COMPARISON OF GRADE-INCREMENTED VERSUS SPEED-INCREMENTED MAXIMAL EXERCISE TESTS IN TRAINED MEN

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At present, it is generally accepted that grade-incremented treadmill running (GR) invokes a greater maximal aerobic demand ($\dot{V}O_2$ max) than speed-incremented horizontal running (SR) in normal subjects. This difference in oxygen consumption appears to be due to the subject's inability to maintain the increasing pace during SR, i.e., he never attains a true maximum, and the recruitment of ancillary muscle groups during GR (4, 25, 29).

Nevertheless, SR is still widely used as an aerobic capacity test. It appears most popular among Japanese researchers (18, 20, 21, 23), although it has been used elsewhere (16, 32). Indeed, Mathews and Fox (17) recommend that speed rather than grade be increased during maximal exercise tests of individuals with high aerobic capacities.

The original conclusion that GR elicits a higher $\dot{V}O_2$

max than SR was based on tests of untrained subjects (29). Thus, a comparison of responses in highly trained subjects undergoing GR and SR evaluation needs yet to be documented and, in so doing, may remove the uncertainty regarding the possible differences between these two modes of maximal aerobic power testing. The purpose of the present study was to assess the differences between GR and SR in eliciting maximal physiological responses in highly trained individuals.

Methods

Ten well-trained adult males, each a skilled runner, were subjects for this study (Table I). Each subject had refrained from strenuous activity for more than 8 hours prior to testing and reported to the laboratory at least 2 hours postabsorptive. The order for the GR and SR tests was randomly assigned with 2-10 days intervening between tests.

Table I

Subject Physical and Physiological Characteristics

Subject	Age (yrs)	Height (cm)	Weight (kg)	% fat*	$\dot{V}O_2$ max** (ml/kg/min)	Performance Comments/Training Schedule
KC	24.91	184.1	77.15	7.0	67.6	Runs 193 km/mo.
GD	24.33	186.0	72.15	4.6	74.0	4:07 mile
PD	26.83	173.1	53.90	3.4	75.3	2:27 marathon
PG	22.33	177.2	76.00	7.4	63.9	Runs 130 km/mo
RG	22.75	170.8	60.00	5.6	72.0	4:01 mile
SG	39.75	171.8	62.58	6.7	70.6	2:34 marathon
BH	24.00	183.2	74.45	7.0	70.3	5th in Olympic trials 50 km walk
JM	27.67	179.0	75.08	5.1	65.7	18:52 3.5-mile cross-country
GS	24.75	184.3	72.73	5.4	70.2	3:05 marathon
JW	24.10	171.6	72.05	8.8	60.5	All Big 10 rugby halfback
Mean	26.08	178.1	69.61	6.1	69.0	
SD	5.07	6.0	7.90	1.6	4.6	

* Predicted from Brozek and Keys, *Brit.J.Nutr.*, 5: 194-206, 1951.

** Determined by grade-incremented treadmill running.

The pretest procedures consisted of 15 minutes of seated rest followed by a 5-minute horizontal warmup run at 11.3 km/hr (7 mph). The warmup and the maximal run were separated by a 5-minute interval which allowed the subject to adjust the mouthpiece and respiratory valve (modified Otis-McKerrow) to his comfort.

The protocol for GR followed the procedure reported by Costill and Fox (6). The speed was subjectively set according to the performance ability of the subject in order to produce exhaustion within 8-12 minutes. Speeds ranged from 12.9-17.7 km/hr (8-11 mph) and remained constant throughout the run. Following the first 4 minutes at 0% grade, the inclination was raised to 4%. Thereafter, the grade was increased 2% every 2 minutes until voluntary termination by the subject.

The SR test followed the same pattern as GR with the initial speed chosen to exhaust the subject within 12 minutes; initial speeds ranged from 12.9-16.1 km/hr (8-10 mph). Following the first 4 minutes at constant speed, the speed was increased 0.8 km/hr (0.5 mph) every 2 minutes until voluntary termination. The grade remained level (0%) throughout the test.

Pulmonary ventilation ($\dot{V}_E$), expired gas temperature, and breathing rate (f_b) were recorded on an ink strip-chart recorder (Gould-Brush 220). A potentiometer attached to a Parkinson-Cowan (CD 4) dry gas meter provided the ventilation input signals. Expired gas was sampled using an apparatus previously described in detail (19). One-minute aliquots of the expirate were taken in metallized polyethylene bags (15) and were electronically analyzed (Beckman E-2 O₂ and MSA Lira 300 CO₂ analyzers) within 5 minutes of collection. The electronic analyzers were frequently calibrated using reference gases which had been analyzed on a Lloyd-Gallenkamp apparatus. Oxygen consumption was computed according to Consolazio *et al.* (5), with the highest value being accepted as the VO₂ max. Heart rate (HR) was obtained by an electrocardiographic telemetry system (Narco Bio-System) during the last 15 seconds of each minute of the run. Laboratory conditions for these experiments remained stable throughout the testing period (temperature = 23.5 ± 0.7 °C; relative humidity = 47.0 ± 2.4%).

Results

Maximal values for all cardiorespiratory parameters are presented in Table II, VO₂ max (l/min and ml/kg/min), tidal volume (V_T), and O₂ pulse were significantly greater during GR. Heart rate, ventilatory equivalent (VE), pulmonary ventilation ($\dot{V}_E$), breathing rate (f_b), and respiratory exchange ratio (R) did not differ between the two tests. The mean duration and end-grade for GR were 10.40 ± 1.34 mins and 8.4 ± 1.3%, respec-

tively. The mean duration and end-speed for SR were 10.50 ± 0.84 mins and 13.1 ± 0.9 min/hr, respectively.

Table II

Maximal Cardiorespiratory Parameters from Two Forms of Treadmill Stress (mean ± SD)

Variable	GR	SR	diff. (G-S)	r*	t ratio**
$\dot{V}O_2$ max (l/min)	4.78 ±0.45	4.63 ±0.51	0.15 ±0.15	.96	2.97 ^a
$\dot{V}O_2$ max (ml/kg/min)	69.0 ±4.6	66.9 ±5.3	2.1 ±2.3	.91	2.87 ^a
$\dot{V}_E$ (l/min BTPS)	162.9 ±15.1	159.4 ±20.5	3.5 ±10.7	.86	1.04
f_b (breaths/min)	56.2 ±11.4	58.4 ±13.2	-2.2 ±4.9	.93	-1.43
V _T (l/breath)	2.98 ±0.59	2.84 ±0.58	0.14 ±0.15	.97	2.99 ^a
$\dot{V}_E$ ($\dot{V}_E/\dot{V}O_2$)	2.77	2.84	-0.08	.79	-1.60
ml x 100	±0.24	±0.211	±0.15		
HRmax (bpm)	186.3 ±16.6	187.6 ±18.0	-1.3 ±5.2	.96	0.34
O ₂ pulse (ml/beat)	25.8 ±3.2	24.9 ±3.5	0.9 ±1.0	.95	2.68 ^a
R	1.12	1.12	0.0	.40	0.29
($\dot{V}CO_2/\dot{V}O_2$)	±0.05	±0.07	±0.7		

* Correlation between maximal values for GR versus SR.

** t-test for paired observations.

^a Significant at p < .05.

Discussion

This study was designed to determine if significant differences existed between GR and SR in eliciting maximal aerobic power and associated physiologic measures in well-trained subjects. Our results suggest that GR imposes a greater aerobic demand on trained subjects than SR and, therefore, agree with the observations of normal subjects by Taylor *et al.* (29). The data in this study also agree closely with the results of Hermansen and Saltin (13) who found a 0.2 l/min difference in VO₂ max between graded and nongraded running to exhaustion in "healthy" male subjects. Molnar *et al.* (24) likewise noted an increasing tendency toward higher VO₂ max values with greater elevations in treadmill running.

Using O₂ pulse as an index of stroke volume (2, 9, 31), the greater VO₂ max during GR may have resulted from a significantly larger cardiac output since maximal HR was approximately equal for the two tasks. However, since O₂ pulse must also involve to some degree, the arteriovenous oxygen difference, and because the

latter's contribution to interpreting a maximal exercise response remains controversial (22), further research must be undertaken to determine the meaning of $\dot{V}O_2$ pulse under maximal stress conditions.

During uphill running, auxiliary muscle groups, such as the erector spinae and shoulder girdle muscles involved in arm movement, may be recruited and contribute to an overall larger oxygen requirement than during SR (26). Additionally, it is possible that the increased rate of muscular contractions during SR impeded venous return (28) by creating high intramuscular pressures which could restrict blood flow to the working tissues (3, 12). Therefore, although the rhythmic contractions of running have been thought to promote muscle blood flow (10), local muscle circulation may have been compromised due to the reduced relaxation period during SR (11).

It is interesting to note that a plateau for oxygen uptake was reached by only half of our subjects in both test conditions (Figure 1). This observation coincides with the children studies of Åstrand (1) who used a discontinuous treadmill test and Cumming and Friesen (7) who used a continuous bicycle test. To date there is no known clear commentary on oxygen uptake plateauing in adult subjects undergoing continuous progressive treadmill stress. Our results do not conform to the standard criterion of Taylor *et al.* (29) who suggested that the identity of $\dot{V}O_2$ max could be obtained by noting the point at which increased work resulted in less than 150 ml increase in oxygen consumption. Additional consideration should be given to the relationship of the subject's age and proximity to his maximal HR (27), the point at which anaerobic threshold is attained (8, 30), a high R (14), and fatigue or loss of coordination by the subject (16) in establishing guidelines for identifying $\dot{V}O_2$ max. Furthermore, arterial lactic acid concentration may be used as an indicator of all-out effort (2, 27).

In conclusion, these results do not confirm the use of SR as a test for evaluating maximal aerobic power in trained adult males. The data do, however, provide further support for the use of GR as an effective tool for identifying $\dot{V}O_2$ max.

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Figure 1. Final minutes of oxygen consumption during maximal treadmill stress.

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