25	77.09	15.2	16.4	17.9	18.5	18.6
13	24	83.18	14.2	15.4	15.9	15.7	16.0
14	26	76.95	15.9	16.7	17.3	18.0	18.8
$\bar{X}$	22.7	71.86	15.9	16.9	17.8	18.2	18.5
SD	± 4.6	± 5.87	± 1.0	± 1.2	± 1.2	± 1.5	± 1.5

Loading condition-power in $W \cdot kg^{-1}$

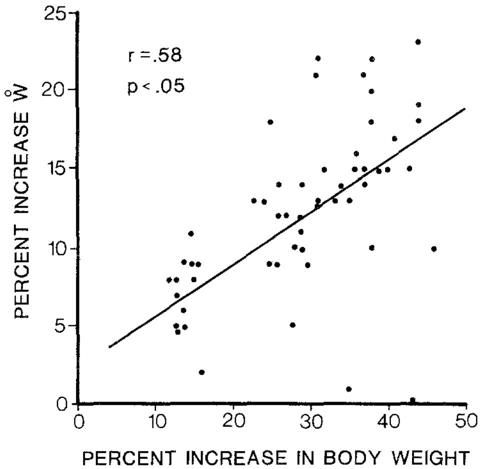

Fig. 1. Correlation between percent increase in external power output and added load (expressed relative to body weight)

to the mean maximal "anaerobic" power output values (14.7 to 15.7 $W \cdot kg^{-1}$) reported by Margaria et al. (1966). When subjects were weighted with an external load of 29.2 kg, the mean $\dot{W}$ increased to 18.5 $W \cdot kg^{-1}$. As stated above, this represents an average increase of 16% in $\dot{W}$. It can be seen from Table 1 that mean $\dot{W}$ increased as the load increased with very few exceptions. Only for Subject No. 1 were the results somewhat inconsistant.

A repeated measures one-way analysis of variance of the $\dot{W}$ data in Table 1 reveals significant effects as a result of loading. The analysis of variance produced a F ratio of 72.4. The Tukey HSD test was performed to determine significant differences among the means of the five experimental conditions. Of the 10 comparisons made, all were significantly different except for the single comparison between the fourth and fifth condition.

Discussion

Although there is contemporary interest in the measurement of $\dot{W}$ during brief maximal work cycles, few investigators have examined factors capable of influencing this measurement. Harrison (1970) has reported that subjects must be optimally loaded when attempting to produce maximal $\dot{W}$ during brief repetitive work cycling tests. We have also examined the influence of loading upon the measurement of $\dot{W}$ (unpubl. observ.). For five subjects performing brief (6 s) cycling tests on a modified Monark cycle ergometer, we found a mean $\dot{W}$ of 925 W when pedalling against a load of 68.7 N. However, when the subjects were optimally loaded (mean of 98.1 N) the mean $\dot{W}$ was 1089 W, an increase of 18%.

With a cycle ergometer, it is possible to pedal fast enough so that $\dot{W}$ is zero. This occurs at zero load when all the energy is expended in overcoming internal friction. A similar situation occurs when the load is increased so much that the subject is unable to turn the crank. Somewhere in between, a maximal work rate will occur which results from optimal loading.

In running uphill against gravity, we felt that it would be presumptuous to assume that body weight provides an optimal load for the elicitation of maximal work rates. We feel that the data in the present experiment substantiates this. In these tests, external loading produced an increase in $\dot{W}$ for each subject without exception. Similar but rather limited findings were reported by Blix (1901) who found $\dot{W}$ increases of 7 and 16%, respectively, when two subjects each loaded with 30 kg ran upstairs.

Although we have been able to demonstrate an increase in mean $\dot{W}$, we are uncertain as to why increased loads resulted in increased $\dot{W}$. It may be that additional loads weighted each subject such that stride length became more optimal, or possibly the increased weight resulted in a more optimal running speed-load interaction. For cycling, Harrison (1970) has suggested that loading effects the force-velocity interaction with consequential changes in $\dot{W}$.

Furthermore, although we have demonstrated that loading produced an increase in mean $\dot{W}$, it is unclear whether the load of 29.2 kg resulted in a true mean maximal $\dot{W}$. Although the statistical analysis indicated that the difference between the fourth and fifth experimental conditions was not significant, viewing Table 1 it appears that mean W might have continued to increase slightly had a heavier load been used. Additional loading was not used in the present study, because it became impractical from a mechanical standpoint. Stairway treads form a built-in limitation to stride length, and, as a result, beyond 29.2 kg it became difficult to stride from stairtread-to-stairtread. Because of this limitation, it is doubtful that man's true capacity for this type of activity has been determined.

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