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Comparison of oxygen uptake during a conventional treadmill test and the shuttle walking test in chronic airflow limitation

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Comparison of oxygen uptake during a conventional treadmill test and the shuttle walking test in chronic airflow limitation. S.J. Singh, M.D.L. Morgan, A.E. Hardman, C. Rowe, P.A. Bardsley. ©ERS Journals Ltd 1994.

ABSTRACT: The purpose of this study was to investigate the relationship between performance on the shuttle walking test and maximal oxygen uptake ($\dot{V}O_2max$) during a conventional treadmill test in patients with chronic airflow limitation.

Two different techniques were used to measure oxygen consumption, *i.e.* conventional Douglas bag techniques (treadmill test) and a portable oxygen consumption meter (shuttle test). Initially, 19 patients performed a shuttle walking test (after one practice walk) and a maximal treadmill walking test, in a randomized, balanced design. Subsequently, 10 patients, (after one practice) completed an unencumbered shuttle walking test and one supporting the portable oxygen consumption meter, in random order.

The results of the first experiment revealed a strong relationship between performance during the shuttle walking test and $\dot{V}O_2max$ during the treadmill walking test (r=0.88). The results of the second experiment consistently demonstrated an incremental increase in oxygen consumption and ventilation in response to the increasing intensity of the shuttle walking test. Again, a strong relationship between $\dot{V}O_2max$ and performance on the shuttle test was demonstrated (r=0.81).

We concluded that the shuttle walking test is a valid field exercise test of functional capacity. Performance on the test relates strongly to $\dot{V}O_2max$, the traditional indicator of cardiorespiratory capacity.

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We have previously shown that the 10 m shuttle walking test is a reproducible measure of functional capacity in patients with chronic airflow limitation [1]. The purpose of this study was to examine the relationship between the traditional measure of functional capacity, maximal oxygen consumption ($\dot{V}O_2max$), and performance on the shuttle walking test in a similar group of patients.

Maximal oxygen uptake is regarded as an index of cardiorespiratory capacity. It may be used to prescribe an appropriate training intensity in rehabilitation programmes [2], and to identify improvements in endurance fitness. The most precise method of measuring $\dot{V}O_2max$ is by analysis of expired air during a maximal laboratory exercise test but, for a variety of reasons, this is not always possible. Consequently, field exercise tests are often employed, but they usually require the patient to judge his or her pace correctly and to understand the requirements of the test. Such self-paced tests may provide an imprecise estimate of functional capacity, since they are subject to the effects of mood and encouragement [3]. The 12 min corridor walking test, for example, has been shown to have only a moderate relationship with $\dot{V}O_2max$ [4].

The shuttle walking test that we have developed is externally-paced, and consequently less likely to be influenced by encouragement. It is also incremental, stressing the patient to a symptom-limited maximal performance.

This paper examines the relationship between patients' performance on the shuttle walking test and $\dot{V}O_2max$, employing two different approaches. In the first experiment, we measured $\dot{V}O_2max$ during a conventional treadmill test and examined its relationship with shuttle test performance. In the second experiment, we made ambulatory measurements of the oxygen uptake during the shuttle walking test. These two experiments allowed us to examine the relationship between $\dot{V}O_2max$ and performance, and to confirm that the shuttle walking test provokes a maximum performance from patients in the same way as a conventional treadmill test.

Patients and method

Patients

Patients with stable chronic airflow limitation were recruited from medical clinics and informed consent was obtained. Patients were excluded if they were known to be hypoxic, had cor pulmonale or ischaemic heart disease. Individuals presenting with any other disorder that might influence exercise performance were also excluded.

Twenty two patients were recruited for the study, which consisted of two separate experiments. In the first, we examined the relationship between shuttle test performance and $\dot{V}O_2$max measured during treadmill walking (n=19). In the second, we examined the patients' physiological responses during the shuttle walking test (n=10). Seven patients completed both experiments. The study was approved by the Local Ethics Committee.

Study design

For each experiment, patients were required to make three visits to the hospital at intervals of approximately one week, always at the same time of day. They were requested not to take any bronchodilator therapy for 3 h prior to testing, but received all other medication as normal. The baseline measurements were the same for all three visits for both experiments and included spirometry (forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC)), completion of the Chronic Respiratory Disease Questionnaire (CRDQ) [5] and measurement of height and weight. The first visit was for familiarization. The patients performed one practice shuttle walking test according to the established protocol [1]. Briefly, the test requires patients to walk at increasing speeds up and down a 10 m course. The speed of walking, increasing every minute, is controlled by audio signals played from a tape cassette. During the shuttle walking test, heart rate was recorded using a short range telemetry device (Sports Tester PE3000 Polar Electro, Finland) and Borg breathlessness score [6] was recorded before and after completion of the test.

The relationship between performance on the shuttle walking test and treadmill $\dot{V}O_2$max (Experiment 1)

Nineteen patients were recruited (17 males and 2 females; mean (SD) age 61 (7) yrs; weight 72 (14) kg; height 1.70 (0.06) m). In addition to the practice shuttle walking test, on the first visit referred to above, the patients were familiarized with the treadmill (Cambridge 3060). A modified Balke treadmill test [7] was employed, which uses a constant speed with increases of the gradient from 0%, by 2.5%, every 2 min. The speed of walking was gauged for each patient, aiming for each individual to reach a symptom-limited $\dot{V}O_2$max in 6–10 min. The second and third visit were presented to the patient in a randomized, balanced design, *i.e.* the treadmill walk followed a week later by the second shuttle walking test or *vice versa*. The treadmill visit required the patients to perform a symptom-limited maximal exercise test. Expired air was collected in a series of Douglas bags during the second minute of each 2 min exercise period and analysed for oxygen (O_2) and carbon dioxide (CO_2). The last collection of expired air was made during the final minute of exercise, as indicated by the patient. During the second minute of each stage, heart rate was recorded from the monitor and the perceived breathlessness was recorded. The results from the second shuttle walking test were used to evaluate the relationship between the results from the treadmill test and performance on the field exercise test.

Measurement of $\dot{V}O_2$ during the shuttle walking test (Experiment 2)

Ten patients (6 males and 4 females; aged 64 (7) yrs, weight 70 (15) kg; height 1.65 (0.07) m; FEV_1 1.02 (0.38) *l*; FVC 2.06 (0.49) *l*) were recruited, and familiarized with the shuttle walking test and the equipment employed to measure ambulatory oxygen consumption. In the following two visits they performed an unencumbered shuttle walking test and a shuttle walking test during which oxygen uptake was determined, in a randomized balanced design.

Oxygen uptake was determined during the shuttle walking test using a portable oxygen consumption meter (Oxylog P.K. Morgan). This allows the ambulatory measurement of ventilation (inspiratory flow ($\dot{V}I$)), percentage of O_2 in expired air, and hence oxygen consumption. A data logger (Grant Instruments) was connected to the Oxylog to record and store the data, which were later retrieved *via* a dedicated software package.

Patients were required to wear the Oxylog and logger in a back-pack, the mouthpiece being supported by a head harness (Hans Rudolph). The total weight of the equipment was 4.1 kg. Prior to this study, the validity of the Oxylog measurements were examined as described below. The reliability of the Oxylog had been confirmed previously in a small group of healthy individuals.

Assessment of the validity of the Oxylog. Comparisons were made with Oxylog measurements ($\dot{V}O_2$ and ventilation, $\dot{V}I$) and conventional Douglas bag measurements during treadmill walking in 5 patients and in 10 healthy volunteers. A consistent underestimation of ventilation (all volumes converted to $\dot{V}I$ at STDP) was identified with the Oxylog system which was attributable in part to the poorly fitting face mask, a problem previously reported [8, 9]. Subsequently, a mouthpiece (Hans Rudolph 1410), which was more acceptable to this group of patients, was incorporated into the system. With the mouthpiece, there was no significant difference in the measurement of $\dot{V}O_2$max between the Oxylog and Douglas bags, although a small but significant underestimation in ventilation by the Oxylog persisted. The option of the Oxylog was, therefore, favoured in preference to ambulatory Douglas bag collection, which is both cumbersome and difficult to operate for repeated collections.

Statistical analysis

Analysis was performed according to the recommendations of BLAND and ALTMAN [10], using the CIA V1.1 software package and "Minitab V.8" statistical package for IBM compatible computers to examine the agreement between tests. The relationships between performance variables were evaluated using standard parametric tests. Results of the CRDQ were subject to appropriate non-parametric analysis [11]. Values are presented as mean (SD) unless otherwise stated, and a 5% level of significance was adopted throughout.

Results

All patients completed the study. The results of the CRDQ revealed that all patients were psychologically and emotionally stable. Examination of the results of the four components of the questionnaire revealed no significant difference between study days.

Relationship between performance on the shuttle walking test and treadmill $\dot{V}O_2max$ (Experiment 1)

The relationship between the distance walked on the shuttle walking test and the directly determined $\dot{V}O_2max$ was strong (r=0.88) (fig. 1). It was represented by the regression equation (with 95% confidence intervals): $\dot{V}O_2max$=4.19 (1.12–7.17) + 0.025 (0.018–0.031) distance where $\dot{V}O_2max$ is in ml·min⁻¹·kg⁻¹ and distance is in metres. As anticipated, there was a poor relationship between the FEV_1 values and the shuttle performance (r=0.36).

The results of the treadmill test are shown in table 1. The mean walking speed was 2.52 mph and the mean duration of the test was 7.1 min. When the equation [(FEV_1 × 18.9) + 19.7)] was used to predict maximal ventilation [12], this group of patients attained a mean

Table 1. – Treadmill study (n=19), performance and ventilatory results

		Result	
FEV_1 *l*		1.4	(0.5)
FEV_1/FVC		54.8	(11.5)
FVC *l*		2.67	(0.73)
$\dot{V}O_2max$	$ml \cdot min^{-1} \cdot kg^{-1}$	14.2	(4.1)
	% pred	66.2	(19.1)
$\dot{V}Emax$	$l \cdot min^{-1}$	44.2	(14.1)
	% pred	94.8	(18.7)
HRmax	$beat \cdot min^{-1}$	133	(18)
	% pred	78.5	(11.8)

Data are presented as mean and SD in parentheses. FEV_1: forced expiratory volume in one second; FVC: forced vital capacity; $\dot{V}O_2max$: maximal oxygen uptake; $\dot{V}Emax$: maximal expiratory flow; HR: heart rate; % pred: percentage of predicted value.

maximal ventilation representing 95% of predicted. Nine patients exceeded 100% of their predicted maximal ventilation. The mean maximal heart rate attained during the treadmill test represented 76% of predicted maximum heart rate. This rate was significantly greater than that observed during the shuttle walking test (mean difference 17 (11) beats·min⁻¹). At comparable speeds of walking, the heart rate was higher during the treadmill test (at 0% inclination) than at a similar speed in the shuttle walking test in all but five patients (total 19).

Measurement of $\dot{V}O_2$ during the shuttle walking test (Experiment 2)

The unencumbered shuttle test result was designated as the "control visit" and the other the "Oxylog visit".

The relationship between the peak $\dot{V}O_2$ recorded and the shuttle distance walked is shown in figure 2 (r=0.81). The mean distance walked was 375 (137) m for the control visit and 302 (133) m for the Oxylog visit ($p<0.05$).

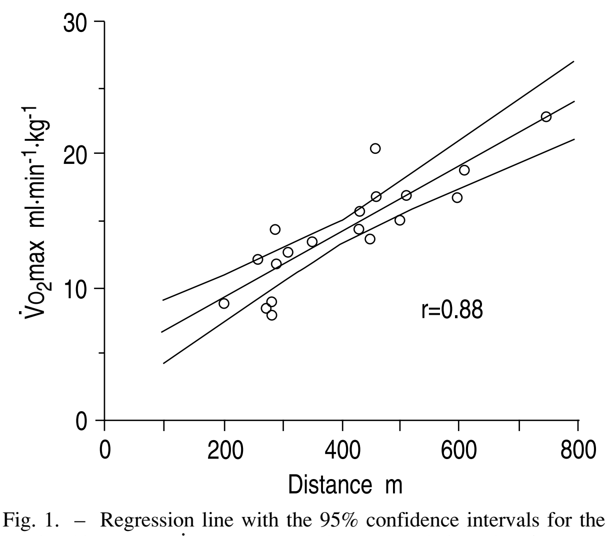

Fig. 1. – Regression line with the 95% confidence intervals for the relationship between $\dot{V}O_2$ max measured on the treadmill and performance distance on the shuttle walking test (n=19). $\dot{V}O_2max$: maximal oxygen consumption.

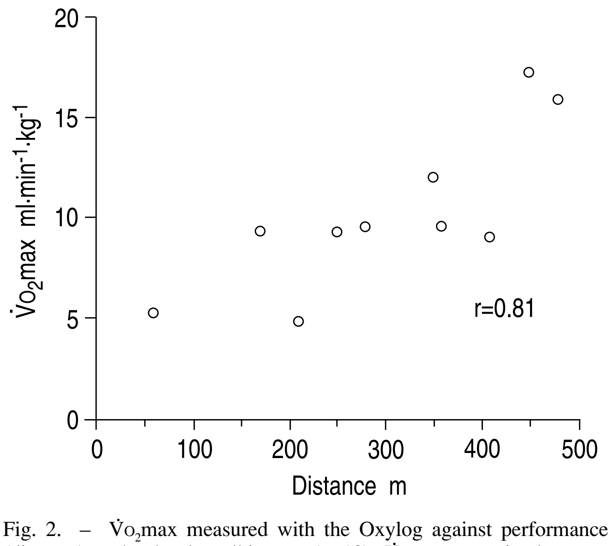

Fig. 2. – $\dot{V}O_2max$ measured with the Oxylog against performance (distance) on the shuttle walking test (n=10). $\dot{V}O_2max$: maximal oxygen consumption.

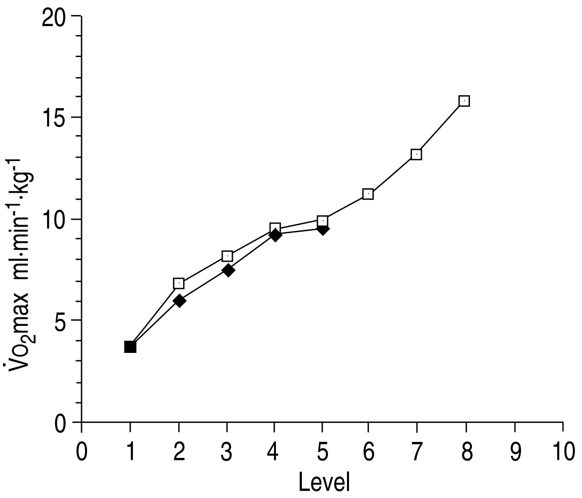

Fig. 3. – Oxygen consumption response of two representative patients during shuttle walking test measured with the Oxylog. $\dot{V}O_2$max: maximal oxygen consumption.

The distance was shorter for all patients on the Oxylog visit but there was no significant difference in the mean maximal heart rate (120 (14) and 118 (10) beats·min^{-1} for the control and Oxylog visits, respectively) or postexercise Borg breathlessness score (5.5 and 5.1, respectively).

The data obtained from the Oxylog revealed that each patient demonstrated a gradual increase in the level of ventilation and $\dot{V}O_2$ during the shuttle walking test. A linear increase in $\dot{V}O_2$ was demonstrated as the patient progressed through successive levels of the shuttle walking test (fig. 3). A corresponding linear increase in ventilation was demonstrated.

The mean maximal $\dot{V}I$ recorded was 24.9 (9.4) *l*·min^{-1} (body temperature and pressure saturated with water vapour (BTPS)). Using the prediction equation most appropriate for this severely affected group of patients, (37.5 × FEV_1) [13], the mean maximal ventilation represents 69% of predicted. Two patients exceeded 90% of predicted, a further two 80%. (These calculations derive a predicted maximal expired ventilation and the Oxylog measures inspired volumes). The mean $\dot{V}O_2$ attained was 0.74 (0.42) *l*·min^{-1} (or 10.1 ml·min^{-1}·kg^{-1}).

Seven patients participated in both the treadmill and the Oxylog experiments. The mean $\dot{V}O_2$max measured in this subgroup was 12.9 (3.6) ml·min^{-1}·kg^{-1} during the treadmill test and 11.1 (4.2) ml·min^{-1}·kg^{-1} during the shuttle walking test. These two maximal values were strongly related (r=0.86) and were not significantly different (mean difference, 1.8 ml·min^{-1}·kg^{-1}, 95% confidence interval (95% CI) -0.9–4.5). The relationship between the maximal values of expiratory flow ($\dot{V}E$) and $\dot{V}I$ recorded after the treadmill and shuttle test were not significantly different in this subgroup.

Discussion

$\dot{V}O_2$max is considered to be the reference measurement of functional capacity. To ensure that performance on the shuttle walking test provides a valid measure of a patient's functional capacity, we have examined the relationship between shuttle test performance and $\dot{V}O_2$max. The main finding was that the relationship with treadmill walking was strong, with 77% of the variance common to both tests. Because of the linear relationship between walking speed and oxygen consumption, this is not surprising. However, it is not the case in self-paced tests, *e.g.* the 6 min walking test.

The strong relationship between performance and $\dot{V}O_2$max was repeated in the second experiment, which examined the physiological response to the shuttle test. Although performance was impaired, probably by supporting the equipment, maximal $\dot{V}O_2$ values measured during the shuttle test were strongly related to the completed distance.

Patients consistently reported that the oxygen consumption equipment had inhibited their performance. The performance data from the Oxylog experiment are consistent with a previous report that the addition of equipment has inhibited patient performance [14]. It is worth noting that the degree of underperformance appears to have been similar in all patients, so that the relationship between performance and $\dot{V}O_2$max was maintained. The strength of these relationships allows the prediction of a patient's $\dot{V}O_2$max from performance on the shuttle walking test (fig. 1) with a degree of confidence that has not previously been possible using other field exercise tests. Patients with varying degrees of impairment (judged on FEV_1, range 0.51–3.11 *l*) were recruited, suggesting that this procedure is appropriate to a wide range of patients with chronic airflow limitation.

For ease of administration, self-paced tests are frequently employed for exercise assessment [15, 16] in spite of the poor relationship that they have with $\dot{V}O_2$max. This results in the continued use of the corridor walking tests, despite the fact that they may not be a valid indicator of a patient's maximal capacity. Our demonstration that the relationship between $\dot{V}O_2$max and performance on the shuttle walking test is strong goes some way to resolving these difficulties by providing a simple field exercise test that relates well to a patient's $\dot{V}O_2$max. A reduction in exercise tolerance and a concomitant fall in $\dot{V}O_2$max are well-documented in the progression of chronic airflow limitation [17]. It would, therefore, seem possible to adopt this simple, but valid, exercise test that reflects this physiological parameter to monitor the course of the disease and of its management.

Because of the strong relationship demonstrated between $\dot{V}O_2$max and performance for both experiments an objective training stimulus could be prescribed for an individual patient, based upon their performance on the shuttle walking test. From this value a walking speed could be selected which relates to a specific percentage of the predicted $\dot{V}O_2$max. The appropriate level of training could be further secured by linking it to a perceived level of breathlessness or heart rate.

Nine individuals exceeded 100% of their predicted $\dot{V}E$, during the treadmill exercise test, suggesting a ventilatory limit to exercise. Examination of the spirometry of these nine individuals showed that their FEV_1 values were at the lower end of the range. Results of the study measuring ambulatory O_2 consumption during the shuttle test revealed that no patient reached or exceeded 100% of their predicted $\dot{V}$Emax, but six exceeded 70% or more. In view of the discrepancy between the Oxylog and Douglas bag measurements, it is probable that these patients reached a higher $\dot{V}$Imax than the figures suggest. A small additional increase in $\dot{V}$I may be accounted for by the variation in the R value at maximal exercise (Oxylog assumes an R value of 1).

Cardiovascular factors appeared to be relatively unimportant in limiting the exercise tolerance as the group of patients had little breathing reserve. The maximal heart rates were lower than predicted values anticipated for the patients' age.

The heart rate response for both exercise tests (treadmill and shuttle walking test) produced the same pattern, *i.e.* an incremental increase with the increase in exercise intensity. There was, however, some disparity observed in the maximal heart rate recorded after the treadmill and shuttle tests. The treadmill test provoked a higher maximal heart rate than the shuttle walking test. At a comparable submaximal walking speed, the heart rate was again higher on the treadmill than on the shuttle walking test. This may be accounted for by the laboratory environment and the equipment that patients were required to carry during the treadmill test. Alternatively, the treadmill test may genuinely have been a more stressful exercise test, because of protocol variation, although this is not supported by the patients' subjective ratings of the two tests. The limited comparative $\dot{V}O_2$ data determined during treadmill walking and during the shuttle walking test reveals that the latter does provide an adequate stimulus to elicit maximal values. The $\dot{V}O_2$max values from the seven patients who participated in both the studies were not significantly different. This supports the hypothesis that the shuttle walking test does provoke a comparable maximal exercise response to a conventional treadmill test.

The incremental increases in heart rate, $\dot{V}$I and $\dot{V}O_2$ observed during the shuttle walking test confirm that the shuttle walking test provokes a gradual physiological response to exercise of increasing intensity, similar to that observed during a treadmill test. It is acknowledged, however, that the shuttle walking test does not replace the usefulness of the laboratory-based exercise test but does provide a valid, simple adjunct to the assessment of patients with chronic airflow limitation. The gradual increase in intensity allows the test to be conducted with a relatively low risk in any hospital corridor or gym.

In conclusion, performance on the shuttle walking test relates strongly to direct measures of $\dot{V}O_2$max, allowing the prediction of $\dot{V}O_2$max. During shuttle walking, the cardiorespiratory response to exercise develops in an incremental fashion. It comprises a simple but valid exercise test that is acceptable to the patients and attractive to the operator, not least because of its inherent standardization. Furthermore, the test allows a more secure intra- and intersubject comparison than has previously been possible with field tests. Overall, the present study substantiates the proposal that the shuttle walking test is an incremental maximal field exercise test of disability that provides an objective measure of a patient's cardiorespiratory capacity.

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