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Step Increment versus Constant Load Tests for Determination of Maximal Oxygen Uptake*

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Abstract. Ten male subjects performed five maximal treadmill running tests at 7 mph. Tests included two (test-retest) progressive, step increment (2½% grade elevation), discontinuous tests (DCT); a progressive, step increment, continuous test (CT) and two constant load tests (CL and CL + 2½%). A DCT test was performed first for establishment of peak elevation levels as constant load tests were performed at the peak elevation level attained (CL) and at a level 2½% higher (CL + 2½%). The second DCT test and the remaining three tests were administered randomly. Peak performance capability (operationally defined as duration at highest grade elevation) was markedly reduced during progressive tests as compared with constant load tests. There was a similar reduction in peak performance capability during the CT test as compared with the DCT test. Maximal oxygen uptake ($\dot{V}O_2$max) was quite similar among the various tests. It was concluded that $\dot{V}O_2$max attained during progressive, step increment, tests is unaffected by cumulative submaximal work. Discontinuous and continuous progressive tests provide similar $\dot{V}O_2$max results.

Key words: Maximal oxygen uptake – Treadmill running – Progressive loading – Constant load.

Introduction

Maximal oxygen uptake ($\dot{V}O_2$max) is generally accepted as a sound physiological indicator of man's capacity for sustaining hard physical work. Various approaches and methods for the assessment of $\dot{V}O_2$max have been reported (Åstrand, 1967; Mitchell et al., 1958; Taylor et al., 1955; Newton, 1963). It is known that the specific nature of a work task (i.e., treadmill walking or running, bicycling, arm cranking, etc.) will influence results (Åstrand, 1967; Faulkner et al., 1971; Hermansen et al., 1969; McArdle et al., 1973; Stamford, 1975). For a given work task,

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however, the influence of testing protocol is not known. For example, what is the relationship between duration of work versus work load in the assessment of $\dot{V}O_2max$? Progressive, step increment tests generally employ work bouts of approximately 3 min. In contrast, constant load tests during which work loads were varied so that exhaustion terminated exercise in 2–8 min have been demonstrated effective (Åstrand et al., 1961). Unfortunately, data comparing the aforementioned protocols are limited and somewhat conflicting. Such a comparison is thought necessary in the continuing effort toward standardization of $\dot{V}O_2max$ assessment procedures.

A study by Horvath and Michael (1970) which compared results obtained from step increment versus constant load tests reported higher $\dot{V}O_2max$ values associated with the latter technique. A fixed order of test administration, however, may have biased results as the step increment test was always administered first. Newton (1963) observed that results from progressive, step increment, testing (Balke Walking Test) were similar to those obtained during a constant load running test adjusted to exhaust subjects in 3–5 min. These results are suspect in view of the fact that $\dot{V}O_2max$ values obtained from the Balke Test are generally found to be approximately 6% lower when compared with step increment tests employing running (McArdle et al., 1973; Stamford, 1975). The purpose of the present study was to compare $\dot{V}O_2max$ obtained from progressive continuous and discontinuous maximal tests with results obtained from constant load maximal tests.

Methods

Ten male undergraduate and graduate students at the University of Louisville volunteered as subjects. Their mean age ($\pm$ standard deviation) was 20.13 $\pm$ 2.3 years, mean bodyweight was 79.82 $\pm$ 5.1 kg, and mean height was 178.46 $\pm$ 8.4 cm. Subjects were not chosen with respect to any particular variable and represented a variety of fitness levels ($\dot{V}O_2max$ range = 41.1–61.5 ml · kg^{-1} · min^{-1}).

Each subject performed a total of five maximal treadmill running tests.

Tests included:

1. Progressive, step increment, discontinuous test (DCT) – Subjects ran at 7 mph for 3 min at 0% grade. This was followed by a 10 min rest period. Treadmill elevation was increased 2½% for each successive 3 min run. An alternating work and rest regimen was imposed until subjects could no longer complete a given 3 min run. Throughout all tests, subjects were verbally encouraged to perform to maximal limits. Expired air was collected during the final 2 min (30 s samples) of each run.

2. Progressive, step increment, continuous test (CT) – Subjects ran at 7 mph for 2 min at 0% grade. Treadmill elevation was increased 2½% every 2 min until subjects could no longer continue. Expired air was collected each minute (30 s samples) following a heart rate of 180 beats · min^{-1}.

3. Constant load test (CL) – Subjects ran at 7 mph at the highest grade elevation attained during the DCT test. Grade elevation was held constant and the test terminated when subjects could no longer continue. Expired air was collected each minute (30 s samples) from the initial 1 and ½ min through termination of the test.

4. Constant load plus 2½% test (CL + 2½%) – Subjects ran at 7 mph at 2½% higher than the highest grade elevation attained during the DCT test. Grade elevation was held constant and the test was terminated when subjects could no longer continue. Expired air was collected each minute (30 s samples) from the initial 1 and ½ min through termination of the test.

The DCT test was performed initially by all subjects so that peak grade elevation could be determined for the CL and CL + 2½% tests. Peak work output was operationally defined as duration at peak elevation levels. Data obtained from this initial test were not utilized in the comparison of $\dot{V}O_2max$ values among tests. Rather, the DCT test was again performed; however, the second performance was randomly assigned as were the remaining three tests. $\dot{V}O_2max$ values obtained from the two DCT tests were highly reliable (r = 0.93) and not significantly different (t-ratio = 0.246).

All subjects were thoroughly familarized with treadmill running prior to performance of the first test. Each test was preceeded by a warm-up consisting of walking at 3.5 mph at 10% grade elevation for 10 min. The warm-up was followed by a 5 min rest period. Testing was conducted at the same time of day for each subject and separated by a minimum of 48 h. Pre-test protocol was emphasized and included reporting to the laboratory in a well rested condition a minimum of 2 h following the intake of food.

During exercise, subjects breathed through a Collins triple "J" valve. Ventilatory volume ($\dot{V}_E$) was determined from a Parkinson-Cowan dry gas meter and expired air was collected in meteorological balloons. Air samples were immediately analyzed for O_2 and CO_2 concentrations by means of frequently calibrated Beckman E_2 and LB-2 analyzers. Heart rate (*HR*) was recorded electrocardiographically during the final 15 s of each minute of exercise.

Statistical analysis of obtained data included an analysis of variance of repeated measures and a correlation matrix. Statistical significance was established at $P < 0.05$.

Results

Table 1 contains mean values ± standard deviation for $\dot{V}O_2$max (STPD), *HR*max, maximum respiratory exchange ratio (*R*), $V_E$max (BTPS), maximum grade elevation attained for a given test and warm-up *HR*. An analysis of variance for repeated measures was utilized to determine significant differences for each variable in the DCT, CT, CL and CL + 2½% tests. No significant *F*-ratios were found. The mean duration at peak elevations differed as follows: DCT – 3 min; CT – 1.6 min; CL – 3.9 min; CL + 2½% – 2.65 min.

A plateau in $\dot{V}O_2$ sufficiently adequate to assume $\dot{V}O_2$max was found for each testing protocol (Taylor et al., 1955). Mean differences of 137 and 112 ml · min^{-1} were found between final successive work levels of the DCT and CT tests respectively, $\dot{V}O_2$ declined somewhat during the final work bout in three subjects on the DCT test. The final two $\dot{V}O_2$ determinations differed less than 70 ml · min^{-1} on the CL and CL + 2½% tests.

The interrelationships between $\dot{V}O_2$max on the various tests are presented as a correlation matrix in Table 2. All correlation coefficients were significant and indicate a high degree of relationship between tests.

Table 1. Comparisons of physiologic data among maximal treadmill tests ($N = 10$)

Variable	Discontinuous (DCT)	Continuous (CT)	Constant load (CL)	Constant load + 2½% (CL + 2½%)	*F*-ratio[a]
$\dot{V}O_2$ max ml · min^{-1}	3991 ± 474	3933 ± 386	3917 ± 473	3921 ± 434	0.075
$\dot{V}O_2$ max ml · kg^{-1} · min^{-1}	50.14 ± 7.32	49.58 ± 8.04	49.30 ± 8.01	49.41 ± 8.27	0.029
HR max bts · min^{-1}	202 ± 7.8	207 ± 9.4	200 ± 8.4	200 ± 9.0	1.426
HR warm-up bts · min^{-1}	153 ± 22.8	152 ± 20.1	152 ± 20.5	152 ± 21.1	0.544
$\dot{V}_E$max (BTPS) l · min^{-1}	143 ± 25.8	148 ± 20.0	150 ± 22.9	151 ± 20.5	1.231
R	1.02 ± 0.03	1.09 ± 0.04	1.09 ± 0.05	1.09 ± 0.05	2.644
Elevation max %	8.5 ± 2.69	8.5 ± 2.69	8.5 ± 2.69	11.0 ± 2.69	–

[a] *F*-ratio of 2.86 and 4.38 significant at $P < 0.05$ and 0.01, respectively

Table 2. Correlation matrix for $\dot{V}O_2$ max (ml × kg^{-1} × min^{-1}) ($N = 10$)

Test	2	3	4
1. Discontinuous	0.93	0.89	0.87
2. Continuous		0.88	0.87
3. Constant load			0.91
4. Constant load + 2½%			

$r = 0.735$ significant at $P < 0.01$

Discussion

Results of the present study indicate that progressive, step increment, techniques applied to maximal performance testing reduce peak work output capability. Duration at peak elevation levels was 1.6 and 3 min, respectively for the CT and DCT tests as compared with 3.9 min for the CL test. Although DCT testing required 3 min work bouts, it is unlikely that subjects could have pushed beyond this limit at peak elevation since much verbal encouragement was required to ensure completion of the entire bout. Further, if subjects were capable of greater work performance than 3 min, the subsequent work bout could probably have been completed or near completed. Duration time for the final (unsuccessful) work bout of the DCT test was only 1.8 min which is reflective of the degree of stress encountered on the previous bout and supports the 3 min previous bout as a valid representative of peak work output. Duration time for the CL + 2½% test was 2.65 min as compared with1.8 min at the same elevation for the DCT test. These results further support a decrement in peak work output through progressive, step increment, techniques. Differences between DCT and CT tests (3 min versus 1.6 min) indicate that partial recovery resulting from alternating work and rest bouts will greatly increase duration at peak elevations.

Notwithstanding the effects of progressive, step increment, techniques with respect to limitations upon peak work output, $\dot{V}O_2$max was quite similar for all tests. These data indicate that $\dot{V}O_2$max is unaffected by the cumulative effects of submaximal work. In addition, the present data suggest that $\dot{V}O_2$max is not necessarily associated with a given level of absolute work. For example, two subjects reached $\dot{V}O_2$max at 7½% during the CT test and plateaued during the first minute at 10%. These $\dot{V}O_2$max values were similar to those obtained during work performance at 12½% (CL + 2½% test).

$\dot{V}O_2$max values were similar for DCT and CT tests. These data agree with those of other investigators who have reported no significant differences in $\dot{V}O_2$max between continuous versus discontinuous tests (Davies et al., 1970; Maksud et al., 1971; Shephard et al., 1968; Wyndham et al., 1966). Since similar results are derived from continuous or discontinuous tests, implementation of either technique will depend upon the objectives of the investigator. Discontinuous testing offers the advantage of steady state data providing work bouts are expanded to 5 min. On the other hand, from the standpoint of administrative feasibility for testing large numbers of subjects, continuous testing is preferred owing to the reduced time requirement. In the present study, discontinuous testing required approximately 45 min to 1 h whereas continuous tests could be completed in approximately 15 min (not including warm-up, electrode placement, etc. in either case).

Constant load testing is sometimes utilized in place of progressive, step increment techniques. Data from the present study indicate that a range of work levels may bring about an accurate assessment of $\dot{V}O_2$max. Additional data is required, however, at work levels below those obtained through progressive techniques (i.e., $<$ peak elevation). Until such data is reported and accurate work level prediction procedures are developed, progessive tests must be considered the more prudent alternative.

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