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MAXIMUM OXYGEN UPTAKE UTILISING DIFFERENT TREADMILL PROTOCOLS

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ABSTRACT

The study compared five treadmill protocols (four utilising a motorised, and one a non-motorised, treadmill) on maximum oxygen uptake. The five male and five female subjects, all actively engaged in training, were assigned the tests in random order.

Statistical analysis revealed no significant differences between the five protocols for maximal oxygen uptake, maximum ventilation, maximum heart rate and blood lactate inflection point, relative to maximal oxygen uptake. Significant differences were observed between the 3' protocol with incline increments of 1.5% and all other protocols on time to exhaustion ($p < 0.01$) and maximum blood lactate levels (HLA, $p < 0.05$).

The results indicate that the protocols used in this study did not significantly influence the maximum oxygen uptake attained.

Key words: Oxygen uptake, Motorised treadmill, Non-motorised treadmill.

INTRODUCTION

Maximum oxygen uptake ($\text{VO}_2 \text{ max}$) is probably the most widely used measure for the assessment of physiological capacity, and, providing that the criteria for this are attained, it remains one of the most objective assessments of physical fitness. Similarly, there is a need for specificity, both in the selection of test protocols and ergometry, to assess $\text{VO}_2 \text{ max}$ (Bouchard et al, 1979). It is essential that laboratory tests physiologically simulate as closely as is practically possible the training and competitive environment. The non-motorised treadmill (NMT) is a recently developed ergometer, which requires the subject's own power to drive the belt. It appeared conceivable, therefore, that this ergometer might provide

a closer simulation of track running than the motorised treadmill.

Previous work completed in our laboratory compared two maximal protocols on the motorised and non-motorised treadmill. No significant differences were observed on selected variables: maximum oxygen uptake ($\text{VO}_2 \text{ max}$), maximum heart rate (fH), maximum ventilation (VE) and maximum lactate (HLA), although there was a tendency to achieve higher $\text{VO}_2 \text{ max}$ and HLA on the non-motorised treadmill.

The motorised treadmill has been used extensively

to elicit a maximal work level, resulting in the development of numerous protocols designed to meet specific requirements (Balke and Ware, 1959; Bruce et al, 1963; Åstrand and Saltin, 1961; Costill and Fox, 1969). This study was designed to compare VO_2 max and other physiological parameters, using five selected treadmill protocols.

Methods

The subjects were five males and five females, who were actively engaged in athletics and sport, and well habituated to treadmill running. All were randomly assigned five maximal treadmill protocols, which included four on the motorised treadmill (Woodway) and one on the non-motorised treadmill (Woodway). The five protocols were completed by each subject, within six weeks of commencing the study.

The motorised treadmill protocols consisted of a five minute 'warm-up' at 10 kph (women), or 12 kph (men), followed by:

1. Constant speed, 12 kph (women), or 14 kph (men), with increases in slope of 1.5% each minute.
2. Constant speed (as in 1) with increases in slope of 1.5% every two minutes.
3. Constant speed (as in 1) with increases in slope of 1.5% every three minutes.
4. Horizontal treadmill with speed increases of 1 kph each minute, commencing at 12 kph (women) and 14 kph (men).
5. NMT (horizontal) with speed increases of 2 kph every three minutes, starting at 10 kph. Preceded by a five minute warm-up at 8 kph.

Criteria for the attainment of maximum work were voluntary exhaustion, a VO_2 'plateau' of 150 ml following consecutive increases in work load, a respiratory exchange ratio (R) > 1.0 , and maximum blood lactate levels $> 10.0 \text{ mmol.l}^{-1}$. VO_2 was measured, using an on-line computerised gas analysis system (Beckman) calibrated against a Tissot gas meter and Lloyd Haldane chemical gas analyser. Expired air was channelled through a high velocity low resistance valve (Jakeman and Davies, 1979). Exercise heart rates were ascertained by cardiometer (Cardionics) and lung capacities by wedge spirometer (Vitalograph). Capillary blood samples ($50 \mu\text{l}$) were obtained by pin prick at 20 second intervals during continuous running, and at two and five minutes post-test, to ascertain lactate inflection point [4 mmol.l^{-1}] (Mader et al, 1976) and post-exercise lactate levels (Gass et al, 1981). Samples were subsequently assayed in duplicate according to the methods of Guttman and Wahlefeld (1974).

Prior to the commencement of each test, haemoglobin (Hb), pack cell volume (PCV), weight, forced vital

capacity (FVC) and forced expiratory volume (FEV_1) were determined (Table I).

The data was analysed by a two factor analysis of variance, the Newman Keuls procedure being used to examine specific differences following a significant F ratio (Winer, 1974). The regressions of VO_2 versus treadmill stage, and VO_2 versus heart rate, were also calculated.

TABLE I
Some physiological characteristics of the subjects

Subject	Hb (g/dl)	FEV_1 (Litres)	VC (Litres)	Weight (kg)
1*	12.7	3.3	4.4	62.7
2	15.2	4.0	5.2	66.4
3	15.4	3.7	4.95	51.4
4*	12.9	3.5	4.4	60.5
5	15.8	4.9	5.55	65.5
6*	15.0	3.45	4.2	56.4
7*	11.9	3.2	4.45	63.6
8	16.3	4.3	5.05	60.0
9*	13.1	3.4	4.3	55.0
10	15.3	3.85	5.65	59.5
Mean	14.4	3.76	4.82	60.1
SD	1.54	0.524	0.535	4.76

*Women

Results

No significant differences were observed between the five treadmill protocols at maximum for $\text{VO}_2 \text{ ml.min}^{-1}$, $\text{VO}_2 \text{ ml.kg}^{-1} \text{ min}^{-1}$, fH and VE l.min^{-1} (Table II). Significant differences were observed between the three minute protocol and all other protocols on treadmill endurance time ($p = < 0.01$, Table III) and, with the exception of the two minute protocol, on maximum lactate levels ($p = < 0.05$, Table IV). No significant differences were observed between the one, two and three minute protocols on lactate inflection points. These averaged 86% VO_2 max (Table V).

Examination of the oxygen consumption relative to VO_2 max utilised at different stages of the graded incremental motorised treadmill protocols, indicates similarities between the one minute and three minute protocols, with the two minute protocol demonstrating a tendency to demand a lower % VO_2 max at the higher work levels, and a greater % VO_2 max at the lower levels (Fig. 1). When VO_2 ($\text{ml.kg}^{-1} \text{ min}^{-1}$) values are compared to HR values at the different stages, the two minute protocol demonstrated a lower VO_2 for a given HR than all other protocols (Fig. 2).

TABLE II

Maximum oxygen uptake (VO_2 ml.kg⁻¹ min⁻¹) following five treadmill protocols

Subject	1 Min 1.5%	2 Min 1.5%	3 Min 1.5%	1 Min 1 kph	NMT
1*	50.5	48.3	49.4	50.7	52.6
2	62.7	67.8	71.3	68.9	67.8
3	67.6	68.8	70.2	69.2	72.9
4*	42.9	44.7	44.1	43.5	47.3
5	71.8	67.8	70.9	61.1	63.6
6*	61.9	60.4	61.2	60.4	68.4
7*	38.3	40.1	41.3	42.0	40.0
8	64.6	68.5	71.7	69.6	69.4
9*	62.9	59.3	60.9	59.3	58.4
10	72.4	73.2	72.1	71.1	73.1
Mean	59.6	59.8	61.3	59.6	61.4
SD	11.1	11.0	11.6	10.3	11.4

*Women

TABLE III

Treadmill time to exhaustion (mins) following five treadmill protocols

Subject	1 Min 1.5%	2 Min 1.5%	3 Min 1.5%	1 Min 1 kph	NMT
1*	6.1	8.9	10.6	7.6	4.4
2	10.1	12.1	12.0	15.0	6.6
3	10.1	13.0	14.6	8.6	7.0
4*	3.0	4.5	4.5	4.5	3.0
5	8.6	9.0	7.6	7.6	7.6
6*	7.6	12.1	15.5	5.6	6.5
7*	4.0	7.1	5.6	5.0	3.5
8	7.6	12.1	14.0	8.6	6.1
9*	7.6	14.0	16.6	9.7	5.1
10	9.1	18.7	19.2	9.0	10.1
Mean	7.4	11.2	12.0	8.1	6.0
SD	2.5	3.9	4.9	3.0	2.2

*Women

Pre-test levels of Hb, FEV₁, VC and bodyweight (Table I) were not significantly different between any of the testing days. Throughout all the tests the laboratory environment remained stable. Seventy four per cent of all tests exhibited a VO_2 'plateau', and 98% an $R > 1.0$.

Discussion

Our results have demonstrated no significant differences on VO_2 max over the five treadmill protocols, suggesting

TABLE IV

Maximum blood lactate concentrations (mmol/l) following five treadmill protocols

Subject	1 Min 1.5%	2 Min 1.5%	3 Min 1.5%	1 Min 1 kph	NMT
1*	12.3	12.1	8.8	15.3	16.0
2	11.0	11.5	11.0	10.0	11.0
3	15.3	13.0	11.3	13.1	13.0
4*	12.7	15.0	12.7	13.3	13.4
5	15.8	14.3	10.8	13.3	15.0
6*	12.6	15.8	13.0	11.1	16.5
7*	14.8	11.0	11.7	12.5	11.6
8	15.0	14.0	13.3	15.4	14.0
9*	8.0	8.8	9.7	8.0	9.0
10	14.2	15.0	9.0	15.4	11.1
Mean	13.2	13.1	11.1	12.7	13.1
SD	2.4	2.2	1.6	2.5	2.4

*Women

TABLE V

Lactate inflection points (4 mmol/l) expressed as % VO_2 max

Subject	1 Min 1.5%	2 Min 1.5%	3 Min 1.5%
1*♀	86	83	86
2†	92	92	91
3†	85	87	85
4*♀	86	89	91
5*	75	76	78
6*♀	80	87	83
7♀	87	88	85
8	85	84	83
9†♀	92	92	93
10†	91	85	86
Mean	85.9	86.4	86.1
SD	3.34	4.86	4.51

NB The women are subjects 1, 4, 6, 7 and 9

† Endurance trained

* Sprint trained

that all the selected protocols would be valid methods of eliciting VO_2 max. It is interesting to note however the individual variations. Four subjects gained their highest VO_2 max on the non-motorised treadmill (Table II). The test-retest reliability on randomly repeated tests attained a level of $r = 0.96$, with no significant differences being noted. Subject 5 (Table II) demonstrated the greatest between test variation, which could not be attributed to any physiological disorder, reflected by Hb concentration, body weight, VC and FEV₁.

FIG.1

FIG.2

Bouchard et al (1979) have highlighted the need for specificity in the assessment of maximum aerobic power, suggesting that there is a whole repertoire of values for maximum aerobic power of the human machine, depending on the conditions under which it is determined.

The two minute and three minute protocols exhibited the greatest endurance time (Table III). Protocols, which elicit lower treadmill endurance times, tend to be favoured, in order that premature termination of a test, due to local muscle fatigue, can be eliminated (Gibson et al, 1979). The same authors have suggested that either the gradient or the speed should be varied in treadmill work tests, but not both, because of possible mechanical inefficiency at some stages. Tests requiring speed increments, as opposed to incline increments, exhibit lower endurance times (Table III). Both Kash et al (1966) and Sucec (1981) have shown progressively incremented horizontal tests to be valid methods of measuring $\dot{V}O_2$ max.

The preference for the gradient test has been based on the observations of Taylor et al (1955) who found that subjects were unable to maintain running skill at the higher speeds, with 25% of subjects unable to demonstrate a $\dot{V}O_2$ 'plateau'. This was contrary to our results, where only 6% of tests did not demonstrate a $\dot{V}O_2$ 'plateau' on the speed incremented tests, and 20% on the gradient increment tests.

The slope of the regression lines during submaximal level comparisons of % $\dot{V}O_2$ max versus treadmill stage (Fig. 1), and $\dot{V}O_2$ (ml.kg⁻¹ min⁻¹) versus HR (Fig. 2) demonstrated differences in response between the two minute protocols, the one minute 1.5% and the three minute protocols. These differences must therefore question the validity of submaximal prediction of $\dot{V}O_2$ max. The two minute protocol appears to be more economical in terms of oxygen requirements, than the one and three minute protocols during the latter stages of the test. Costill and Fox (1969) have favoured the two minute protocol for the testing of endurance trained athletes and Åstrand and Saltin (1961), and Nagle (1973), have observed that a $\dot{V}O_2$ steady state was reached by the second minute of each progressive work load.

No significant differences were observed between the three gradient incremented protocols on lactate inflection point, which was set at the 4 mmol.l⁻¹ level (Mader et al, 1976). The authors recognise that there may be some inter-subject variability in this method, and that the level at which blood lactate begins to increase non-linearly might be a more reliable estimate of muscle lactate metabolism (Davis et al, 1976). Individual scores ranged from 75-87% in the 'sprint' trained subjects, in comparison to ranges of 85-93% in the specifically endurance trained athletes (Table V). Subjects 4 and 7 were women who were not as actively engaged in endurance training and subject 8 was a 1500 m athlete. Between test differences are also apparent in some subjects (4, 6 and 10). Tolerance of prolonged exercise at a high percentage of $\dot{V}O_2$ max is a characteristic of the endurance performer (Costill et al, 1973) and for this type of athlete a high positive correlation between muscle respiratory capacity, the lactate concentrations.

Post-test blood lactate concentrations were significantly lower during the three minute protocol than all other protocols, corresponding to a longer treadmill endurance time. One subject (no. 9, Table IV) did not exhibit lactate levels > 10.0 mmol; this is not unusual in females (Drinkwater et al, 1975).

$\dot{V}O_2$ max is regarded as one of the more important physiological criteria of endurance capacity (Åstrand and Saltin, 1961) and is, therefore, an important feature of an athlete's fitness profile. The choice of ergometer is dependent on the task to be simulated and is very

important to the concept of specificity. The closer one can simulate the specific muscular action involved in an activity, the more objective and valuable the VO_2 max assessment becomes. To this extent, this study has highlighted the contribution of the non-motorised treadmill as a valid method of attaining VO_2 max. In

addition, it has demonstrated that the protocols used in this study did not significantly influence the maximal oxygen consumption attained. However, we have found that some protocols are perceived more favourably by individuals, and the results indicated that some subjects attained higher maximum values on specific protocols.

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BOOK REVIEW

Title: PEDIATRIC AND ADOLESCENT SPORTS MEDICINE
Authors: Edited by Lyle J. Micheli, MD. Various contributors
Publisher: Little Brown and Company, Boston, Massachusetts 02106
Price: \$35.75

This book, the work of a distinguished team of contributors deals with sports medicine problems of children and adolescents who are taking an increasing role in modern sport. Having outlined the problems experienced by parents and coaches, the opening chapter, by the editor, deals with stress, and injuries to which the young are more susceptible. It encourages close supervision of their activities.

Emergency treatment of head, cervical spine, chest, heart, and soft part injuries is described. One small but important point, is the omission of the under-water sealed bottle in the treatment of pneumothorax.

Preparticipation medical examination and first aid measures for dealing with a variety of situations are described and guidelines for doctors which could disqualify the would-be competitor from intensive or contact sports are enumerated. These are suggested by the American Medical Association. In some of the conditions described, modified sport might be permissible. This is a useful contribution for practitioners who monitor competitors and supervise sports meetings as a part-time interest.

When assessing upper extremity injuries, distinction must be made between macrotrauma and overuse syndromes. Clinical pointers are described and illustrated and a variety of conditions analysed. The pre-adolescent is at less risk of injury to the lower extremity than the older student. Children are more susceptible to growth-plate injuries and avulsions of musculotendon insertions from bone. In this chapter particular reference is made to knee joint injuries and the adjacent structures. When dealing with ankle sprains one must be alert to the possibility of epiphyseal fractures or growth-plate injuries of the tibia and fibula.

With care, many spinal injuries can be prevented. Adequate warm-up with stretching exercises is advised. Care of the suspected injury is described and the value of rehabilitation in spinal injury stressed. Scoliosis is not a contraindication to participation, many scoliotics having reached high sporting standards. Low back pain, its causes and management are detailed.

The problems of asthma, diabetes, and epilepsy in sport are mentioned. It is pointed out that in the latter condition many activities can be enjoyed under supervision.

Healthy diet and the use of supplements such as iron in young women competitors is described and attention is given to the pre-game meal and the socially deprived athlete.

Further chapters deal with psychological manifestation in sport, the female athlete, the handicapped participant, with a final chapter on conditioning.

I have enjoyed reading this book which is equally valuable to the doctor, the physiotherapist, or the physical educationist. It is well produced. Each chapter concludes with many references which will give specialised information to those anxious to further their studies of sports medicine.

Noel Bleasdale