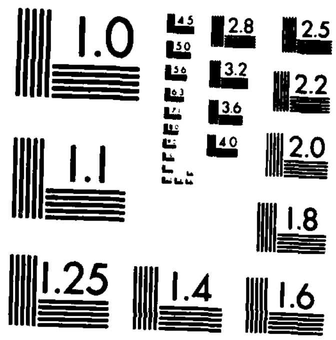
AD-A141 374 MAXIMAL POWER OUTPUTS DURING THE WINGATE ANAEROBIC TEST (U) ARMY RESEARCH INST OF ENVIRONMENTAL MEDICINE NATICK MA J F PATTON ET AL. 03 MAY 84 USARIEM-M23/84 1/1

UNCLASSIFIED F/G 6/19 NL



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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
M23/84

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Maximal Power Outputs During the Wingate Anaerobic Test

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
J. F. Patton, M.M. Murphy and F.A. Frederick

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
US Army Research Institute of Environmental Medicine, Natick, MA 01760, USA

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
US Army Medical Research and Development Command
Fort Detrick, Frederick, MD 21701

12. REPORT DATE
3 May 1984

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Anaerobic power, Wingate Test, Power Putput

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
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were 0.096 and 0.094 kg/kg BW, respectively (average setting of 0.095 kg/kg BW). Both PPO and MPO were significantly higher (15.5% and 13.0%, respectively) using a resistance setting of 0.095 compared to the Wingate setting of 0.075 kg/kg BW. The test-retest reliability for PPO and MPO ranged between 0.91 and 0.93 at both resistance settings. Body weight, % body fat and thigh volume did not significantly estimate the individual resistance settings eliciting maximal PO's. The data suggest that resistance be assigned according to the subjects BW but consideration be given to increasing this resistance from that presently used in various laboratories.

HUMAN RESEARCH

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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Maximal Power Outputs During the Wingate Anaerobic Test

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ABSTRACT

The purpose of this study was to determine the resistance settings which elicit maximal values of power output (PO) values during performance of the Wingate Test (WT). Nineteen male subjects (mean age, 25.1 yrs; mean VO_2 max, 3.52ℓmin^{-1}) performed multiple WT in a random order at resistance settings ranging from 0.055 to 0.115 kg/kg BW. Tests were carried out on a Monark cycle ergometer modified to permit instantaneous application of resistance. Revolutions were determined by a computer interfaced frequency counter. The mean resistance settings eliciting the highest peak power (PPO) and mean power (MPO) outputs were 0.096 and 0.094 kg/kg BW, respectively (average setting of 0.095 kg/kg BW). Both PPO and MPO were significantly higher (15.5% and 13.0%, respectively) using a resistance setting of 0.095 compared to the Wingate setting of 0.075 kg/kg BW. The test-retest reliability for PPO and MPO ranged between 0.91 and 0.93 at both resistance settings. Body weight, % body fat and thigh volume did not significantly estimate the individual resistance settings eliciting maximal PO's. The data suggest that resistance be assigned according to the subjects BW but consideration be given to increasing this resistance from that presently used in various laboratories.

Introduction

The development of procedures for measuring the maximal capacity of human muscle to generate power during high-intensity, short duration exercise has received considerable attention in recent years. Such procedures have ranged from simple field tests such as sprinting (16) to laboratory techniques comprising a variety of exercise modes, e.g. treadmill running (4), stairclimbing (15), vertical jumping (3,5) and cycle pedalling (1,17,19). While no single test has gained the popularity equivalent to the determination of VO_2 max as a measure of aerobic capicity, the Wingate Test (WT) has received considerable interest in a number of laboratories as a measure of anaerobic capacity (2,8,11,12).

The WT consists of 30s of supramaximal cycling (or arm cranking) exercise against a frictional resistance determined relative to the subject's body weight. The resistance setting used for leg exercise in laboratories reporting on power outputs is 75 gm/kg body weight (for Monark and Bodyquard cycle ergometers). While this resistance has been reported to elicit the highest power outputs, the data were obtained on young subjects (1). The question remains whether such a resistance setting results in the highest power outputs attainable in adults.

The purpose of the present study, therefore, was to compare power outputs achieved in adult subjects using the Wingate resistance setting to those obtained over a range of resistances relative to body weight.

Materials and Methods

Nineteen healthy, male subjects volunteered to participate in this study. Before initiation of any testing, subjects were fully apprised of the purpose, methods, and potential risks of the study. Each volunteer reserved the right to withdraw at any time without retribution. The group's age was 25.1 $\pm$ 2.0 yrs ($\bar{X} \pm SD$), height 176.8 $\pm$ 4.1 cm, weight 75.5 $\pm$ 10.5 kg, percent body fat determined by skinfold (7) 17.0 $\pm$ 4.1%, lean body mass 62.4 $\pm$ 6.4kg, and right thigh volume determined by water displacement 5.53 $\pm$ 0.98ℓ (20). The group had a VO_2 max of 3.52 $\pm$ 0.32$\ell \cdot min^{-1}$ as determined using a discontinuous cycle ergometer protocol.

The WT was performed on a Monark cycle ergometer modified to permit the instantaneous application of resistance (9). The weighted pendulum was replaced by a counterbalanced lever arm to which weights were attached at calculated positions in order to obtain the desired resistance. Below the lever arm a microswitch was fixed to the cycle frame and used to control the onset of the test. Pedal revolutions were measured by four magnets attached to the rim of the flywheel. When the weighted lever arm was lowered to a horizontal position the switch closed and pulses from the magnets were fed into a universal counter (Hewlett-Packard 5328A). The resolution of this system was 0.067 revolutions. A desktop computer (Hewlett-Packard 85) was used for timing, control and data acquisition by reading the output of the counter at the end of each sec of the test.

A curve relating power output (PO) and resistance setting was determined for each subject. The settings were relative to body weight (BW) measured during the first session and ranged between 0.055 and 0.115 kg/kg BW. Ten to twelve WT's were performed by each subject in a random order at intervals approximating 0.005 kg/kg BW within the above range. Each session was spaced apart by at least 24 hrs. Tests were repeated at the 0.075 kg/kg BW setting for each subject and at the mean resistance setting for the group which resulted in the highest PO to determine test-retest reliability.

Prior to each test, subjects warmed up on a standard Monark ergometer for 2-4 min at an intensity of 75-125 W. Two to three sprints of 4-6s each were interspersed. The seat height was adjusted for each subject and the feet firmly strapped to the pedals. Subjects were initially instructed to attain a pedal rate of about 120 RPM and then to the command "Ready, Go", they commenced pedalling as fast as possible against the ergometers inertial resistance only. Upon reaching a maximal pedal rate (within 1-2s) the lever arm was immediately lowered applying resistance to the flywheel, closing the switch and triggering the computer to start timing the test. Subjects were instructed to remain seated and verbally encouraged to maintain maximal pedal rates throughout the test. At the end of 30s the computer calculated the PO's every sec and averaged them for each 5s period. From the six 5s periods the following variables were computed: peak power output (PPO), the highest PO during any 5s period; mean power output (MPO), the average PO generated during the entire 30s; and power decrease (PD), the difference between PPO and the lowest 5s PO divided by the time elapsed.

A one-way ANOVA was used to compare PO data collected at the 0.075 setting and the mean resistance setting resulting in the highest PO's. Anthropometric measures were used in stepwise multiple regression procedures in an attempt to estimate the resistance settings producing the hightest PPO and MPO.

Results

Figure 1 presents a composite of the individual curves of PO versus resistance setting. As can be seen, all three PO variables increased as the relative resistance increased from 0.055 to approximately 0.080 kg/kg BW. Thereafter some fluctuation occurred in the PO's but little significant change is evident. A slight decline in PO's is suggested at resistance settings above 0.100 kg/kg BW.

The resistance settings (kg/kg BW) which resulted in the highest PO's were: PPO, 0.096 ± 0.009 (mean ± SD), range 0.084-0.112; MPO, 0.094 ± 0.009, range 0.073-0.112; PD, 0.095 ± 0.009, range 0.074-0.112. The settings, therefore, differed little among the three variables and averaged 0.095 kg/kg BW. However, considerable individual variability occurred as evidenced by the wide ranges in resistance settings. A high correlation was found ($r=0.87$, $p<.001$) between resistance settings eliciting maximal values for PPO and MPO.

The mean data for PPO, MPO and PD obtained at the 0.095 kg/kg BW setting and at the Wingate setting of 0.075 kg/kg BW are shown in Table 1. Both PPO and MPO are significantly higher on an absolute basis (15.5% and 13.0%, respectively) at the 0.095 setting compared to that of 0.075. PD was also significantly higher (21.[illegible]%) at the 0.095 setting as a result of the greater force applied (7.1 kg vs 5.6 kg) and the lower mean pedal revolutions attained. It was noted, however, that at resistance settings above 0.100 kg/kg BW, some subjects had difficulty in maintaining contact with the saddle throughout the test.

Reliability data for PPO, MPO and PD are shown in Table 2. Only 13 of the 19 subjects performed a second WT at the 0.095 kg/kg BW setting. Correlation coefficients for PPO and MPO ranged from 0.91 to 0.93 at both resistance settings. Reliability coefficients for PD were considerably lower (0.74 at 0.075 kg/kg BW and 0.43 at 0.095 kg/kg BW).

Body weight (r=-0.45 and -0.41) and % body fat (r=-0.42 and -0.52) were the only anthropometric measures which, when used separately, correlated significantly ($p<.05$) with those individual resistance settings which produced the highest values for PPO and MPO, respectively. Stepwise multiple regression techniques using BW, % body fat, and thigh volume did not significantly estimate the resistance settings eliciting maximal PO's.

Discussion

The popularity of the Wingate Test resides primarily in its simplicity as maximal power outputs are readily determined with little sophisticated equipment. Since power is a function of the force applied to the flywheel (resistance setting) and the velocity of pedalling, there exists an optimal combination of these two factors where maximal power values are obtained. Basic information on the force-velocity relationship during muscular contraction would suggest that the greater the resistance at the flywheel, the slower the maximal pedalling rate. Thus the relationship between resistance setting and power output over the 30s WT should be represented by a parabolic shaped curve. In an earlier publication, Bar-Or (1) found such a relationship to exist for children up to 15 yrs of age where a resistance setting of 0.075 kg/kg BW resulted in the highest power outputs for leg has since been used in many publications reporting on PO's using WT (2,11,12,14,18).

The major finding in the present study was that a similar relationship between resistance and PO exists in adult males but maximal PO values occur at a mean resistance setting significantly greater than previously shown by Bar-Or. These results are in basic agreement with recently published data on load optimization for the WT (6,8). Evans and Quinney (8) using subject similar in body weight to those of the present study found that a mean force 7.2 kg elicited maximal values for MPO. This force is equivalent to a relative resistance setting of 0.097 kg/kg BW and thus similar to that reported herein. More recently Dotan and Bar-Or (6) reported an optimal load of 0.087 kg/kg BW for maximal MPO in men during leg exercise but could not show a load-optimum for maximal PPO as values had still not peaked at the highest setting used (0.092 kg/kg BW). In light of the present findings and the data of Evans and Quinney (8), it would appear that these authors may have been able to achieve higher maximal PO values by going to higher resistance settings. Furthermore, it is difficult to conceive why such a discrepancy would occur between resistance settings eliciting maximal values for MPO and PPO. Indeed, the present data reveal that maximal values for these two variables occurred at the same mean resistance setting and were also significantly intercorrelated.

As a result of the large individual variation which existed in the location of the resistance setting producing maximal PO values, no well-defined peak in the PO vs. force curve was evident for the group although a tendency was apparent toward an inverted, U-shaped curve. These data agree with the results of Dotan & Bar-Or (6) who found a parabolic relationship between MPO and force. Furthermore, these authors reported that only 35% of individual resistance settings producing maximal MPO values fell within the resistance range in which the group maximum occurred thus implying a large individual variation.

The Wingate resistance setting and that derived from individual maximal PO versus force curves gave reliable test-retest values for both PPO and MPO. These data agree with previously published reliability coefficients on the Wingate setting (10,12) and show that similar reliabilities also occur at higher resistance settings.

Evans and Quinney (8) were able to estimate the resistance setting eliciting maximal MPO from body weight and leg volume using multiple stepwise regression. In the present study, however, such techniques failed to demonstrate a significant relationship between any of the anthropometric variables measured and resistance setting, even though our subjects demonstrated similar heterogeneity in anthropometry and anaerobic fitness as those of Evans and Quinney. The lack of such a relationship agrees, however, with the findings of Katch (13) who reported that body weight and leg volume were of little predictive importance during the early portion (first 30s) of a 2 min cycle ergometer test of anaerobic capacity.

In conclusion, considerable variability occurs among individuals in resistance settings eliciting maximal PO values. However, these settings cannot be reliably predicted using such anthropometric measures as BW, % body fat or thigh volume. It is suggested, therefore, that the resistance setting continue to be assigned according to the subject's BW but consideration be given to increasing it from that presently used in many laboratories.

Acknowledgement

The authors wish to express their sincere appreciation to Dora Ward and Emily Hamilton for the excellent preparation of the manuscript and to the subjects for their dedicated performance of the various tests.

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Figure 1

Mean values (± SE) for peak power, mean power and power decrease versus resistance settings relative to body weight

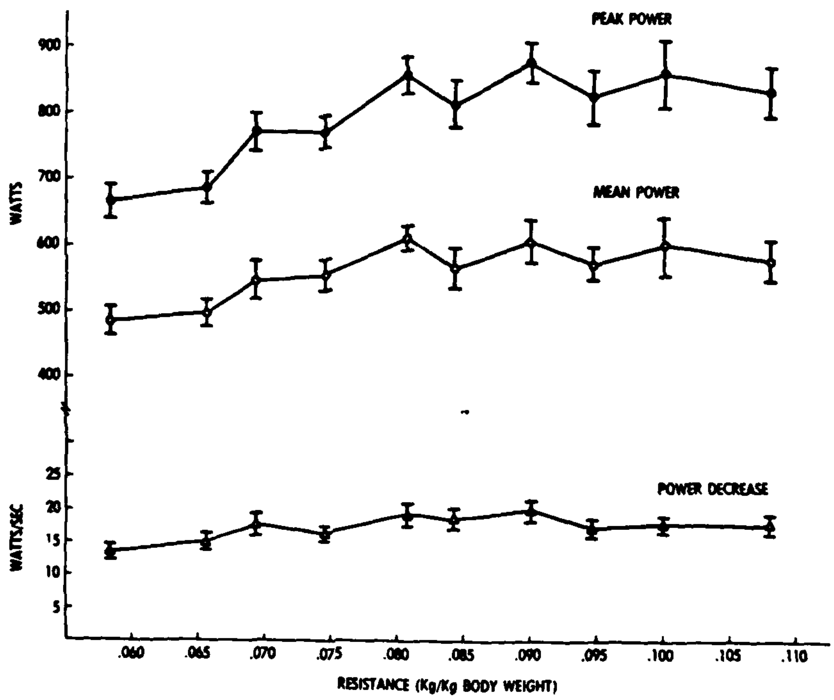

Table 1. Maximal Power Outputs at Resistance Settings of 0.075 and 0.095 kg/kg BW (mean ± SD)

	0.075	0.095
Peak Power		
W	770 ± 94	888 ± 114*
W/kg	10.3 ± 1.1	11.8 ± 1.4*
W/	141.2 ± 18.9	162.8 ± 22.8*
Mean Power		
W	555 ± 89	627 ± 87*
W/kg	7.4 ± 0.9	8.4 ± 0.9
W/	101.4 ± 14.5	114.8 ± 15.1*
Power Decrease		
W/s	16.3 ± 3.4	19.8 ± 3*
Force, kg	5.7 ± 0.8	7.1 ± 0.9*
Mean Pedal Rev/s	1.66 ± 0.21	1.50 ± 0.18*

* $p < .001$, $n=19$

Table 2. Test-retest reliabilities for maximal power outputs at resistance settings of 0.075 and 0.095 kg/kg BW (mean ± SD)

	Test 1	Test 2	r
0.075 kg/kg BW (n=19)			
Peak Power (W)	755 ± 104	768 ± 91	0.93
Mean Power (W)	547 ± 83	566 ± 87	0.93
Power Decrease (W/s)	15.9 ± 3.0	15.9 ± 3.5	0.74
0.095 kg/kg BW (n=13)			
Peak Power (W)	822 ± 191	820 ± 200	0.91
Mean Power (W)	565 ± 122	555 ± 122	0.93
Power Decrease (W/s)	18.0 ± 4.8	20.0 ± 5.7	0.43

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